Topics in the November 2013 Exam Paper for CHEM1101

Click on the links for resources on each topic.

2013-N-2:

- Filling Energy Levels in Atoms Larger than Hydrogen

2013-N-3:

- Nuclear and Radiation Chemistry
- Wave Theory of Electrons and Resulting Atomic Energy Levels

2013-N-4:

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

2013-N-5:

- Bonding - MO theory (larger molecules)

2013-N-6:

- VSEPR

2013-N-7:

- Nuclear and Radiation Chemistry

2013-N-8:

- Types of Intermolecular Forces

2013-N-9:

- Thermochemistry
- First and Second Law of Thermodynamics

2013-N-10:

- Thermochemistry
- First and Second Law of Thermodynamics

2013-N-11:

- Thermochemistry
- First and Second Law of Thermodynamics

2013-N-12:

- Chemical Equilibrium

2013-N-13:

- Chemical Equilibrium

2013-N-14:

- Equilibrium and Thermochemistry in Industrial Processes
- Electrochemistry

2013-N-15:

- Electrochemistry

2207(a)

THE UNIVERSITY OF SYDNEY

CHEMISTRY 1A - CHEM1101

CONFIDENTIAL

SECOND SEMESTER EXAMINATION

NOVEMBER 2013 **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 14, 20 and 28 are for rough working only.

OFFICIAL USE ONLY

Multiple choice section

	Marks	
Pages	Max	Gained
2-11	31	

Short answer section

	Marks			
Page	Max	Gained		Marker
12	5			
13	5			
15	4			
16	8			
17	5			
18	5			
19	4			
21	2			
22	6			
23	4			
24	5			
25	4			
26	5			
27	7			
Total	69			

	Marks
• Name the element described by the following configuration.	1
[Kr] $5s^2\ 4d^{10}$	
• Write out the valence electron configuration of the following anions and in each case explain why the anion is less stable than the separated atom and electron.	4
Ne^-	
N^-	

THE REMAINDER OF THIS PAGE IS FOR ROUGH WORKING ONLY.

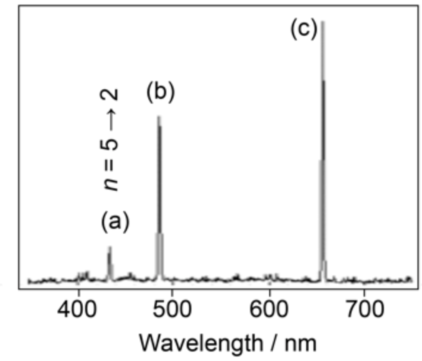
	Marks
• Complete the blanks in the following nuclear equations.	2
$^{54}_{27}Co \rightarrow ^{54}_{26}Fe + \square$	
$\square \rightarrow ^{234}_{90}Th + \alpha$	
• Explain why the electron on an H atom does not crash into the nucleus.	3

THE REMAINDER OF THIS PAGE IS FOR ROUGH WORKING ONLY.

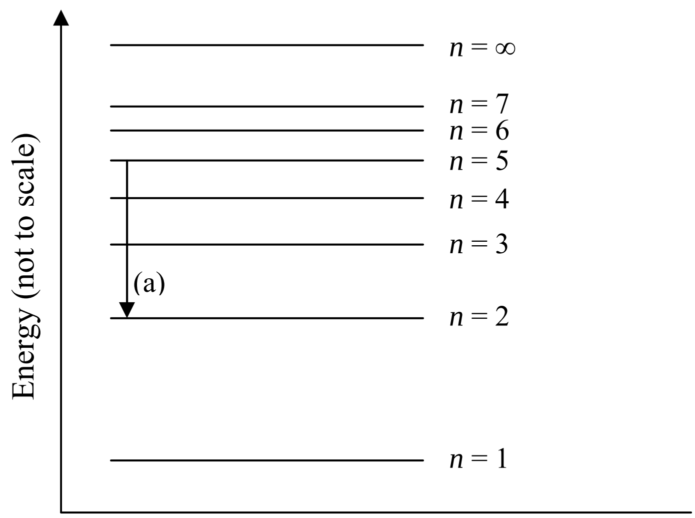
Page Total:

Marks
4

- The emission spectrum of an H atom in the visible region of the electromagnetic spectrum is shown below, showing three clear transitions, labelled (a), (b) & (c). The quantum numbers associated with one of the transitions is assigned for you.



Complete the energy level diagram below to illustrate the energy levels of an H atom associated with all three transitions

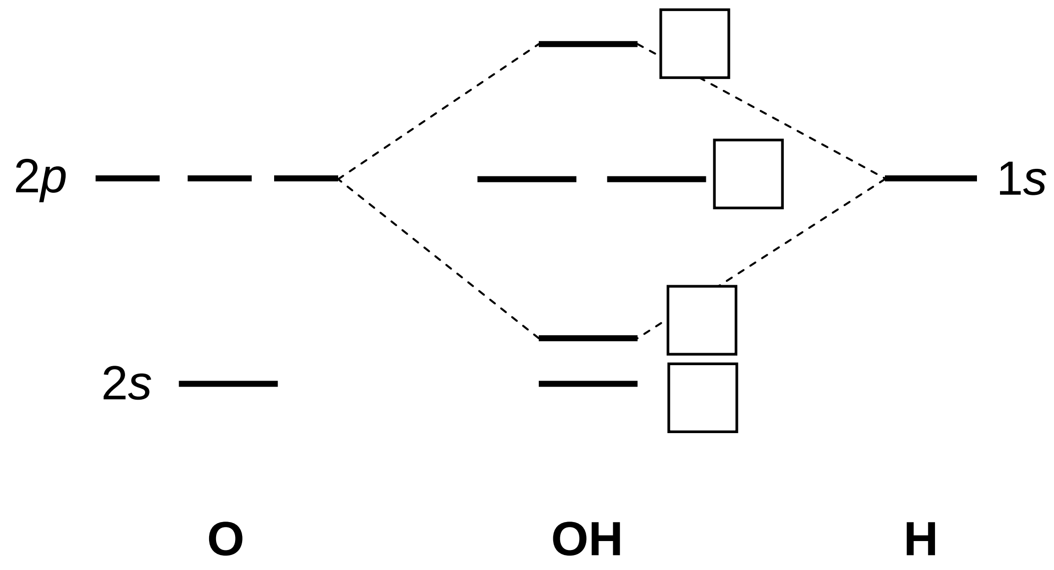


Calculate the wavelength (in nm) of transition (a).

Answer:

Marks
8

- The OH radical is the most important species in the atmosphere for removing pollutants. A molecular orbital diagram of this species is shown below. Core orbitals are omitted.



Using arrows to indicate electrons with their appropriate spin, indicate on the above diagram the ground state occupancy of the atomic orbitals of O and H, and of the molecular orbitals of OH.

In the provided boxes on the above diagram, label the molecular orbitals as *n*, σ, σ^*, π, π^*, etc.

What is the bond order of the O–H bond?

Why do we call OH a "radical"? How does the MO diagram support this?

Marks
5

- Complete the following table. The central atom is underlined. Carbon dioxide is given as an example. Where applicable, give all resonance structures and identify the major contributors according to the theory of formal charges.

Molecule	Lewis structure	Shape of molecule	Dipole? (Y/N)
$\underline{C}O_2$	:O=C=O:	linear	N
$\underline{P}F_3$			
$N\underline{N}O$			

THE REMAINDER OF THIS PAGE IS FOR ROUGH WORKING ONLY.

Marks
5

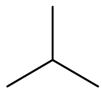
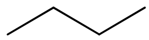
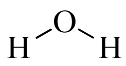
- The generation of energy in a nuclear reactor is largely based on the fission of either ^{235}U or ^{239}Pu. The fission products include every element from zinc through to the *f*-block. Explain why most of the radioactive fission products are β-emitters.

The radioactivity of spent fuel rods can be modelled by the exponential decay of ^{137}Cs, which has a half-life of 30.23 years. What is the specific activity of ^{137}Cs, in Bq g^{-1}?

Answer:

Marks
4

- In terms of the type and size of intermolecular forces involved, explain the trend in boiling points of the following compounds.

Substance	Stick structure	Boiling Point (°C)
ethane, C_2H_6		−89
2-methylpropane, C_4H_{10}		−12
butane, C_4H_{10}		−1
water, H_2O		100

THE REMAINDER OF THIS PAGE IS FOR ROUGH WORKING ONLY.

Page Total:

Marks
2

- Two samples of iron are prepared so that the heavier has a heat capacity of 50.0 J K^{-1} and the lighter has a heat capacity of 19 J K^{-1}. Initially, the heavier sample is at a temperature of 100.0 °C and the lighter sample is at 20.0 °C. Calculate the final equilibrium temperature after the two samples have been placed in thermal contact. Show working.

Answer:

THE REMAINDER OF THIS PAGE IS FOR ROUGH WORKING ONLY.

Page Total:

Marks
6

- Paraffin wax candles primarily consist of long, saturated, hydrocarbon chains such as triacontane ($C_{30}H_{62}$). Assuming a 1.00 kg candle is made of pure triacontane, how many moles of triacontane will it contain?

Answer:

Estimate the atomisation enthalpy, $\Delta_{atom}H$, for triacontane, based on the following tabulated average bond enthalpies.

bond	ΔH / kJ mol^{-1}	bond	ΔH / kJ mol^{-1}
C–C	346	C–H	414
C–O	358	O–H	463
C=O	804	O=O	498

Answer:

Write out a chemical equation for the complete combustion of triacontane.

Using the same table of average bond enthalpies, estimate the atomisation enthalpy of each product of the complete combustion.

THIS QUESTION CONTINUES ON THE NEXT PAGE.

Marks
4

Estimate the molar enthalpy of combustion of triacontane, $\Delta_c H$.

Answer:

Using this enthalpy of combustion, calculate the energy released by the combustion of the candle.

Answer:

THE REMAINDER OF THIS PAGE IS FOR ROUGH WORKING ONLY.

Page Total:

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.

THIS QUESTION CONTINUES ON THE NEXT PAGE.

Marks
4

This reaction mixture is now allowed to come to equilibrium at 298 K in a fixed volume container. Calculate the equilibrium pressure of Cl_2.

Answer:

THE REMAINDER OF THIS PAGE IS FOR ROUGH WORKING ONLY.

Page Total:

Marks

- Both magnesium oxide and zinc oxide can be reduced to their respective metals by carbon at temperatures of over 1200 K. Which oxide requires the higher temperature for reaction? Give reasons for your answer. **2**

- Balance the following redox reaction, which is carried out in an acidic solution. **3**

$$I^- + IO_3^- \rightarrow I_2$$

Working

Answer:

Marks
7

- The following redox reaction occurs in a voltaic cell:

$$2Al(s) + Cr_2O_7^{2-}(aq) + 14H^+(aq) \rightarrow 2Al^{3+}(aq) + 2Cr^{3+}(aq) + 7H_2O(l)$$

Calculate the standard cell potential, $E°_{cell}$, for the cell at 25 °C.

Answer:

Calculate the cell potential, E_{cell}, at 25 °C when $[Cr_2O_7^{2-}(aq)] = 7.2 \times 10^{-5}$ M, $[Al^{3+}(aq)] = 0.55$ M, $[Cr^{3+}(aq)] = 0.75$ M and the pH is 2.35.

Answer:

What is the effect on the E_{cell} of decreasing the concentration of $Cr_2O_7^{2-}$ in the cathode compartment?

What is the effect on the E_{cell} of adding a 0.35 M solution of $Al(NO_3)_3$ to the anode compartment?

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
10^{12}	tera	T

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
$Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^- \rightarrow 2Cr^{3+}(g) + 7H_2O$	+1.36
$Cl_2(g) + 2e^- \rightarrow 2Cl^-(aq)$	+1.36
$O_2(g) + 4H^+(aq) + 4e^- \rightarrow 2H_2O$	+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
$Sc^{3+}(aq) + 3e^- \rightarrow Sc(s)$	–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

CHEM1101 - CHEMISTRY 1A

Useful formulas

Quantum Chemistry

$E = h\nu = hc/\lambda$

$\lambda = h/mv$

$E = -Z^2 E_R(1/n^2)$

$\Delta x \cdot \Delta(mv) \geq h/4\pi$

$q = 4\pi r^2 \times 5.67 \times 10^{-8} \times T^4$

$T\lambda = 2.898 \times 10^6$ K nm

Electrochemistry

$\Delta G° = -nFE°$

Moles of $e^- = It/F$

$E = E° - (RT/nF) \times 2.303 \log Q$

$\quad = E° - (RT/nF) \times \ln Q$

$E° = (RT/nF) \times 2.303 \log K$

$\quad = (RT/nF) \times \ln K$

$E = E° - \frac{0.0592}{n} \log Q$ (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

$t_{½} = \ln 2/\lambda$

$A = \lambda N$

$\ln(N_0/N_t) = \lambda t$

^{14}C age = 8033 $\ln(A_0/A_t)$ years

Kinetics

$t_{½} = \ln 2/k$

$k = Ae^{-Ea/RT}$

$\ln[A] = \ln[A]_o - kt$

$\ln\frac{k_2}{k_1} = \frac{E_a}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$

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 = $^4/_3\ \pi r^3$

Thermodynamics & Equilibrium

$\Delta G° = \Delta H° - T\Delta S°$

$\Delta G = \Delta G° + RT \ln Q$

$\Delta G° = -RT \ln K$

$\Delta_{univ}S° = R \ln K$

$\ln\frac{K_2}{K_1} = \frac{-\Delta H°}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$

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]