UNIVERSITY OF SWAZILAND

BACHELOR OF SCIENCE

SUPPLEMENTARY EXAMINATION 2007

TITLE OF PAPER	:	PHYSICAL CHEMISTRY
COURSE NUMBER	:	C202
TIME	:	3 HOURS
INSTRUCTIONS	:	THERE ARE SIX QUESTIONS
	:	ANSWER ANY FOUR QUESTIONS
	:	BEGIN THE ANSWER TO EACH QUESTION ON A SEPARATE SHEET OF PAPER
	:	DATA SHEETS ARE PROVIDED WITH THIS EXAMINATION PAPER

DO NOT OPEN THIS PAPER UNTIL THE INVIGILATOR INSTRUCTS YOU TO DO SO.

Question 1(25 marks)

a) Write short notes on Van der Waals equation [10]

Use diagrams, equations or plots to clarify your notes where necessary.

b) A real gas equation of state for a gas is given by:

$$(P+5an^2/V^2)(V-3nb)=nRT \quad (1)$$

(i) Derive an expression for $V_{m,c}$, Tc and P_c. [6]
(ii) Find an expression for the Boyle's temperature, T_B. [4]
(iii) Estimate the temperature at which oxygen behaves as an ideal gas, T_B given the constants: $a=6.493\ L^2atmmol^{-2}$, $b=5.622x10^{-2}Lmol^{-1}$ [2]
(iv) Estimate the radii of real gas molecules using equation (1) for real gases given a critical molar volume of 250 cm^3mol^{-1} [2]

QUESTION 2 [25 marks]

a) Using examples and/or diagrams compare and contrast the following terms
   i) reversible and irreversible expansion [5]
   ii) path and state functions [5]
   iii) change in internal energy and change in enthalpy [5]

b) 4 moles of butane occupies 24 L at 310 K.
   i) Derive an expression for reversible isothermal expansion. [5]
   ii) Calculate the work done and heat involved when the gas expands isothermally against a constant external pressure of 100 torr until its volume has doubled. [2]
   iii) Calculate the efficiency of the system in 1 b (ii) above. [3]

Question 3 [25 Marks]

a) Derive the integrated Gibbs-Helmholtz equation [3]

$$\frac{\Delta G_2}{T_2}-\frac{\Delta G_1}{T_1}=\Delta H\left(\frac{1}{T_2}-\frac{1}{T_1}\right)$$

from the fundamental thermodynamic equation $dG = VdP - SdT$

b) Given the reaction:

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

Calculate the change in Gibbs free energy ΔG^{θ}
i) at 298K [5]
ii) at 500K [5]
iii) Comment on the significance of the values obtained in (i) and (ii). [2]

c)
(i) Using an appropriate Master Equation derive the Maxwell's relation

$$(\delta S/\delta V)_T=(\delta P/\delta T)_V \quad [5]$$

(ii) Using the Maxwell's relation in (i) find the expression for internal energy change with volume under isothermal conditions for real gases using van der Waal's relation:

$$(P+an^2/V^2)(V-nb)=nRT \quad [5]$$

Question 4 [25 Marks]

a) Compare and contrast **Any One Pair** of the following concepts:
   i) Statistical view and the thermodynamic view of entropy [10]
   ii) Adiabatic and Isothermal expansion [10]
   iii) Second and Third law of thermodynamics [10]

   For each concept include the origin or a short derivation showing its origin, an example where applicable and the role or implication of each of the concepts in thermodynamics.

b) 1.00 mol of perfect gas at $27^{o}C$ is expanded isothermally from an initial pressure of 3.00 atm to a final pressure of 1.00 atm . Calculate q, w, ΔS_{sys}, ΔS_{surr} and ΔS_{tot} if the expansion is done:
   (1) reversibly, and [5]
   (2) against a constant external pressure of 1.00 atm. [5]
   (3) adiabatically against a constant pressure of 1.00 atm. [5]

Question 5 [25 Marks]

a) Write short notes on **any two** of the following
   i) enthalpy change [5]
   ii) internal energy change [5]
   iii) Hess's Law [5]

b) To Calibrate a calorimeter a 0.120 g naphthalene, $C_{10}H_8(s)$, was burnt at constant volume and it caused the temperature of the calorimeter to rise by 3.05 K. Then 0.10 g of an unknown compound was burned in the same calorimeter, causing a temperature rise of 2.05 K.
   i) Calculate the heat capacity of the calorimeter [3]
   ii) Is the unknown compound phenol, $C_6H_5OH(s)$ or ethanol, $CH_3CH_2OH(l)$ whose enthalpies of combustion are $\Delta_C H^\theta$=-3054 $kJmol^{-1}$ and -1368 $kJmol^{-1}$ respectively. [4]

c) Calculate the standard enthalpies of formation of:

   i) $KClO_3(s)$ from the enthalpy of formation of KCl [4]
   ii) NOCl(g) from the enthalpy of formation of NO [4]
   Given the attached table and the following information:

$2KClO_3(s) \rightarrow 2KCl(s)+3O_2(g)$	$\Delta_f H^\theta$=-89.4 kJ/mol
$2NOCl(g) \rightarrow 2NO(g)+Cl_2(g)$	$\Delta_f H^\theta$=+76.5 kJ/mol

QUESTION 6 [25 MARKS]

a) Write short notes on any Two of the following: [10]

i) Phase rule
ii) Eutectic temperature
iii) Freezing point depression
iv) Boiling point elevation
v) Azeotrope

b) i) Using the chemical potential expression:

$$\mu_A = \mu_A^* + RT \ln \chi_A$$

where μ_A^* is the chemical potential of the pure solvent A, derive the expression for the boiling point elevation in terms of the boiling point of the pure solvent T, its enthalpy of evaporation and the molality of the solute m_S. [5]

c) i) What is the approximate relative molecular mass of compound X if 1.00g of X added to 20.0 g benzene leads to a freezing point depression of 1.51°C ? [5]

ii) Why is the freezing point depression preferred to boiling point elevation for the determination of relative molecular masses ? [2]

iii) Why would benzene be a better solvent to use than ethanol ? [3]

Useful Relations	General Data		
$(RT)_{298\cdot15K}$=2.4789 kJ/mol	**speed of light**	**c**	**2.997 925x10^{8} ms^{-1}**
$(RT/F)_{298\cdot15K}$=0.025 693 V	charge of proton	*e*	1.602 19x10^{-19} C
T/K: 100.15 298.15 500.15 1000.15	Faraday constant	F=L*e*	9.648 46x10^{4} C mol^{-1}
T/Cm^{-1}: 69.61 207.22 347.62 695.13	**Boltzmann constant**	**k**	**1.380 66x10^{-23} J K^{-1}**
1mmHg=133.222 N m^{-2}	**Gas constant**	**R=Lk**	**8.314 41 J K^{-1} mol^{-1}**
hc/k=1.438 78x10^{-2} m K			**8.205 75x10^{-2} dm^{3} atm K^{-1} mol^{-1}**
1atm | 1 cal | 1 eV | 1cm^{-1}			
=1.01325x10^{5} Nm^{-2} | =4.184 J | =1.602 189x10^{-19} J | =0.124x10^{-3} eV	**Planck constant**	**h**	**6.626 18x10^{-34} Js**
=760torr **=1 bar** | | =96.485 kJ/mol = 8065.5 cm^{-1} | =1.9864x10^{-23}J		$\hbar = \frac{h}{2\pi}$	1.054 59x10^{-34} Js
	Avogadro constant	**L or N$_{av}$**	**6.022 14x10^{23} mol^{-1}**
SI-units:	Atomis mass unit	u	1.660 54x10^{-27} kg
1 L = 1000 ml = 1000cm^{3} = 1 dm^{3}	**Electron mass**	**m$_e$**	**9.109 39x10^{-31} kg**
1 dm = 0.1 m	Proton mass	m$_p$	1.672 62x10^{-27} kg
1 cal (thermochemical) = 4.184 J	Neutron mass	m$_n$	1.674 93x10^{-27} kg
dipole moment: 1 Debye = 3.335 64x10^{-30} C m	Vacuum permittivity	$\varepsilon_o = \mu_o^{-1}c^{-2}$	8.854 188x10^{-12} J^{-1} C^{2} m^{-1}
force: ***1N=1J m^{-1}= 1kgms^{-2}***=10^{5} dyne pressure: ***1Pa=1Nm^{-2}***=1Jm^{-3}	Vacuum permeability	μ_o	4πx10^{-7} Js^{2}C^{-2} m^{-1}
1J = 1 Nm power: 1W = 1J s^{-1} potential: 1V =1 J C^{-1}	Bohr magneton	$\mu_B = e\hbar/2m_e$	9.274 02x10^{-24} JT^{-1}
magnetic flux: 1T=1Vsm^{-2}=1JCsm^{-2} current: 1A=1Cs^{-1}	Nuclear magneton	$\mu_N = e\hbar/2m_p$	5.05079x10^{-27} JT^{-1}
Prefixes:	Gravitational constant	G	6.67259x10^{-11} Nm^{2}kg^{-2}
p n m m c d k M G	**Gravitational**	**g**	**9.80665 ms^{-2}**
pico nano micro milli centi deci kilo mega giga	**acceleration**		
10^{-12} 10^{-9} 10^{-6} 10^{-3} 10^{-2} 10^{-1} 10^{3} 10^{6} 10^{9}	Bohr radius	a$_0$	5.291 77x10^{-11} m

Standard molar enthalpies of formation at 298.15 K

	M_r	ΔH_f^θ/KJ/mol		M_r	ΔH_f^θ/KJ/mol
$H_2O(g)$	18.015	-241.8	$O_3(g)$	47.998	+142.7
$H_2O(l)$	18.015	-285.8	$NO(g)$	30.006	+90.2
$H_2O_2(l)$	34.015	-187.8	$NO_2(g)$	46.006	+33.2
$NH_3(g)$	17.031	-46.1	$N_2O_4(g)$	92.012	+9.2
$N_2H_4(l)$	32.045	+50.6	$SO_2(g)$	64.063	-296.8
$N_3H(l)$	43.028	+264.1	$H_2S(g)$	34.080	-20.6
$N_3H(g)$	43.028	+294.1	$SF_6(g)$	146.054	-1209
$HNO_3(l)$	63.013	-174.1	$HF(g)$	20.006	-271.1
$NH_2OH(s)$	33.030	-114.2	$HCl(g)$	36.461	-92.3
$NH_4Cl(s)$	53.492	-314.4	$HCl(aq)$	36.461	-167.2
$HgCl_2(s)$	271.50	-224.3	$HBr(g)$	80.917	+36.4
$H_2SO_4(l)$)	98.078	-814.0	$HI(g)$	127.912	+26.5
$H_2SO_4(aq)$	98.078	-909.3	$CO_2(g)$	44.010	-393.5
$NaCl(s)$	58.443	-411.0	$CO(g)$	28.011	-110.5
$NaOH(s)$	39.997	-426.7	$Al_2O_3(\alpha,s)$	101.945	-1675.7
$KCl(s)$	74.555	-435.9	$SiO2(s)$	60.085	-910.9
$KBr(s)$	119.011	-392.2	$FeS(s)$	87.91	-100.0
$KI(s)$	166.006	-327.6	$FeS_2(s)$	119.975	-178.2
DIATOMICS	Eg. N_2, O_2, H_2	0	$AgCl(s)$	143.323	-127.1

Enthalpies of fusion and evaporation ΔH_m/KJ/mol at the transition temperature

	T_f/K	Fusion[a]	T_b/K	Evaporation[b]	
He	3.5	0.021	4.22	0 084	
Ar	83.81	1.188	87.29	6.506	
H_2	13.96	0.117	20.36	0.9183	
N_2	63.15	0.719	77.35	5.586	
O_2	54.36	0.444	90.18	6.820	
Cl_2	172.12	6.406	239.05	20.410	
Br_2	265.90	10.573	332.35	29.45	
I_2	386.75	15.52	458.39	41.80	
Hg	234.29	2.292	629.73	59.296	
Ag	1234	11.30	2436	250.63	
Na	370.95	2.601	1156	98.01	
CO_2	217.0	8.33	194.64	25.23⊥	
H_2O	273.15	6.008	373.15	40.656	(44.016 at 298.15 K)
NH_3	195.40	5.652	239.73	23.351	
H_2S	187.61	2.377	212.80	18.673	
CH_4	90.68	0.941	111.66	8.18	
C_2H_6	89.85	2.86	184.55	14.7	
C_6H_6	278.65	10.59	353.25	30.8	
CH_3OH	175.25	3.159	337.22	35.27	(37.99 at 298.15K)

⊥ Sublimation: [a]various pressures: [b]at 1atm

Temperature dependence of heat capacities, $C_{p,m} = a+bT+cT^{-2}$

	a/J $K^{-1}mol^{-1}$	b/10^{-3}J $K^{-2}mol^{-1}$	c/10^5J $Kmol^{-1}$
Gases (298-2000K)			
He, Ne, Ar, Kr, Xe	20.78	0	0
H_2	27.28	3.26	0.50
O_2	29.96	4.18	-1.67
N_2	28.58	3.77	-0.50
Cl_2	37.03	0.67	-2.85
CO_2	44.23	8.79	-8.62
H_2O	30.54	10.29	0
NH_3	29.75	25.10	-1.55
CH_4	23.64	47.86	-1.92
C(S)	16.86	4.77	-8.54

Standard molar enthalpies of formation and combustion at 298.15 K.

	M_r	ΔH_f^θ/KJ/mol	ΔH_c^θ/KJ/mol
$CH_4(g)$	16.043	-74.81	
$C_2H_2(g)$	26.038	+226.8	-1300
$C_2H_4(g)$	28.054	+52.30	-1411
$C_2H_6(g)$	30.070	-84.64	-1560
C_3H_6 cyclopropane(g)	42.081	53.35	-2091
C_3H_6 (propene(g)	42.081	20.5	-2058
C_4H_{10} n-butane (g)	58.124	-126.11	-2877
C_5H_{12} n-pentane(g)	72.151	-146.4	-3536
C_6H_{12} cyclohexane (l)	84.163	-156.2	-3920
C_6H_{14} n-hexane (l)	86.178	-198.7	-4163
C_6H_6 benzene (l)	78.115	+48.99	-3268
C_8H_{18} n-octane (l)	114.233	-249.8	-5471
$C_{10}H_8$ naphthalene (l)	128.175	+78.53	-5157
CH_3OH (l)	32.042	-239.0	-726.1
CH_3CHO (g)	44.054	-166.0	-1193
CH_3CH_2OH (l)	46.070	-277.0	-1368
CH_3COOH (l)	60.053	-484.2	-874.5
$CH_3COOC_2H_5$ (l)	88.107	-486.6	-2231
C_6H_5OH (s)	94.114	-165.0	-3054
$C_6H_5NH_2$ (l)	93.129	-31.1	-3393
$NH_2CO.NH$, urea(s)	60.056	-333.0	-632.2
$CH_2(NH_2)CO_2H$, glycine (s)	75.068	-537.2	-964.4
$C_6H_{12}O_6$, α-D-glucose (s)	180.159	-1274	-2802
$C_6H_{22}O_6$, β-D-glucose (s)	180.159	-1268	-2808
$C_{12}H_{22}O_{11}$, sucrose (s)	342.303	-2222	-5645
$CH_3CH(OH)COOH$ lactic acid (s)	90.079	-694.0	-1344

Source: American Institute of Physics handbook, McGraw-Hill.

Heat capacities at 25°C

	$C_{v,m}$ JK^{-1} mol^{-1}	$C_{p,m}$ JK^{-1} mol^{-1}
He, Ne, Ar, Kr, Xe	12.47	20.78
H_2	20.50	28.81
O_2	21.01	29.33
N_2	20.83	29.14
CO_2	28.83	37.14
NH_3	27.17	35.48
CH_4	27.43	35.74
N_2O_4		77.28
NO_2		37.20

F.P Depression, B.P. Elevation

Solvent	F.P °C	K_f °C kg mol^{-1}	B.P (°C, 101kNm^{-2})	K_b °C kg mol^{-1}
Water	0	1.86	100.0	0.52
Benzene	5.51	5.10	80.1	2.60
Acetic Acid	16.6	3.90	118.1	3.10
Cyclohexane	6.5	20.2	81.4	2.79
Camphor	177.7	40.0	205	-
Nitrobenzene	5.7	6.9	210.9	5.24
Ethanol	-177		78.5	1.22
Chloroform	-64		61.3	3.63

Third Law entropies at 25°C, S_m^θ/J K^{-1} mol^{-1}

Solids		Liquids		Gases	
Ag	42.68	Hg	76.02	H_2	130.6
C(gr)	5.77	Br_2	152.3	N_2	192.1
C(d)	2.44			O_2	205.1
Cu	33.4			Cl_2	223.0
Zn	41.6	H_2O	70.0		
I_2	116.7			CO_2	213.7
S(Rh)	31.9	HNO_3	155.6	HCl	186.8
				H_2S	205.6
AgCl	96.2	C_2H_5OH	161.0	NH_3	192.5
AgBr	104.6	CH_3OH	126.7	CH_4	186.1
$CuSO_4 5H_2O$	305.4	C_6H_6	49.03	C_2H_6	229.4
$HgCl_2$	144	CH_3COOH	159.8	CH_3CHO	265.7
Sucrose	360.2	C_6H_{12}	298.2		

Standard molar Gibbs free energy and molar entropy of formation at 298.15 K

	M_r	ΔG_f^θ/KJ/mol	S^θ/J K^{-1} mol^{-1}		M_r	ΔG_f^θ/KJ/mol	S^θ/J K^{-1} mol^{-1}
H_2O(g)	18.015	-228.57	188.83	O_3(g)	47.998	163.2	238.93
H_2O(l)	18.015	-120.35	109.6	NO(g)	30.006	86.55	210.76
H_2O_2(l)	34.015	-120.35	109.6	NO_2(g)	46.006	51.31	240.06
NH_3(g)	17.031	-16.45	192.45	N_2O_4(g)	92.012	97.89	304.29
N_2H_4(l)	32.045	149.43	121.21	SO_2(g)	64.063	-300.19	248.22
N_3H(l)	43.028	327.3	140.6	H_2S(g)	34.080	-33.56	205.79
N_3H(g)	43.028	328.1	238.97	SF_6(g)	146.054	-1105.3	291.82
HNO_3(l)	63.013	-80.71	155.60	HF(g)	20.006	-273.2	173.78
NH_2OH(s)	33.030			HCl(g)	36.461	-95.30	186.91
NH_4Cl(s)	53.492	-202.87	94.6	HCl(aq)	36.461	-131.23	56.5
$HgCl_2$(s)	271.50	-178.6	146.0	HBr(g)	80.917	-53.45	198.70
H_2SO_4(l))	98.078	-690.00	156.90	HI(g)	127.912	1.70	206.59
H_2SO_4(aq)	98.078	-744.53	20.1	CO_2(g)	44.010	-394.36	213.74
NaCl(s)	58.443	-384.14	72.13	CO(g)	28.011	-137.17	197.67
NaOH(s)	39.997	-379.49	64.46	AL_2O_3(□,s)	101.945	-1582.3	50.92
KCl(s)	74.555	-409.14	82.59	SiO_2	60.09	-856.64	41.84
KBr(s)	119.011	-380.66	95.90	FeS(s)	87.91	-100.4	60.29
KI(s)	166.006	-324.89	106.32	FeS_2(s)	119.975	-166.9	52.93
				AgCl(s)	143.323	-109.79	96.2
He(g)	4.003	0	126.15	Hg(g)	200.59	31.82	174.96
Ar(g)	39.95	0	154.84	Hg(l)	200.59	0	76.02
H_2(g)	2.016	0	130.684	Ag(g)	107.87	245.65	173.00
N_2(g)	28.013	0	191.61	Ag(s)	107.87	0	42.55
O_2(g)	31.999	0	205.138	Na(g)	370.95	76.76	153.71
O_3(g)	47.998	163.2	238.93	Na(s)	22.99	0	51.21
Cl_2(g)	70.91	0	223.07				
Br_2(g)	159.82	3.110	245.46				
Br_2(l)	159.82	0	152.23				
I_2(g)	253.81	19.33	260.69				
I_2(s)	253.81	0	116.135				

	M_r	ΔG_f^θ/KJ/mol	S^θ/J K^{-1} mol^{-1}
organic compounds			
CH_4(g) methane	16.043	-50.72	186.26
C_2H_2(g) ethyne	26.038	209.20	200.94
C_2H_4(g) ethene	28.05	68.15	219.56
C_2H_6(g) ethane	30.070	-32.82	229.60
C_3H_6 cyclopropane(g)	42.081	104.45	237.55
C_3H_6 propene(g)	42.081	62.78	267.05
C_4H_{10} n-butane (g)	58.124	-17.03	310.23
C_5H_{12} n-pentane(g)	72.151	-8.20	348.40
C_6H_{12} cyclohexane (l)	84.163	26.8	
C_6H_{14} n-hexane (l)	86.178		204.3
C_6H_6 benzene (l)	78.115	124.3	173.3
C_6H_6 benzene (g)	78.115	129.72	269.31
C_8H_{18} n-octane (l)	114.233	6.4	361.1
$C_{10}H_8$ naphthalene (l)	128.175		
CH_3OH (g)	32.042	-161.96	239.81
CH_3OH (l)	32.042	-166.27	126.8
CH_3CHO (g)	44.054	-128.86	250.3
CH_3CH_2OH (l)	46.07	-174.78	160.7
CH_3COOH (l)	60.053	-389.9	159.8
$CH_3COOC_2H_5$ (l)	88.107	-332.7	259.4
C_6H_5OH (s)	94.114	-50.9	146.0
$C_6H_5NH_2$ (l)	93.129		
$CH_2(NH_2)CO_2H$, glycine (s)	75.068	-373.4	103.5
$C_6H_{12}O_6$, □-D-glucose (s)	180.159		
$C_6H_{22}O_6$, □-D-glucose (s)	180.159	-910	212
$C_{12}H_{22}O_{11}$, sucrose (s)	342.303	-1543	360.2
$CH_3CH(OH)COOH$	90.079		
lactic acid (s)			

Source: American Institute of Physics handbook, McGraw-Hill.

NON-METALS

METALLOIDS

METALS

Group	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIIIB			IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA
Period 1	1 **H** 1.008																	[illegible]
2	3 **Li** 6.94	4 **Be** 9.01											5 **B** 10.81	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	11 **Na** 22.99	12 **Mg** 24.31											13 **Al** 26.9	14 **Si** 28.09	[illegible]	[illegible]	[illegible]	[illegible]
4	19 **K** 39.10	20 **Ca** 40.08	21 **Sc** 44.96	22 **Ti** 47.90	23 **V** 50.94	24 **Cr** 52.01	25 **Mn** 54.9	26 **Fe** 55.85	27 **Co** 58.71	28 **Ni** 58.71	29 **Cu** 63.54	30 **Zn** 65.37	31 **Ga** 69.7	32 **Ge** 72.59	33 **As** 74.92	[illegible]	[illegible]	[illegible]
5	37 **Rb** 85.47	38 **Sr** 87.62	39 **Y** 88.91	40 **Zr** 91.22	41 **Nb** 91.22	42 **Mo** 95.94	43 **Tc** 98.9	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	[illegible]	[illegible]
6	55 **Cs** 132.9	56 **Ba** 137.3	71 **Lu** 174.9	72 **Hf** 178.5	73 **Ta** 180.9	74 **W** 183.8	75 **Re** 186.2	76 **Os** 190.2	77 **Ir** 192.2	78 **Pt** 195.1	79 **Au** 196.9	80 **Hg** 200.6	81 **Tl** 204.4	82 **Pb** 207.2	83 **Bi** 208.9	84 **Po** 210	85 **At** 210	[illegible]
7	87 **Fr** 223	88 **Ra** 226.0	103 **Lr** 257	104 **Unq**	105 **Unp**	106 **Unh**	107 **Uns**	108 **Uno**	109 **Une**									

Lanthanides	57 **La** 138.9	58 **Ce** 140.1	59 **Pr** 140.9	60 **Nd** 144.2	61 **Pm** 146.9	62 **Sm** 150.9	63 **Eu** 151.3	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
Actinides	89 **Ac** 227.0	90 **Th** 232.0	91 **Pa** 231.0	92 **U** 238.0	93 **Np** 237.1	94 **Pu** 239.1	95 **Am** 241.1	96 **Cm** 247.1	97 **Bk** 249.1	98 **Cf** 251.1	99 **Es** 254.1	100 **Fm** 257.1	101 **Md** 258.1	102 **No** 255

*Numbers below the symbol indicates the **atomic masses**; and the numbers above the symbol indicates the atomic numbers.*

SOURCE: International Union of Pure and Applied Chemistry, I mills, ed., Quantities, Units, and symbols in Physical Chemistry, Blackwell Scientific publications, Boston, 1988, pp 86-98.