Name: ________________________ Student Number: ______________________

Chemistry 1000 Final Exam – Version A
Fall 2007

INSTRUCTIONS

1) Read the exam carefully before beginning. There are 19 questions on pages 2 to 12 followed by 2 pages of "Data Sheet" (including periodic table) and a blank page for any rough work. **Please ensure that you have a complete exam. If not, let an invigilator know immediately**. All pages must be submitted at the end of the exam.
2) If your work is not legible, it will be given a mark of zero.
3) Marks will be deducted for incorrect information added to an otherwise correct answer.
4) You may use a calculator.
5) Show your work for all calculations. Answers without supporting calculations will not be given full credit.
6) Marks will be deducted for improper use of significant figures and for answers with incorrect/missing units.
7) **Do not open the exam until you are told to begin. Beginning prematurely will result in removal of your exam paper and a mark of 0.**
8) You have **3 hours** to complete this exam. Nobody may leave the exam room during the first hour or the last 15 minutes of the exam.

Q	Mark
1	/ 20
2	/ 5
3	/ 3
4	/ 3
5	/ 3
6	/ 10
7	/ 7
8	/ 3
9	/ 8
10	/ 14

Q	Mark
11	/ 3
12	/ 3
13	/ 8
14	/ 7
15	/ 10
16	/ 10
17	/ 6
18	/ 6
19	/ 1

Total	**/ 130**

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1. Fill in the blank(s). **[20 marks]**

(a) Lanthanum has the following isotopic composition:

Isotope	Abundance (%)
$^{138}_{57}La$	0.090
$^{139}_{57}La$	99.910

Without doing any calculations, what is the approximate molar mass of La? **139 g/mol**

(b) Give the chemical formula for the product formed when cesium is combusted in air. **CsO_2**

(c) In the reaction between Cr^{3+} and water, **Cr^{3+}** is the Lewis acid and **water** is the Lewis base. The pH of this solution will be **less than** seven. *(greater than, less than or approximately equal to?)*

(d) For each of the ions below, give the electron configuration in line notation ***using the noble gas abbreviation***.

i. Sn^{2+} **[Kr] $5s^2$ $4d^{10}$** ii. Sn^{4+} **[Kr] $4d^{10}$**

(e) For each of the ions in part (d), indicate whether it is paramagnetic or diamagnetic.

i. Sn^{2+} **diamagnetic** ii. Sn^{4+} **diamagnetic**

(f) Give the electron configuration for a neutral atom of silicon using line notation. ***Do not use the noble gas abbreviation.*** **$1s^2$ $2s^2$ $2p^6$ $3s^2$ $3p^2$**

(g) How many valence electrons does a neutral atom of silicon have? **4**

(h) Name the allotrope of carbon that can conduct electricity. **graphite**

(i) What is the Cl-C-Cl bond angle in CCl_4? **109.47°** *(109.5°)*

(j) What is the geometry of a molecule that has five atoms attached to a central atom with no lone pairs? **trigonal bipyramidal** What bond angle(s) would you expect to find in this molecule? **90°, 120°, 180°** *(90°, 120°)*

(k) Phosphorus has a single naturally occurring isotope. A naturally occurring neutral atom of phosphorus has **15** protons, **16** neutrons and **15** electrons.

(l) Name the instrumental technique discussed in CHEM 1000 that can be used to separate different isotopes of the same element. **mass spectrometry**

(m) What is the chemical name for the ClO_4^- ion? **perchlorate**

1 mark per blank

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2. Give the name and symbol for the element which meets each description. **[5 marks]**

Description	Symbol	Name
The alkaline earth metal with the smallest atomic radius.	**Be**	**beryllium**
The halogen in period 3.	**Cl**	**chlorine**
The neutral element which has a valence electron configuration of $4s^2\ 3d^7$	**Co**	**cobalt**
The neutral element which has a valence electron configuration of $3s^2\ 3p^3$	**P**	**phosphorus**
The most electronegative element.	**F**	**fluorine**

½ mark per box

3. Give a valid set of quantum numbers for the valence electron in Rb. **[3 marks]**

$n = 5$ $l = 0$ $m_l = 0$ $m_s = +½$ or $-½$

1 mark for "it's a 5*s* electron" (does not need to be stated outright; award if n and l correct)

½ mark per quantum number

4. Assuming you could measure them by similar means, which of the following would be the largest: He, Li^+ or Be^{2+}? Justify your answer. **[3 marks]**

He 1 mark

All three have identical electronic configurations, but He has the smallest *Z*, and thus the weakest attraction between the electrons and nucleus. 2 marks

5. Which of the following compounds would you expect to have the lowest melting point, aluminium oxide, lithium oxide or potassium bromide? Justify your answer. **[3 marks]**

KBr 1 mark

The melting point of an ionic solid increases as the strength of attraction between ions increases (i.e. as magnitude of ions' charges increase and ionic radii decrease). K^+ is larger than Li^+ and Al^{3+} and has a smaller charge than Al^{3+}. Br^- is larger and has a smaller charge than O^{2-}. 2 marks

(argument need not include radii as charges are enough to determine correct answer in this case)

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6. **[10 marks]**

(a) Draw Lewis structures (and resonance structures, if appropriate) for the following ions:

IF_2^+ and IF_4^+

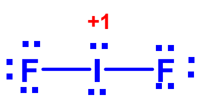
Clearly show the formal charge of any atom with a non-zero formal charge.

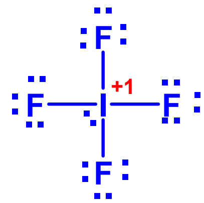
(b) Predict the geometry of each ion.

(c) Calculate the oxidation state of the iodine atom in each ion.

(d) Which of the two ions would you expect to be the stronger oxidizing agent and why?

(a)





2 marks each (1 for Lewis structure; 1 for formal charge)

(b) bent see saw 1 mark each

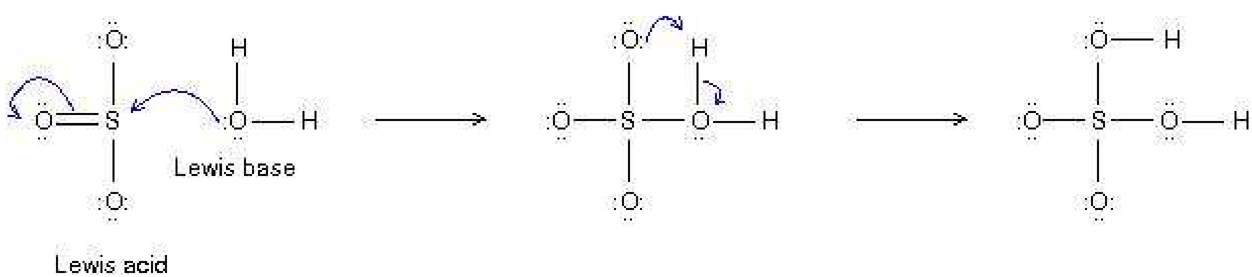
(c) +3 +5 1 mark each

(d) IF_4^+ 1 mark

The oxidation state of the I atom is furthest from the normal oxidation state of I.

<u>or</u> The iodine atom in IF_4^+ is more electron deficient (has a higher oxidation state) therefore it gains electrons more readily, making it a better oxidizing agent. 1 mark

7. Show, using appropriate Lewis structures, that the reaction of sulfur trioxide with water is a Lewis acid-base reaction. Identify the Lewis acid and the Lewis base. **[7 marks]**



1 mark for water Lewis structure

1 mark for SO_3 Lewis structure

2 marks for product's Lewis structure (not necessary to show rearrangement of product to sulfuric acid)

3 marks for identifying water as Lewis base, SO_3 as Lewis acid and direction of electron flow from Lewis base to Lewis acid

The emphasis in marking this question should be on writing plausible Lewis structures, on keeping proper track of the electrons as we go, and on getting the right product.

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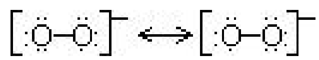
8. Draw a Lewis structure (and resonance structures, if appropriate) for the superoxide ion. Clearly show the formal charge of each oxygen atom. **[3 marks]**



1 mark for superoxide = O_2^-
1 mark for each resonance structure

9. Describe the Haber-Bosch process for the industrial production of ammonia. Be sure to include balanced equations for any relevant reactions and explain why any special conditions (e.g. use of a catalyst, pressure, heat, etc.) are necessary. **[8 marks]**

5 marks for Haber-Bosch process

- Balanced reaction equation ($N_{2(g)} + 3\ H_{2(g)} \rightarrow 2\ NH_{3(g)}$) 1 mark
- Requirement for catalyst (also heat and high pressure) 1 mark
- Reaction does *not* go to completion 1 mark
- Mixture of $N_{2(g)}$, $H_{2(g)}$ and $NH_{3(g)}$ is cooled to condense the ammonia out of the mixture of gases 1 mark
- Remaining $N_{2(g)}$ and $H_{2(g)}$ are recycled so that eventual yield (after many cycles) is about 100% 1 mark

3 marks for why catalyst and pressure/heat is needed

- The bonds in nitrogen and hydrogen are very strong. (N_2 bond energy is 946 kJ/mol and H_2 bond energy is 436 kJ/mol according to the table on the data sheet.) A catalyst allows these bonds to be broken without forming free H and N atoms. Therefore, less energy input is necessary for the reaction to proceed. 2 marks
- Increasing the pressure forces the hydrogen and nitrogen molecules into closer proximity therefore promoting reaction.

  or

  Adding heat to the reaction chamber provides the energy necessary for the reaction to proceed in a forward direction.

  1 mark

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10. Write a balanced chemical equation for each of the reactions described below. *Include states of matter.* **[14 marks]**

(a) Aluminium oxide reacts with excess aqueous acid.

$Al_2O_{3(s)} + 6H^+_{(aq)} \rightarrow 2Al^{3+}_{(aq)} + 3H_2O_{(l)}$ or $Al_2O_{3(s)} + 6H_3O^+_{(aq)} \rightarrow 2Al^{3+}_{(aq)} + 9H_2O_{(l)}$

(b) Aluminium oxide reacts with excess aqueous base.

$Al_2O_{3(s)} + 2OH^-_{(aq)} + 3H_2O_{(l)} \rightarrow 2[Al(OH)_4]^-_{(aq)}$

(c) Calcium oxide reacts with water.

$CaO_{(s)} + H_2O_{(l)} \rightarrow Ca(OH)_{2(s)}$ or $CaO_{(s)} + H_2O_{(l)} \rightarrow Ca(OH)_{2(aq)}$

(d) Chlorine gas disproportionates in aqueous base to form the chloride ion, the hypochlorite ion and one other product.

$Cl_{2(g)} + 2OH^-_{(aq)} \rightarrow Cl^-_{(aq)} + OCl^-_{(aq)} + H_2O_{(l)}$

(e) Potassium metal reacts with fluorine gas.

$2K_{(s)} + F_{2(g)} \rightarrow 2KF_{(s)}$

(f) Sodium metal is produced by electrolysis of molten sodium chloride.

$2NaCl_{(l)} \rightarrow 2Na_{(l)} + Cl_{2(g)}$

(g) Hydrogen gas is prepared *via any method discussed in either lab or lecture of CHEM 1000.*

Any reasonable reaction – metal + acid; alkali metal + water; aluminium + strong base; etc.

2 marks each; 1 mark for reactants/products; 1 mark for balancing

Deduct 0.5 mark per states of matter error to a max. of 1 mark per equation

11. In the lime-soda process for the softening of water, the first step involves the addition of calcium hydroxide to a solution containing calcium ions and hydrogen carbonate ions. Write a balanced chemical equation for this reaction, including the states of matter of all chemical species. *(hint: What happens if you react the hydrogen carbonate ion with hydroxide?)* **[3 marks]**

$Ca(OH)_{2(s)} + Ca^{2+}_{(aq)} + 2HCO^-_{3(aq)} \rightarrow 2CaCO_{3(s)} + 2H_2O_{(l)}$

1 mark for reactants

1 mark for products

1 mark for balanced

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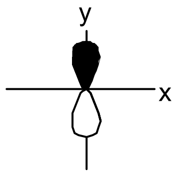
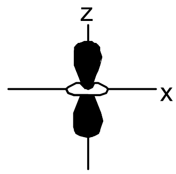
12. Sketch each of the orbitals listed below. For each orbital, use a set of axes to clearly show its orientation. **[3 marks]**

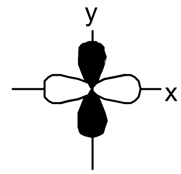
(a) $2p_y$



(b) $3d_{z^2}$



(c) $3d_{x^2-y^2}$



1 mark each (half marks if phases not shown or incorrect)

13. The diagram at the right shows the unit cell of CaF_2 (with an additional four "grey atoms" below the unit cell). **[8 marks]**

(a) How many grey atoms are **inside** one unit cell? 8 1 mark

(b) How many black atoms are **inside** one unit cell? 4 1 mark

(c) In the diagram at the right, which colour of atoms corresponds to the calcium cations?

black 2 marks

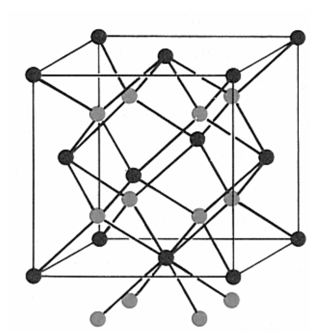
(d) Describe the structure in terms of the ion packing (i.e. the lattice).

Face-centered cubic lattice of Ca^{2+} 1 mark

F^- fill the tetrahedral holes 1 mark

(e) Is this packing description typical of an ionic solid? If so, why? If not, what is unusual about it?

Not typical. Usually, an ionic solid is described as a lattice of anions with cations in the holes. 2 marks



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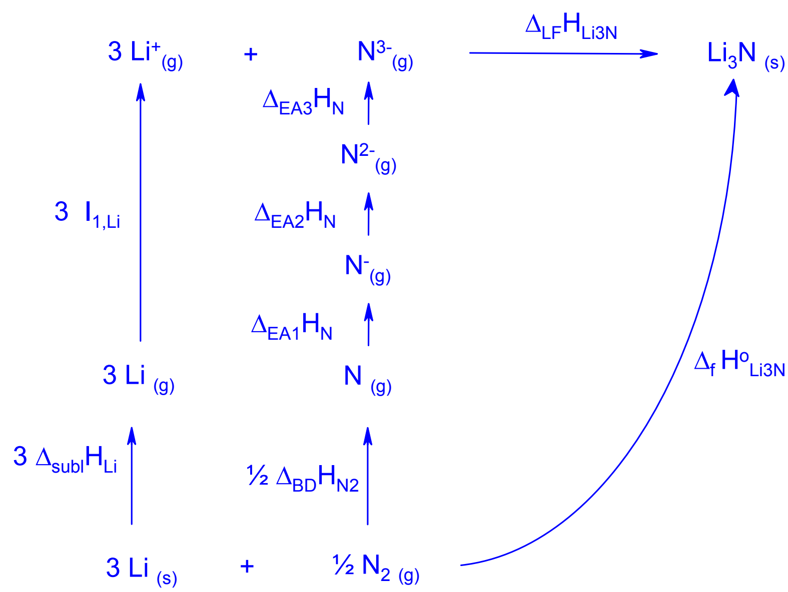
14. **[7 marks]**

(a) Give the chemical name for Li_3N.

lithium nitride 1 mark

(b) Sketch a Born-Haber cycle for Li_3N. Clearly label the enthalpy change involved with each step.



1 mark for 3 $Li_{(s)}$ and ½ $N_{2(g)}$

4 marks for Born-Haber cycle [½ mark per step (i.e. arrow) for 8 steps]

(c) Write an equation that would allow you to calculate the lattice enthalpy for Li_3N *if* the required thermochemical data were provided. (It's not.)

$$\Delta_{LF}H_{Li_3N} = \Delta_f H^o_{Li_3N} - \left[3\Delta_{subl}H_{Li} + 3I_{1,Li} + \frac{1}{2}\Delta_{BD}H_{N\equiv N} + \Delta_{EA1}H_N + \Delta_{EA2}H_N + \Delta_{EA3}H_N\right]$$

1 mark

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15. The $[Fe(CN)_6]^{4-}$ complex is very stable and nontoxic. **[10 marks]**

(a) What is the oxidation state of iron in this complex?

+2 1 mark

(b) What is the chemical name for this complex?

hexacyanoferrate(II) 1 mark

give ½ mark for hexacyanoiron(II)

(c) Write the electron configuration for a neutral iron atom in line notation ***using the noble gas abbreviation***.

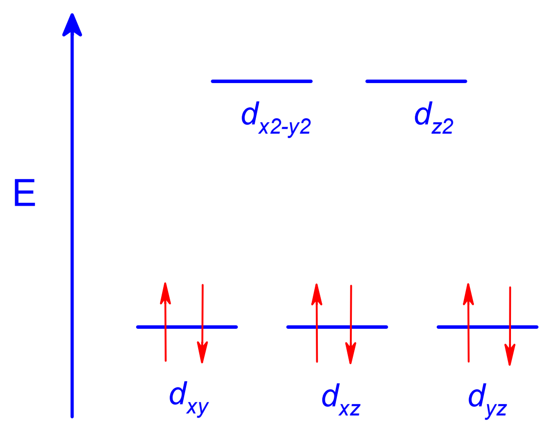
[Ar] $4s^2\ 3d^6$ 1 mark

(d) Write the electron configuration for the iron ion found in the above complex in line notation ***using the noble gas abbreviation***.

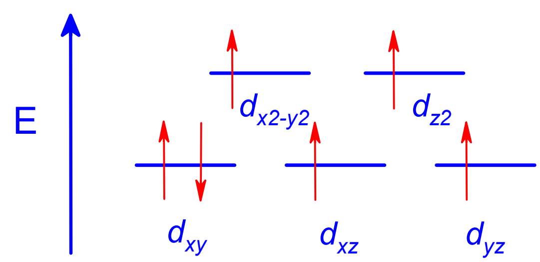
[Ar] $3d^6$ 1 mark

(e) Draw two energy level diagrams showing the splitting of the *d* orbitals in this complex, including the correct number of electrons. Draw both possibilities for the electron configuration and name them.

4 marks (1 per picture; 1 per name)



Low Spin



High Spin

(f) Which of the two electron occupancy diagrams drawn in part (d) do you anticipate is correct? Justify your answer.

Low spin. 1 mark

Cyano is a strong field ligand. 1 mark

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16. A hydrogen atom in an excited state has its electron in a 4*d* orbital. **[10 marks]**

(a) How many 4*d* orbitals are there in a single hydrogen atom?

5 1 mark

(b) List all possible values for each of the four quantum numbers for the electron in this hydrogen atom.

$n = 4$ $l = 2$ $m_l = -2, -1, 0, +1$ or $+2$ $m_s = +½$ or $-½$ 2 marks

(c) What wavelength of light will be emitted if this electron returns directly to the ground state? *Express your answer using an appropriate SI prefix so that the value is between 0.1 and 1000.*

Ground state means $n = 1$. 1 mark

$$E_{n=4} = -R_H\left(\frac{Z^2}{n^2}\right) = -2.179\times10^{-18}\,J\left(\frac{1^2}{4^2}\right) = -1.362\times10^{-19}\,J$$ 1 mark

$$E_{n=1} = -R_H\left(\frac{Z^2}{n^2}\right) = -2.179\times10^{-18}\,J\left(\frac{1^2}{1^2}\right) = -2.179\times10^{-18}\,J$$ 1 mark

$$E_{photon} = E_{n=4} - E_{n=1} = \left(-1.362\times10^{-19}\,J\right) - \left(-2.179\times10^{-18}\,J\right) = 2.043\times10^{-18}\,J$$ 2 marks

$$\lambda_{photon} = \frac{hc}{E_{photon}} = \frac{\left(6.626\times10^{-34}\,\frac{J}{Hz}\right)\left(2.9979\times10^{8}\,\frac{m}{s}\right)}{2.043\times10^{-18}\,J} = 9.724\times10^{-8}\,m = 97.24\,nm$$

2 marks

-1 mark if final answer has missing/incorrect/inappropriate units

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17. A piece of magnesium with a mass of 185 mg is dropped into a beaker containing 75 mL of 1.25 M $HCl_{(aq)}$. Once the reaction is complete, what is the concentration of $HCl_{(aq)}$ remaining in the beaker? **[6 marks]**

$$Mg_{(s)} + 2HCl_{(aq)} \rightarrow MgCl_{2(aq)} + H_{2(g)}$$ 1 mark

$$n_{Mg} = \frac{m_{Mg}}{M_{Mg}} = \frac{0.185g}{24.305\frac{g}{mol}} = 0.007611mol$$ 1 mark

$$n_{HCl-initial} = M_{HCl}V_{HCl} = \left(1.25\frac{mol}{L}\right)(0.075L) = 0.09375mol$$ 1 mark

$$n_{HCl-final} = n_{HCl-initial} - n_{HCl-reacted}$$

$$n_{HCl-final} = (0.09375mol) - \left(0.007611molMg \times \frac{2molHCl}{1molMg}\right) = 0.07853mol$$ 2 marks

$$M_{HCl-final} = \frac{n_{HCl-final}}{V_{HCl}} = \frac{0.07853mol}{0.075L} = 1.047\frac{mol}{L} = 1.0\frac{mol}{L}$$ 1 mark

-1 mark if final answer does not have 2 sig. fig.

-1 mark if final answer has missing/incorrect units

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18. Thallium(III) oxide decomposes to thallium(I) oxide and oxygen gas at temperatures above 700 °C. **[6 marks]**

(a) Write a balanced chemical equation for this reaction. *(Thallium = Tl)*

$$Tl_2O_{3(s)} \rightarrow Tl_2O_{(s)} + O_{2(g)}$$ 1 mark

(b) You have an impure sample of thallium(III) oxide. In a lab, you heat 65 grams of the impure sample to 750 °C (atmospheric pressure = 88100 Pa). The oxygen generated is collected in a balloon and measured to have a volume of 1.6 L at 22.5 °C. What was the mass of pure thallium(III) oxide in the original sample?

1 mark

$$T = 22.5 + 273.15 = 295.65K$$

1 mark

$$V = 1.6L \times \frac{1m^3}{1000L} = 0.0016m^3$$

1 mark

$$n_{O_2} = \frac{PV}{RT} = \frac{(88100Pa)(0.0016m^3)}{\left(8.3145\frac{m^3 \cdot Pa}{mol \cdot K}\right)(295.65K)} = 0.05734mol$$

1 mark

$$n_{Tl_2O_3} = n_{O_2} = 0.05734mol$$

1 mark

$$m_{Tl_2O_3} = n_{Tl_2O_3} \times M_{Tl_2O_3} = (0.05734mol)\left(456.764\frac{g}{mol}\right) = 26.19g = 26g$$

-1 mark if final answer does not have 2 sig. fig.

-1 mark if final answer has missing/incorrect units

19. What was the most useful and/or interesting thing you learned in CHEM 1000? **[1 mark]**

1 mark if answered question

…AND THAT'S ALL FOR CHEM 1000.
HAPPY HOLIDAYS!

DATA SHEET

Fundamental Constants and Conversion Factors

Atomic mass unit (u)	1.6605×10^{-27} kg	Kelvin temperature scale	0 K = -273.15 ˚C
Avogadro's number	6.02214×10^{23} mol^{-1}	Planck's constant	6.626×10^{-34} J·Hz^{-1}
Bohr radius (a_0)	5.29177×10^{-11} m	Proton mass	1.0072765 u
Coulomb constant (k)	8.988×10^{9} N·m^2·C^{-2}	Neutron mass	1.0086649 u
Electron charge (*e*)	1.6022×10^{-19} C	Rydberg Constant (R_H)	2.179×10^{-18} J
Electron mass	5.4688×10^{-4} u	Speed of light in vacuum	2.9979×10^{8} m·s^{-1}
Ideal gas constant (R)	8.3145 J·mol^{-1}·K^{-1} 8.3145 m^3·Pa·mol^{-1}·K^{-1}	Standard atmospheric pressure	1 bar = 100 kPa

Formulae

$c = \upsilon\lambda$ $\quad E = h\upsilon$ $\quad p = mv$ $\quad \lambda = \frac{h}{p}$ $\quad \Delta x \cdot \Delta p > \frac{h}{4\pi}$

$r_n = a_0 \frac{n^2}{Z}$ $\quad E_n = -R_H \frac{Z^2}{n^2}$

$E_k = \frac{1}{2}mv^2$ $\quad PV = nRT$

$F = k\frac{(z^+e)(z^-e)}{d^2}$ $\quad E = k\frac{(z^+e)(z^-e)}{d}$

$pK_a \approx 15.14 - 88.16pm\left(\frac{z^2}{r}\right)$ **or** $pK_a \approx 15.14 - 88.16pm\left(\frac{z^2}{r} + 0.0960pm^{-1}(\chi_{Pauling} - 1.50)\right)$ for aqua complexes

$pK_a \approx 8 - 5p$ for oxoacids $O_pE(OH)_q$

Spectrochemical Series

strong field weak field

CN^- > ethylenediamine > NH_3 > $EDTA^{4-}$ > H_2O > oxalato > OH^- > F^- > Cl^- > Br^- > I^-

Radius Ratio Rules

$\frac{r^+}{r^-}$	**Lattice Type**
0.225 – 0.414	ZnS
0.414 – 0.732	NaCl
> 0.732	CsCl

DATA SHEET

Representative Bond Energies

Bond	Bond Energy (kJ/mol)
H–H	436
H–C	414
H–N	389
H–O	464
H–F	565

Bond	Bond Energy (kJ/mol)
C–C	347
C=C	611
C≡C	837
C–N	305
C–O	360

Bond	Bond Energy (kJ/mol)
N–N	163
N=N	418
N≡N	946
O–O	142
O=O	498

Chemistry 1000 Standard Periodic Table

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1.0079 **H** 1																	4.0026 **He** 2
6.941 **Li** 3	9.0122 **Be** 4											10.811 **B** 5	12.011 **C** 6	14.0067 **N** 7	15.9994 **O** 8	18.9984 **F** 9	20.1797 **Ne** 10
22.9898 **Na** 11	24.3050 **Mg** 12											26.9815 **Al** 13	28.0855 **Si** 14	30.9738 **P** 15	32.066 **S** 16	35.4527 **Cl** 17	39.948 **Ar** 18
39.0983 **K** 19	40.078 **Ca** 20	44.9559 **Sc** 21	47.88 **Ti** 22	50.9415 **V** 23	51.9961 **Cr** 24	54.9380 **Mn** 25	55.847 **Fe** 26	58.9332 **Co** 27	58.693 **Ni** 28	63.546 **Cu** 29	65.39 **Zn** 30	69.723 **Ga** 31	72.61 **Ge** 32	74.9216 **As** 33	78.96 **Se** 34	79.904 **Br** 35	83.80 **Kr** 36
85.4678 **Rb** 37	87.62 **Sr** 38	88.9059 **Y** 39	91.224 **Zr** 40	92.9064 **Nb** 41	95.94 **Mo** 42	(98) **Tc** 43	101.07 **Ru** 44	102.906 **Rh** 45	106.42 **Pd** 46	107.868 **Ag** 47	112.411 **Cd** 48	114.82 **In** 49	118.710 **Sn** 50	121.757 **Sb** 51	127.60 **Te** 52	126.905 **I** 53	131.29 **Xe** 54
132.905 **Cs** 55	137.327 **Ba** 56	**La-Lu**				186.207 **Re** 75	190.2 **Os** 76	192.22 **Ir** 77	195.08 **Pt** 78	196.967 **Au** 79	200.59 **Hg** 80	204.383 **Tl** 81	207.19 **Pb** 82	208.980 **Bi** 83	(210) **Po** 84	(210) **At** 85	(222) **Rn** 86
(223) **Fr** 87	226.025 **Ra** 88	**Ac-Lr**	(261) **Rf** 104	(262) **Db** 105	(263) **Sg** 106	(262) **Bh** 107	(265) **Hs** 108	(266) **Mt** 109	(281) **Dt** 110	(283) **Rg** 111							

	140.115 **Ce** 58	140.908 **Pr** 59	144.24 **Nd** 60	(145) **Pm** 61	150.36 **Sm** 62	151.965 **Eu** 63	157.25 **Gd** 64	158.925 **Tb** 65	162.50 **Dy** 66	164.930 **Ho** 67	167.26 **Er** 68	168.934 **Tm** 69	173.04 **Yb** 70	174.967 **Lu** 71
	232.038 **Th** 90	231.036 **Pa** 91	238.029 **U** 92	237.048 **Np** 93	(240) **Pu** 94	(243) **Am** 95	(247) **Cm** 96	(247) **Bk** 97	(251) **Cf** 98	(252) **Es** 99	(257) **Fm** 100	(258) **Md** 101	(259) **No** 102	(260) **Lr** 103

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