

DEPARTMENT OF CHEMISTRY
UNIVERSITY OF SWAZILAND

C 304

Instrumental Analysis

May 2005 Final Examination

Time Allowed:

Three (3) Hours

Instructions:

1. This examination has six (6) questions, one (1) graph sheet, and one data sheet. The total number of pages is seven (7) excluding this page.
2. Answer any four (4) questions fully; diagrams should be clear, large and properly labeled. Marks will be deducted for improper units and lack of procedural steps in calculations.
3. Each question is worth 25 marks.

Special Requirements:

1. Graph Sheet
2. Data Sheet

YOU ARE NOT SUPPOSED TO OPEN THIS PAPER UNTIL PERMISSION TO DO SO HAS BEEN GIVEN BY THE CHIEF INVIGILATOR.

Some Useful Physical Constants:

$$h = 6.626 \times 10^{-34} \text{ J s}$$

$$c = 2.998 \times 10^8 \text{ m sec}^{-1}$$

$$N = 6.02 \times 10^{23} \text{ mol}^{-1}$$

$$k = 1.381 \times 10^{-23} \text{ JK}^{-1}$$

$$1 \text{ eV} = 1.602 \times 10^{-19} \text{ J}$$

$$R = 8.314 \text{ JK}^{-1} \text{ mol}^{-1}$$

$$\text{Atomic weights: Fe} = 55.85; \text{S} = 32.06; \text{O} = 16.00; \text{H} = 1.008; \text{N} = 14.01; \text{C} = 12.01$$

QUESTION 1 [25]

- (a) Hemin, $C_{20}H_{20}N_4Fe$ is a oxygen carrying porphyrin component of the haemoglobin molecule. Being highly conjugated, hemin shows distinct absorption bands in the UV-visible portion of the electromagnetic spectrum.
- List the upper and lower limit of the UV-visible region in wavenumbers (cm^{-1}) [1]
 - What type of transition is likely to be taking place when molecules of hemin interact with photons in the subregion mentioned in (i) above? [1]
 - What does the spectroscopic term "bathochromic shift" mean? [1]
- (b) Crystals of hemin were dissolved in concentrated nitric acid and the resultant solution diluted to 100 mL to form a 2 ppm solution. A UV-visible spectrum of the resulting solution as taken, whereby in a 11.7 mm cell, it showed a strong absorption at $\lambda_{max} = 520$ nm of 0.528 absorbance units.
- Sketch the spectrum of this compound [1]
 - What is the transmittance in % of the sample at λ_{max} ? [2]
 - Calculate the molar absorptivity of this compound at λ_{max} [2]
- (c) The "monochromator" in a spectrometer is a critical component.
- What role does a "monochromator" play in a spectrometer? [1]
 - Describe, using diagrams, the following filters acting as monochromators in a spectrometer:
 - a band pass filter [3]
 - a cut-off filter [3]
- (d)
 - Use equations to explain why the source and sample in a spectrometer are kept in a darkened compartment [4]
 - Use equations to explain why measurements in a spectrometer are taken at the "peak" rather than at the "shoulder" [6]

QUESTION 2 [25]

- (a) In the analysis of Fe in natural waters, several reagents are added prior to complexation with 1,10 phenanthroline. Explain the role of the following in this analysis:
- hydroxylamine hydrochloride [1]
 - sodium acetate/acetic acid buffer [1]
 - a blank [1]
- (b) A solution of two isomers, ortho- and para-, are simultaneously determined by uv-visible spectroscopy. At 410 nm, the measured absorbance was 0.353, whereas at 560 nm, the absorbance was 0.251 in a 1.00 cm cell.

Calculate the concentration of the two isomers (molar absorptivities at 410 nm are: 6000 for ortho-, 500 for para-; at 560 nm they are 2152 for ortho-, 5260 for para-) [5]

- (c) Use diagrams to explain how the "Molar Ratio Method" can be used to determine stoichiometry [3]
- (d) Draw the expected Job's plot for a complex M_nL_x where $n=x=1$ at low ligand concentration, and $n=1, x=3$ at high ligand concentration [3]
- (e) Two elements, X and Y, are to be analyzed by flame AA and flame emission. The transition for element X is designated $^2S_{1/2} \rightarrow ^2P_{3/2}$ and has a wavelength of 852.1 nm. For Y it is $^1S_0 \rightarrow ^1S_1$ and has a wavelength of 228 nm. What is the ratio of excited to ground state atoms if the flame is operated at 2250 °C for each element? [6]
- (f) Use the ratios obtained in (d) above to decide which element is best analyzed by which method. State a reason for your choice in each case [2]
- (g) Name three elements that are determined by flame photometry in clinical analysis [3]

QUESTION 3 [25]

- (a) The most widely used region in the electromagnetic spectrum for organic functional group identification is the infra-red (IR) region.
- What are the borders of IR in electron volts? [2]
 - Using the CO_2 molecule as an example, describe two (2) common modes of molecular vibrations that give rise to IR radiation [2]
- (b) In dispersive IR, double beam instruments are used, whereby two beams pass through the sampling area before reaching the monochromator and detector.
- Explain why the beam is split into two before reaching the sampling area [2]
 - Explain why the beams pass through the sampling area before reaching the monochromator and not after it [2]
 - Explain why the exact opposite of the arrangement in (ii) above is done in UV-visible instrumentation [2]
- (c) Analytical instruments configured in the Czerny-Turner arrangement of optical components use a "grating" as a monochromator.
- In physical appearance, what does the grating look like? [1]
 - State the Bragg equation for the grating, and explain all the terms that appear in it [3]
 - If the grating is 5 cm wide with 11, 800 lines/mm, calculate its first order resolving power [3]
- (d) Although it is primarily a functional group identification tool, IR spectroscopy may sometimes be successfully used for quantitative analysis of organic compounds. One such case is the quantitative analysis of Thio-Mickler's Ketone (TMK), where the carbonyl functional group of TMK appearing at 1785 cm^{-1} is used. Supposing a 5.2031-g tablet containing TMK is dissolved in 100 mL, and that this solution, together with TMK standards, yielded the following results:

Sample	I	I ₀	Absorbance
0 ppm standard	A	5638	0.000
2 ppm standard	4351	B	0.103
4 ppm standard	3526	5641	C
Unknown	4025	5636	

- i) Calculate A [1]
- ii) Calculate B [1]
- iii) Calculate C [1]
- iv) Draw the calibration curve of TMK [2]
- v) What was the concentration (in $\mu\text{g/g}$) of TMK in the unknown sample [3]

QUESTION 4 [25]

- (a) Analytical chemists agree that the technique of atomic absorption "came of age" with the invention of the hollow cathode lamp by Sir Walsh in 1955.
 - i) Draw and label the hollow cathode lamp [2]
 - ii) Explain how the hollow cathode lamp works [2]
- (b) There are procedures commonly employed by analysts when using a flame atomic absorption spectrophotometer. Explain
 - i) Why in the analysis of Ca in soils, EDTA is added to all solutions [1]
 - ii) Why in the analysis of Sr in foodstuffs, 1000 ppm La is added to all solutions [1]
 - iii) Why in the analysis of Cu in a plant sample, the instrument is operated under "standard additions" mode [1]
- (c) A major breakthrough in atomic absorption spectrophotometry since the invention of the hollow cathode lamp is graphite furnace AA.
 - i) What is the major structural difference between flame AA and graphite furnace AA? [2]
 - ii) Identify the physical stages involved in a furnace program, and describe the processes that occur during each stage [3]
 - iii) Describe two (2) advantages of graphite furnace AA over flame AA [2]
- (d) In 2001, the Swaziland Water Services Corporation acquired a new atomic spectrometer called the Liberty 110 ICP.
 - i) What does the acronym ICP stand for? [1]
 - ii) Explain how a "doughnut" shaped ICP is formed, and why it is preferred over a "tear-drop" shaped ICP. [3]
 - iii) What are the normal operating values of the ICP in terms of:
Power in KW----- [1] Temperature in K----- [1]
 - iv) In the ICP, direct reading of several lines at once is possible. With the aid of a diagram, explain how this is possible [3]
 - v) List two (2) advantages of ICP compared to FAAS or GFAAS [2]

QUESTION 5 [25]

Gas Chromatographic techniques have many applications in analytical chemistry, especially in the area of pesticide and drug analysis.

- (a) In GC, explain what is meant by
- Temperature programming [1]
 - the "race-track" effect [1]
- (b) The power of separation, technically the "resolution" in GC, depends on the plate number, or alternatively the HETP, which has its theoretical origins embodied by the Van Deemter principle. With regards to HETP for a GC packed column,
- explain the origin of "Eddy Diffusion"[1]
 - write down the equation that relates HETP to Eddy Diffusion, and explain all terms that appear in it [2]
 - explain the origin of "Longitudinal Diffusion"[1]
 - write down the equation that relates HETP to Longitudinal Diffusion, and explain all terms that appear in it [2]
- (c) Draw the Van Deemter Plot for packed column GC, and identify the point in the plot that is used to determine the optimum velocity of carrier gas [3]
- (d) A GC instrument equipped with a 3-m steel column packed with Chromosorb W-AW on PEGS stationary phase and a Flame Ionization Detector, was used to quantify two alcohols, methanol and ethanol. 2-butanol was used as an internal standard. In the chromatogram, an unretained air peak appeared at 30 sec, while peaks for the two alcohols of interest appeared at 3 and 3.5 min respectively.
- What is meant by the prefix "AW" in Chromosorb W-AW? [1]
 - State the order in which the three alcohols will elute out of the analytical column [1]
 - Describe the role of 100%v/v 2-butanol in the analysis [1]
 - Draw and label a diagram of an FID, and explain how it works [4]
 - Calculate the capacity factor of ethanol [2]
 - If the column had 320 theoretical plates, what is the width of the methanol peak? [2]
 - Are these two peaks properly resolved? Explain why or why not [3]

QUESTION 6 [25]

Liquid Chromatographic techniques have many applications in analytical chemistry, especially in the area of food and drug analysis.

- (a) In LC, explain what is meant by
- Solvent programming [1]
 - Isocratic elution [1]

- (b) The power of separation, technically the "resolution" in LC, depends on the plate number, or alternatively the HETP, which has its theoretical origins embodied by the Van Deemter principle. With regards to HETP for an LC packed column,
- i) explain the origins of "Resistance to Mass Transfer in the Stationary Phase"[2]
 - ii) write down the equation that relates HETP to Resistance to Mass Transfer in the Stationary Phase, and explain all terms that appear in it [3]
 - iii) explain the origin of "Resistance to Mass Transfer in the Stagnant Mobile Phase"[2]
 - iv) write down the equation that relates HETP to "Resistance to Mass Transfer in the Stagnant Mobile Phase", and explain all terms that appear in it [3]
- (c) Draw the Van Deemter Plot for packed column LC, and identify areas in the plot which are different from those of gas chromatography [3]
- (d) HPLC is widely used for Vitamin A analyses. In a typical analysis, after pre-treatment and priming, both sample and standards are injected into an HPLC instrument fitted with a 20-cm 0.5-in. glass column in a reverse-phase bonded phase mode. Eluents are detected by means of a uv detector at 254 nm.
- i) What does the acronym "HPLC" stand for? [1]
 - ii) Describe the process of "priming" in HPLC [1]
 - iii) What is the reason for the use of bonded phases in HPLC? [1]
 - iv) Use chemical equations to describe how bonded phases are synthesized in the laboratory [3]
- (e) In a lot of instances, column materials are "silinized" in chromatography.
- i) What is the role of "silinization" in chromatography [1]
 - ii) Use chemical equations to describe how silinization is achieved in the laboratory [3]

Indicator	pH range	pKin	Acid	Base
Thymol blue	1.2-2.8	1.6	red	yellow
Methyl yellow	2.9-4.0	3.3	red	yellow
Methyl orange	3.1-4.4	4.2	red	yellow
Bromocresol green	3.8-5.4	4.7	yellow	blue
Methyl red	4.2-6.2	5.0	red	yellow
Chlorophenol red	4.8-6.4	6.0	yellow	red
Bromothymol blue	6.0-7.6	7.1	yellow	blue
Phenol red	6.4-8.0	7.4	yellow	red
Cresol purple	7.4-9.0	8.3	yellow	purple
Thymol blue	8.0-9.6	8.9	yellow	blue
Phenolphthalein	8.0-9.8	9.7	colorless	red
Thymolphthalein	9.3-10.5	9.9	colorless	blue

n	Q ₉₀	n	Q ₉₀	n	Q ₉₀
3	0.94	6	0.56	9	0.44
4	0.76	7	0.51	10	0.41
5	0.64	8	0.47		

15. Bond Enthalpies
kJ mol⁻¹ at 25°C (i.e. Bond Energies)

Single	O	N	C	S	F	Cl
H	463	391	413	368	563	432
C	358	305	346	272	489	328
N	222	163	MISC.	275	192	
S-S	251	H-H	436	C=C	615	
S-F	327	N≡N	946	C≡C	812	
S-Cl	271	N=O	607	C=O	749	

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D.F.	t ₃₀	t ₅₀	t ₇₅	t ₉₀
1	1.0	6.3	13	64
2	0.82	2.9	4.3	9.
3	0.76	2.35	3.2	5.
4	0.74	2.10	2.8	4.
5	0.73	2.02	2.57	4.
6	0.72	1.94	2.05	3.
7	0.71	1.90	2.36	3.
8	0.71	1.86	2.31	3.
9	0.70	1.83	2.26	3.
10	0.70	1.81	2.23	3.
20	0.69	1.72	2.09	2.
30	0.68	1.70	2.04	2.
∞	0.67	1.64	1.96	2.

12. ELECTRODE POTENTIALS, E°

Na ⁺ + e ⇌ Na	-2.713
Mg ²⁺ + 2e ⇌ Mg	-2.37
Al ³⁺ + 3e ⇌ Al	-1.66
Zn ²⁺ + 2e ⇌ Zn	-0.763
Fe ²⁺ + 2e ⇌ Fe	-0.44
Cd ²⁺ + 2e ⇌ Cd	-0.403
Cr ³⁺ + e ⇌ Cr ²⁺	-0.38
Tl ⁺ + e ⇌ Tl	-0.336
V ³⁺ + e ⇌ V ²⁺	-0.255
Sn ²⁺ + 2e ⇌ Sn	-0.14
Pb ²⁺ + 2e ⇌ Pb	-0.126
2H ⁺ + 2e ⇌ H ₂	0.000
S ₂ O ₈ ²⁻ + 2e ⇌ 2S ₂ O ₈ ³⁻	0.09
TiO ₂ ⁺ + 2H ⁺ + e ⇌ Ti ³⁺ + H ₂ O	0.10
S + 2H ⁺ + 2e ⇌ H ₂ S	0.14
Sn ⁴⁺ + 2e ⇌ Sn ²⁺	0.14
Cu ²⁺ + e ⇌ Cu ⁺	0.17
SO ₄ ²⁻ + 4H ⁺ + 2e ⇌ H ₂ O + H ₂ SO ₃	0.17
AgCl + e ⇌ Cl ⁻ + Ag	0.222
Saturated calomel	(0.244)
Hg ₂ Cl ₂ + 2e ⇌ 2Cl ⁻ + 2Hg	0.268
Bi ³⁺ + 3e ⇌ Bi	0.293
UO ₂ ²⁺ + 4H ⁺ + 2e ⇌ U ⁴⁺ + 2H ₂ O	0.33
VO ²⁺ + 2H ⁺ + e ⇌ V ³⁺ + H ₂ O	0.34
Cu ²⁺ + 2e ⇌ Cu	0.34
Fe(CN) ₆ ³⁻ + e ⇌ Fe(CN) ₆ ⁴⁻	0.355
Cu ⁺ + e ⇌ Cu	0.52
I ₃ ⁻ + 2e ⇌ 3I ⁻	0.545
H ₃ AsO ₄ + 2H ⁺ + 2e ⇌ H ₃ AsO ₃ + H ₂ O	0.56
I ₂ + 2e ⇌ 2I ⁻	0.621
2HgCl ₂ + 2e ⇌ Hg ₂ Cl ₂ + 2Cl ⁻	0.63
O ₂ + 2H ⁺ + 2e ⇌ H ₂ O ₂	0.69
Quinone + 2H ⁺ + 2e ⇌ Hydroquinone	0.70
Fe ³⁺ + e ⇌ Fe ²⁺	0.771
Hg ₂ ²⁺ + 2e ⇌ 2Hg	0.792
Ag ⁺ + e ⇌ Ag	0.799
Hg ²⁺ + 2e ⇌ Hg	0.851
2Hg ²⁺ + 2e ⇌ Hg ₂ ²⁺	0.907
NO ₃ ⁻ + 3H ⁺ + 2e ⇌ HNO ₂ + H ₂ O	0.94
HNO ₂ + H ⁺ + e ⇌ NO + H ₂ O	0.98
VO ₂ ⁺ + 2H ⁺ + e ⇌ VO ²⁺ + H ₂ O	0.999
Br ₂ + 2e ⇌ 2Br ⁻	1.08
2IO ₃ ⁻ + 12H ⁺ + 10e ⇌ 6H ₂ O + I ₂	1.19
O ₂ + 4H ⁺ + 4e ⇌ 2H ₂ O	1.229
MnO ₂ + 4H ⁺ + 2e ⇌ Mn ²⁺ + 2H ₂ O	1.23
Cr ₂ O ₇ ²⁻ + 14H ⁺ + 6e ⇌ 7H ₂ O + 2Cr ³⁺	1.33
Cl ₂ + 2e ⇌ 2Cl ⁻	1.358
2BrO ₃ ⁻ + 12H ⁺ + 10e ⇌ 6H ₂ O + Br ₂	1.50
MnO ₄ ⁻ + 8H ⁺ + 5e ⇌ 4H ₂ O + Mn ²⁺	1.51
Ce ⁴⁺ + e ⇌ Ce ³⁺	1.61

13. MEAN ACTIVITY COEFFICIENTS

M	KCl	Na ₂ SO ₄	ZnSO ₄
0.001	0.965	0.89	0.70
0.01	0.901	0.72	0.39
0.1	0.769	0.45	0.15

16. HEATS OF FORMATION
ΔH° in kJ mol⁻¹ at 25°C
All ions in H₂O solution except as noted
All Elements = 0

H _g	218	H ⁺	0.0	H ₂ O _g	-242
O _g	249	Na ⁺	-240	H ₂ O _l	-286
C _g	717	Ag ⁺	106	CO _g	-111
N _g	473	NH ₄ ⁺	-133	CO _{2g}	-394
F _g	79	OH ⁻	-230	NH _{3g}	-46
Cl _g	122	F ⁻	-333	NO _g	90
Br _g	112	Cl ⁻	-167	NO _{2g}	33
I _g	107	Br ⁻	-122	N ₂ O _{4g}	9
S _g	279	I ⁻	-55	SO _{2g}	-297
P _g	315	S ⁼	33	SO _{3g}	-396
Na _g	107	SO ₄ ⁼	-909	H ₂ S _g	-21
K _g	88	CO ₃ ⁼	-677	NaF _g	-574
Na ⁺	609	HF _g	-271	NaCl _g	-411
K ⁺	514	HCl _g	-92	KF _g	-567
F ⁻	-255	HBr _g	-36	KCl _g	-437
Cl ⁻	-233	HI _g	26	AgCl _g	-127
CH _{4g}	-75	HCN _g	135	AgBr _g	-100
C ₂ H _{2g}	227	PH _{3g}	5	PCl _{3g}	-287
C ₂ H _{4g}	52	C ₆ H _{6g}	49	PCl _{5g}	-375
C ₂ H _{6g}	-85	CH ₃ OH _l	-238		
C ₃ H _{8g}	-105	C ₂ H ₅ OH _l	-235		
nC ₄ H _{10g}	-127	C ₂ H ₅ OH _g	-278		
nC ₈ H _{18g}	-209	COCl _{2g}	-219		
CCl _{4g}	-135	CH ₃ Cl _g	-81		

17. ABS. ENTROPY S°
J mol⁻¹ K⁻¹ at 25°C

H _{2g}	131	P _{4wh}	164	SF _{6g}	292
N _{2g}	192	HF _g	174	NO _g	211
O _{2g}	205	HCl _g	187	NO _{2g}	240
Cl _{2g}	223	H ₂ O _g	189	N ₂ O _{4g}	304
F _{2g}	203	CO _g	198	NH _{3g}	192
Cgra	5.7	CO _{2g}	214	PCl _{3g}	312
S _{8r}	254	SO _{2g}	248	PCl _{5g}	365
CH _{4g}	186	SO _{3g}	256	BF _{3g}	254
C ₂ H _{6g}	229	CH ₃ OH _l	127		
C ₃ H _{8g}	270	C ₂ H ₅ OH _l	283		
C ₂ H _{2g}	201	C ₂ H ₅ OH _g	161		
C ₂ H _{4g}	219	(CH ₃) ₂ O _g	266		
C ₆ H _{6g}	269	CH ₃ COOH _l	282		

18. ΔG° FORMATION
kJ mol⁻¹ at 25°C

H _g	203	HF _g	-273	H ₂ O _g	-229
F _g	62	HCl _g	-95	H ₂ O _l	-237
Cl _g	106	HBr _g	-54	SO _{2g}	-300
O _g	232	HI _g	1.7	SO _{3g}	-371
NO _g	87	NH _{3g}	-16	PCl _{3g}	-268
NO _{2g}	51	CO _g	-137	PCl _{5g}	-305
N ₂ O _{4g}	98	CO _{2g}	-394	CH _{4g}	-51
C ₂ H _{4g}	68	C ₂ H _{2g}	209	C ₂ H _{6g}	-33
C ₆ H _{6g}	125	CH ₃ OH _l	-162		
CCl _{4g}	-65	C ₂ H ₅ OH _l	-175		
BF _{3g}	-1120	CHCl _{3g}	-70		
SF _{6g}	-1105	CH ₃ COOH _l	-374		

20. CONC. ACIDS AND BAS

	M.W.	Density	Wt. %	Molality
Acetic	60.05	1.05	99.5	17
H ₂ SO ₄	98.07	1.83	94	17
HF	20.01	1.14	45	2
HCl	36.46	1.19	38	1
HBr	80.91	1.52	48	
HNO ₃	63.01	1.41	69	1
HClO ₄	100.46	1.67	70	1
H ₃ PO ₄	98.00	1.69	85	1
NaOH	40.00	1.53	50	1
NH ₃	17.03	0.90	28	1

21. DENSITIES (g cm⁻³)

Water at	Air (70 cm)	0.0	
0°C	0.9168	Glass	2.7
10°C	0.9997	Na ₂ CO ₃	2.5
20°C	0.9982	NaCl	2.2
22°C	0.9978	BaSO ₄	4.5
24°C	0.9973	AgCl	5.6
26°C	0.9968	Aluminum	2.7
28°C	0.9963	Iron	7.9
30°C	0.9956	Brass	8.4
90°C	0.9653	Mercury	13.6
100°C	0.0006	Platinum	21.4

22. MOBILITIES (m²V⁻¹s⁻¹ × 10⁴)

Li ⁺	39	H ₃ O ⁺	350	1/2 Ba ²⁺
Na ⁺	50	NH ₄ ⁺	73	1/3 La ³⁺
K ⁺	74	Ag ⁺	62	1/2 SO ₄ ²⁻
Cl ⁻	76	OH ⁻	198	1/3 PO ₄ ³⁻
Br ⁻	78	I ⁻	77	NO ₃ ⁻

23. WATER V.P. (torr)

0°C	4.6	25°C	
15°C	12.8	30°C	
20°C	17.5	50°C	

24. MISCELLANEOUS

Std. dev. = √Σ(X_i - X̄)² / (n - 1)
 Conf. limits = X̄ ± t_α / √n
 E = E° - (0.0592/n) log([Red]/[Ox])
 log L_r, I_r = abc = A = log 1/T
 log N_r = log N₀ - 0.301T/T₁
 x = (-b ± √(b² - 4ac)) / 2a
 nλ = 2d sin θ
 2.303 log₁₀ a = log_e a
 h = 6.625 × 10⁻³⁴ J s
 e = 1.602 × 10⁻¹⁹ C
 N_A = 6.022 × 10²³ mol⁻¹
 F = 96487 C
 g = 9.807 m s⁻²
 c = 2.998 × 10⁸ m s⁻¹
 1 amu = 1.661 × 10⁻²⁷ kg
 R = 1.987 cal mol⁻¹ K⁻¹
 = 0.08206 litre atm mol⁻¹ K⁻¹
 = 8.314 J mol⁻¹ K⁻¹
 = 8.314 kPa dm³ mol⁻¹ K⁻¹
 0°C = 273.15 K
 1 eV = 1.602 × 10⁻¹⁹ J
 1 cal = 4.1840 J

1. PERIODIC CHART OF THE ELEMENTS

1 1A Li 6.941	2 2A Be 9.01218											13 3A Al 26.98154	14 4A Si 28.0855	15 5A P 30.97376	16 6A S 32.06	17 7A Cl 35.453	18 8A Ar 39.948
3 Li 6.941	4 Be 9.01218											5 B 10.81	6 C 12.011	7 N 14.0067	8 O 15.9994	9 F 18.99840	10 Ne 20.179
11 Na 22.98977	12 Mg 24.305	3 3B Sc 44.9559	4 4B Ti 47.88	5 5B V 50.9415	6 6B Cr 51.996	7 7B Mn 54.9380	8 8B Fe 55.847	9 8B Co 58.9332	10 8B Ni 58.69	11 1B Cu 63.546	12 2B Zn 65.38	13 Al 26.98154	14 Si 28.0855	15 P 30.97376	16 S 32.06	17 Cl 35.453	18 Ar 39.948
19 K 39.0983	20 Ca 40.08	21 Sc 44.9559	22 Ti 47.88	23 V 50.9415	24 Cr 51.996	25 Mn 54.9380	26 Fe 55.847	27 Co 58.9332	28 Ni 58.69	29 Cu 63.546	30 Zn 65.38	31 Ga 69.72	32 Ge 72.59	33 As 74.9216	34 Se 78.96	35 Br 79.904	36 Kr 83.80
37 Rb 85.4678	38 Sr 87.62	39 Y 88.9059	40 Zr 91.22	41 Nb 92.9064	42 Mo 95.94	43 Tc (98)	44 Ru 101.07	45 Rh 102.9055	46 Pd 106.42	47 Ag 107.8682	48 Cd (112.41)	49 In 114.82	50 Sn 118.69	51 Sb 121.75	52 Te 127.60	53 I 126.9045	54 Xe 131.29
55 Cs 132.9055	56 Ba 137.33	57 La 138.9055	58 Ce 140.12	59 Pr 140.9077	60 Nd 144.24	61 Pm (145)	62 Sm 150.36	63 Eu 151.96	64 Gd 157.25	65 Tb 158.9254	66 Dy 162.50	67 Ho 164.9304	68 Er 167.26	69 Tm 168.9342	70 Yb 173.04	71 Lu 174.967	
87 Fr (223)	88 Ra (226)	89 Ac (227)	104 Unq (260)	105 Unp (262)	106 Unh (263)	107 Uns (263)	108 Uno (265)	109 Une (266)	A value in brackets denotes the mass number of the longest lived or best known isotope.								

4. NET STABILITY CONSTANTS

Ag(CN) ₂ ⁻	5 × 10 ²¹
Ag(NH ₃) ₂ ⁺	1.6 × 10 ⁷
Ag(S ₂ O ₃) ₂ ⁻³	4.7 × 10 ¹³
Al(OH) ₄ ⁻	1.0 × 10 ³³
Ca(EDTA)	1.0 × 10 ¹⁰
Cd(CN) ₄	8.3 × 10 ¹⁶
Cd(NH ₃) ₄ ⁺⁺	5.5 × 10 ⁴
Co(NH ₃) ₆ ⁺³	2 × 10 ¹⁰
Cr(OH) ₄ ⁻	4 × 10 ¹⁰
Cu(CN) ₄ ⁻³	1 × 10 ²⁶
Cu(NH ₃) ₄ ⁺⁺	1.2 × 10 ⁴
Fe(CN) ₆ ⁻³	4.0 × 10 ³³
Fe(CN) ₆ ⁻⁴	2.5 × 10 ³³
Fe(SCN) ₆ ⁺⁺	1.0 × 10 ³
HgCl ₄	1.3 × 10 ¹⁶
Hg(CN) ₄	8.3 × 10 ¹⁶
Hg(SCN) ₄	5.0 × 10 ¹⁶
HgI ₄	6.3 × 10 ¹⁶
Mg(EDTA)	1.3 × 10 ⁸
Ni(NH ₃) ₆ ⁺⁺	4.7 × 10 ⁴
Pb(OH) ₃ ⁻	7.9 × 10 ¹⁶
Zn(CN) ₄	4.2 × 10 ¹⁶
Zn(NH ₃) ₄ ⁺⁺	7.8 × 10 ⁴
Zn(OH) ₄	6.3 × 10 ¹⁶

58 Ce (140.12)	59 Pr (140.9077)	60 Nd (144.24)	61 Pm (145)	62 Sm (150.36)	63 Eu (151.96)	64 Gd (157.25)	65 Tb (158.9254)	66 Dy (162.50)	67 Ho (164.9304)	68 Er (167.26)	69 Tm (168.9342)	70 Yb (173.04)	71 Lu (174.967)
90 Th (232.0381)	91 Pa (231.0359)	92 U (238.0289)	93 Np (237.0482)	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (260)

2. IONIZATION CONSTANTS (K_a) FOR WEAK ACIDS

Acetic	1.9 × 10 ⁻⁵	Hypochlorous	3.7 × 10 ⁻⁸
2-Amino-pyridinium Ion	2 × 10 ⁻⁷	H ₂ S	K ₁ 9 × 10 ⁻⁸ K ₂ 1 × 10 ⁻¹⁵
Ammonium Ion	5.6 × 10 ⁻¹⁰	Imidazolium Ion	1.1 × 10 ⁻⁷
Anilinium Ion	2.3 × 10 ⁻⁵	Lactic	1.4 × 10 ⁻⁴
Arsenic	K ₁ 5.6 × 10 ⁻³	Methylammonium Ion	2.7 × 10 ⁻¹¹
Benzoic	6.7 × 10 ⁻⁵	Monoethanol-ammonium Ion	3 × 10 ⁻¹⁰
Boric	K ₁ 5 × 10 ⁻¹⁰	Nicotinic Ion	9.6 × 10 ⁻⁹
Carbonic	K ₁ 4.3 × 10 ⁻⁷ K ₂ 5.6 × 10 ⁻¹¹	Oxalic	K ₁ 6 × 10 ⁻² K ₂ 6 × 10 ⁻⁵
Chloroacetic	1.5 × 10 ⁻³	Phenol	1.3 × 10 ⁻¹⁰
Chromic	K ₂ 3.2 × 10 ⁻⁷	Phthalic	K ₁ 4 × 10 ⁻⁶ K ₂ 4 × 10 ⁻⁶
Citric	K ₁ 8.7 × 10 ⁻⁴ K ₂ 1.8 × 10 ⁻⁵ K ₃ 4 × 10 ⁻⁶	Phosphoric	K ₁ 7.5 × 10 ⁻³ K ₂ 6.2 × 10 ⁻⁸ K ₃ 4.7 × 10 ⁻¹³
Dichloroacetic	5 × 10 ⁻²	Phosphorous	K ₁ 1.0 × 10 ⁻² K ₂ 2.6 × 10 ⁻⁷
EDTA	K ₁ 7 × 10 ⁻³ K ₂ 2 × 10 ⁻³ K ₃ 7 × 10 ⁻⁷ K ₄ 6 × 10 ⁻¹¹	Pyridinium Ion	1 × 10 ⁻⁵
Formic	2 × 10 ⁻⁴	Succinic	K ₁ 7 × 10 ⁻⁵ K ₂ 2.5 × 10 ⁻⁶
α-D(+)-Glucose	5.2 × 10 ⁻¹³	Sulfuric	K ₁ 1.2 × 10 ⁻² K ₂ 1.2 × 10 ⁻²
Glycinium Ion	K ₁ 4.6 × 10 ⁻³ K ₂ 2.5 × 10 ⁻¹⁰	Sulfurous	K ₁ 2 × 10 ⁻² K ₂ 6 × 10 ⁻⁸
Hydrazinium Ion	5.9 × 10 ⁻⁹	Trimethyl-ammonium Ion	1.6 × 10 ⁻¹⁰
Hydrocyanic	7 × 10 ⁻¹⁰	Uric	1.3 × 10 ⁻⁴
Hydrofluoric	7 × 10 ⁻⁴	Water, K _w , 24°C	1.0 × 10 ⁻¹⁴
Hydroxyl-ammonium Ion	9.1 × 10 ⁻⁷		

3. SOLUBILITY PRODUCT CONSTANTS

AgBr	4 × 10 ⁻¹³	BaC ₂ O ₄	2 × 10 ⁻⁸	KClO ₄	2 × 10 ⁻²
Ag ₂ CO ₃	6 × 10 ⁻¹²	BaSO ₄	1 × 10 ⁻¹⁰	MgCO ₃	1 × 10 ⁻⁵
AgCl	1 × 10 ⁻¹⁰	CaCO ₃	5 × 10 ⁻⁹	MgC ₂ O ₄	9 × 10 ⁻⁵
Ag ₂ CrO ₄	2 × 10 ⁻¹²	CaF ₂	4 × 10 ⁻¹¹	MgNH ₄ PO ₄	2 × 10 ⁻¹³
Ag[Ag(CN) ₂]	14 × 10 ⁻¹²	CaC ₂ O ₄	2 × 10 ⁻⁹	Mg(OH) ₂	1 × 10 ⁻¹¹
AgI	1 × 10 ⁻¹⁶	CdS	1 × 10 ⁻²⁸	MnS	1 × 10 ⁻¹⁵
Ag ₃ PO ₄	1 × 10 ⁻¹⁹	Cu(OH) ₂	2 × 10 ⁻²⁰	PbCrO ₄	2 × 10 ⁻¹⁴
Ag ₂ S	1 × 10 ⁻⁵⁰	CuS	1 × 10 ⁻³⁶	PbS	1 × 10 ⁻²⁸
AgCNS	1 × 10 ⁻¹²	Fe(OH) ₃	1 × 10 ⁻³⁶	PbSO ₄	2 × 10 ⁻⁸
Al(OH) ₃	2 × 10 ⁻³²	Hg ₂ Br ₂	3 × 10 ⁻²³	SrCrO ₄	4 × 10 ⁻⁵
BaCO ₃	5 × 10 ⁻⁹	Hg ₂ Cl ₂	6 × 10 ⁻¹⁹	Zn(OH) ₂	3.6 × 10 ⁻¹⁶
BaCrO ₄	1 × 10 ⁻¹⁰	HgS	1 × 10 ⁻⁵²	ZnS	1 × 10 ⁻²⁴

5. FIRST IONIZATION ENERGIES, e.v.

1A 5.4	2A 9.3											3A 8.3	4A 11	5A 15	6A 14	7A 17		
5.1	7.6	3B 4.3	4B 6.1	5B 6.6	6B 6.8	7B 6.7	8B 6.8	9B 7.4	10B 7.9	11B 7.9	12B 7.6	13B 7.7	14B 9.4	15B 6.0	16B 8.1	17B 10	18B 9.8	19B 12
4.2	5.7	6.6	7.0	6.8	7.2	7.5	7.7	8.3	7.6	9.0	5.8	7.3	8.6	9.0	10			
3.9	5.2	5.9	5.5	6	8.0	7.9	8.7	9.2	9.0	9.2	10	6.1	7.4	8				

6. ELECTRONEGATIVITIES, Pauling

1A 1.0	2A 1.5											3A 2.0	4A 2.5	5A 3.0	6A 3.5	7A 4.0	
0.9	1.3	3B 0.8	4B 1.0	5B 1.3	6B 1.5	7B 1.6	8B 1.5	9B 1.8	10B 1.8	11B 1.9	12B 1.6	13B 1.8	14B 1.8	15B 2.0	16B 2.4	17B 2.8	18B 2.8
0.8	1.0	1.2	1.4	1.6	1.8	1.9	2.2	2.2	2.2	1.9	1.7	1.7	1.8	1.9	2.1	2.5	2.2
0.7	0.9	1.1	1.3	1.5	1.7	1.9	2.2	2.2	2.2	2.4	1.9	1.8	1.8	1.9	2.0	2.2	

7. ATOMIC RADII picometers

1A 155	2A 112											3A 98	4A 91	5A 92	6A 73	7A 71		
190	160	3B 235	4B 197	5B 162	6B 147	7B 134	8B 130	9B 135	10B 126	11B 125	12B 124	13B 128	14B 138	15B 141	16B 137	17B 139	18B 140	19B 114
248	216	178	160	146	139	136	134	134	137	144	154	166	162	159	180	133		
287	222	187	167	149	141	137	135	136	139	146	157	171	175	170	176			

8. IONIC RADII pm

Li ⁺	60	Sr ²⁺	113	S ²⁻	184
Na ⁺	95	Ba ²⁺	135	Se ²⁻	198
K ⁺	133	B ³⁺	20	Te ²⁻	221
Rb ⁺	148	Al ³⁺	50	F ⁻	136
Be ²⁺	31	N ³⁺	171	Cl ⁻	181
Mg ²⁺	65	P ³⁺	212	Br ⁻	195
Ca ²⁺	99	O ²⁻	140	I ⁻	216

9. LATTICE ENERGIES

(All negative) kJ/mol	
F	Cl
Li	1080
Na	914
K	812
Rb	780
Cs	744
Br	781
Cl	728
I	671
Ag	654
Au	613

10. HALF LIVES

H ³	12.3 years	K ⁴⁰	1.28 × 10 ⁸ y	I ¹³¹	8.1 day
F ²⁰	11.4 secs	Ca ⁴⁵	165 days	Cs ¹³⁷	30 yea
C ¹⁴	5730 years	Fe ⁵⁹	45 days	Au ¹⁹⁸	2.69 da
Na ²⁴	15.0 hours	Co ⁶⁰	5.26 y	Ra ²²⁶	1620 ya
P ³²	14.3 days	Br ⁸²	35.5 hours	U ²³⁵	7.1 × 10 ⁸
S ³⁵	88 days	Sr ⁹⁰	28 years	U ²³⁸	4.51 × 10 ⁹
Cl ³⁶	3.1 × 10 ⁵ y	I ¹²⁹	1.7 × 10 ⁷ y	Pu ²³⁹	24,400

Electrode Potentials, E⁰

H⁺ + e⁻ ⇌ 1/2 H₂ E⁰ = 0.000V

Ca²⁺ + 2e⁻ ⇌ Ca(s) E⁰ = -0.246V

" " ⇌ Ag(s) + Cl⁻ E⁰ = -0.023V

Cu²⁺ + 2e⁻ ⇌ Cu(s) E⁰ = +0.34V