Syllabus for the IChO theoretical part

Level 1: These topics are included in the overwhelming majority of secondary school chemistry programs and need not to be mentioned in the preparatory problems.

Level 2: These topics are included in a substantial number of secondary school programs and maybe used without exemplification in the preparatory problems.

Level 3: These topics are not included in the majority of secondary school programs and can only be used in the competition if examples are given in the preparatory problems.

1. The atom

1.1.	*Introduction*		
	1.1.1.	Counting of nucleons	1
	1.1.2.	Isotopes	1
1.2.	*The hydrogen atom*		
	1.2.1.	Concept of energy levels	1
	1.2.2.	Shape of *s*-orbitals	1
	1.2.3.	Shape and orientation of *p*-orbitals	1
	1.2.4.	Shape and orientation of *d*-orbitals	3
	1.2.5.	Understanding the simplest Schrodinger equation	3
	1.2.6.	Square of the wave function and probability	3
	1.2.7.	Quantum numbers (n, l, m_l)	3
1.3.	*Radioactivity*		
	1.3.1.	Types of radioactivity	1
	1.3.2.	Radioactive decay	1
	1.3.3.	Nuclear reactions	2

2. Chemical bonding

2.1.	*VSEPR " Simple molecular structures with*		
	2.1.1.	no more than four electron pairs about central atom	1
	2.1.2.	with central atom exceeding the "octet rule?	3
2.2.	*Delocalization and resonance*		3
2.3.	*Hybrid orbital theory*		3
2.4.	*Molecular orbital theory*		
	2.4.1.	molecular orbital diagram (H_2 molecule)	3
	2.4.2.	molecular orbital diagram (N_2 and O_2 molecules)	3
	2.4.3.	bond orders in O_2, O_2^-, O_2^+	3
	2.4.4.	unpaired electrons and paramagnetism	3

3. Chemical calculations

3.1.1.	Balancing equations	1
3.1.2.	Stoichiometric calculations	1
3.1.3.	Mass and volume relations (including density)	1
3.1.4.	Empirical formula	1
3.1.5.	Avogadro’s number	1
3.1.6.	Concentration calculations	1

4. Periodic trends

4.1.	*Electron configuration*		
	4.1.1.	Pauli exclusion principle	1

4.1.2. Hund's Rule 1
4.1.3. Main group elements 1
4.1.4. Transition metal elements 1
4.1.5. Lanthanide and actinide metals 3
4.2. Electronegativity 1
4.3. Electron affinity 2
4.4. First ionization energy 1
4.5. Atomic size 1
4.6. Ion size 1
4.7. Highest oxidation number 1

5. Inorganic Chemistry

5.1. Introduction
5.1.1. Trends in physical properties of elements (Main groups)
5.1.1.1. melting point 1
5.1.1.2. boiling point 1
5.1.1.3. metal character 1
5.1.1.4. magnetic properties 3
5.1.1.5. electrical conductivity 2
5.1.2. Oxidation number 1
5.1.3. Nomenclature
5.1.3.1. main group compounds 1
5.1.3.2. transition metal compounds 1
5.1.3.3. simple metal complexes 3
5.2. Groups 1 and 2
5.2.1. Trend in reactivity of (heavy elements more reactive) 1
5.2.2. Products of reaction with
5.2.2.1. water 1
5.2.2.2. halogens 1
5.2.2.3. oxygen 2
5.2.3. Basicity of oxides 1
5.2.4. Properties of hydrides 3
5.2.5. Other compounds, properties and oxidation states 3
5.3. Groups 13 " 18 and Hydrogen
5.3.1. Binary molecular compounds of hydrogen
5.3.1.1. Formulae 1
5.3.1.2. Acid-base properties of CH_4, NH_3, H_2O, H_2S 1
5.3.1.3. Other properties 3
5.3.2.
Group 13
5.3.2.1 The oxidation state of boron and aluminium in their oxides and chlorides is +3 1
5.3.2.2. The acid-base properties of aluminium oxide/hydroxide 2
5.3.2.3. Reaction of boron(III) oxide with water 3
5.3.2.4. Reaction of boron(III) chloride with water 3
5.3.2.5. Other compounds, properties and oxidation states 3
5.3.3. Group 14
5.3.3.1. The oxidation state of Si in its chloride and oxide is +4 1
5.3.3.2. The +2 and +4 oxidation states of carbon, tin and lead, the acid-base and redox properties of the oxides and chlorides 2
5.3.3.3. Other compounds, properties and oxidation states 3
5.3.4. Group 15

		5.3.4.1. Phosphorus(+5) oxide and chloride, and their reaction with water	2
		5.3.4.2. Phosphorus(+3) oxide and chloride, and their reaction with water	2
		5.3.4.3. Oxides of nitrogen	
		a. Reaction of NO to form NO_2	1
		b. Dimerization of NO_2	1
		c. Reaction of NO_2 with water	1
		5.3.4.4. Redox properties of	
		a. HNO_3 and nitrates	1
		b. HNO_2 and NH_2NH_2	3
		5.3.4.5. Bi(+5) and Bi(+3)	3
		5.3.4.6. Other compounds, properties and oxidation states	3
	5.3.5.	Group 16	
		5.3.5.1. The +4 and +6 oxidation states of sulfur, reaction of their oxides with water, properties of their acids	1
		5.3.5.2. Reaction of thiosulfate anion with I_2	3
		5.3.5.3. Other compounds, properties and oxidation states	3
	5.3.6.	Group 17 (Halogens)	
		5.3.6.1. Reactivity and oxidant strength decreases from F_2 to I_2	1
		5.3.6.2. Acid-base properties of the hydrogen halides	1
		5.3.6.3. The oxidation state of fluorine in its compounds is "1	1
		5.3.6.4. The "1, +1, +3, +5, +7 oxidation states of chlorine	1
		5.3.6.5. Mononuclear oxo anions of chlorine	2
		5.3.6.6. Reactions of halogens with water	3
		5.3.6.7. Reaction of Cl_2O and Cl_2O_7 with water	3
		5.3.6.8. Other compounds, properties and oxidation states	3
	5.3.7.	Group 18	3
5.4.	*Transition elements*		
	5.4.1.	Common oxidation states of common transition metals: Cr(+2), Cr(+3) Mn(+2), Mn(+4), Mn(+7) Ag(+1) Fe(+2), Fe(+3) Co(+2) Zn(+2) Hg(+1), Hg(+2) Cu(+1), Cu(+2) Ni(+2)	1
	5.4.2.	Colours of ions listed above in aqueous solution	2
	5.4.3.	Insolubility of Ag, Hg and Cu in HCl	2
	5.4.4.	M^{2+} arising by dissolution of the other metals in HCl	2
	5.4.5.	$Cr(OH)_3$ and $Zn(OH)_2$ are amphoteric and the other +2 oxides/hydroxides of the metals listed above are basic	2
	5.4.6.	MnO_4^- and $Cr_2O_7^{2-}$ are strong oxidants in acid solution	1
	5.4.7.	pH dependence of products of $MnO_4^?$ acting as oxidant	2
	5.4.8.	Interconversion between CrO_4^{2-} and $Cr_2O_7^{2-}$	3
	5.4.9.	Other compounds, properties and oxidation states	3
5.5.	*Lanthanides and actinides*		3
5.6.	*Coordination chemistry including stereochemistry*		
	5.6.1.	Definition of coordination number	1
	5.6.2.	Writing equations for complexation reactions given all formulae	1
	5.6.3.	Formulae of common complex ions	
		5.6.3.1. $Ag(NH_3)_2^+$	1
		5.6.3.2. $Ag(S_2O_3)_2^-$	3
		5.6.3.3. $FeSCN^{2+}$	3
		5.6.3.4. $Cu(NH_3)_4^{2+}$	1
		5.6.3.5. Other complex ions –	3

5.6.4.	(6.5) Ligand field theory (*e*g and *t*2g terms, high and low spin)		3
5.6.5.	Stereochemistry		
	5.6.5.1.	(6.7) *cis* and *trans*	3
	5.6.5.2.	enantiomers	3
5.7.	*Selected industrial processes*		
5.7.1.	Preparation of H_2SO_4		1
5.7.2.	Preparation of NH_3		1
5.7.3.	Preparation of Na_2CO_3		2
5.7.4.	Preparation of Cl_2 and NaOH		2
5.7.5.	Preparation of HNO_3		2

6. Physical chemistry

6.1.	*Gases*		
6.1.1.	Ideal gas law		1
6.1.2.	van der Waals'gas law		3
6.1.3.	definition of partial pressure		2
6.1.4.	Dalton's Law		3
6.2.	*Thermodynamics*		
6.2.1.	First Law		
	6.2.1.1.	Concept of system and surroundings	2
	6.2.1.2.	Energy, heat and work	2
6.2.2.	Enthalpy		
	6.2.2.1.	Relationship between internal energy and enthalpy	3
	6.2.2.2.	Definition of heat capacity	2
	6.2.2.3.	Difference between C_p and C_v (ideal gas only)	3
	6.2.2.4.	Enthalpy is a state property (Hess's Law)	2
	6.2.2.5.	Born-Haber cycle for ionic compounds	3
	6.2.2.6.	Use of standard formation enthalpies	2
	6.2.2.7.	Enthalpies of solution and solvation	3
	6.2.2.8.	Bond enthalpies (definition and use)	2
.	6.2.3.	Second Law (Entropy and Free Energy)	
	6.2.3.1.	Entropy definition (dQ / *T*)	3
	6.2.3.2.	Entropy and disorder	3
	6.2.3.3.	Entropy definition ($S = k \ln W$)	3
	6.2.3.4.	Gibbs energy definition (D*G* = D*H* " *T*D*S*)	3
	6.2.3.5.	Using D*G* to predict direction of natural change	3
	6.2.3.6.	Relationship between D*G*њ and equilibrium constant *K*	3
6.3.	*Equilibrium*		
6.3.1.	Acid-base		
	6.3.1.1.	Arrhenius definitions of acids and bases	1
	6.3.1.2.	Bronsted-Lowry definitions	1
	6.3.1.3.	Conjugate acids and bases	1
	6.3.1.4.	pH definition	1
	6.3.1.5.	K_w definition	1
	6.3.1.6.	K_a and K_b as a measure of acid and base strength	1
	6.3.1.7.	Acidity or basicity of ions	1
	6.3.1.8.	Calculation of pH from pK_a(weak acid)	1
	6.3.1.9.	Calculation of pH of a simple buffer solution	2
6.3.2.	Gas phase		
	6.3.2.1.	Equilibrium constant in partial pressures	3
	6.3.2.2.	Relating K_p and K_c	3
6.3.3.	Solubility		

	6.3.3.1.	Solubility constant (product) definition (K_{sp})	2
	6.3.3.2.	Calculation of solubility in water from K_{sp}	2
6.3.4.	Complexometric		
	6.3.4.1.	Complex formation constant (definition)	3
	6.3.4.2.	Problems involving complexometric equilibria	3
	6.3.4.3.	Lewis acids and bases	3
	6.3.4.4.	Hard and soft Lewis acids and bases	3
6.3.5.	Phase		
	6.3.5.1.	Temperature dependence of vapor pressure	3
	6.3.5.2.	Clausius-Clapeyron equation	3
	6.3.5.3.	Single component phase diagrams	
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	6.3.5.4.	liquid-vapor system	
		a. ideal and non-ideal systems	3
		b. diagram	3
		c. use in fractional distillation	3
	6.3.5.5.	Henry's Law	3
	6.3.5.6.	Raoult's Law	3
	6.3.5.7.	Deviation from Raoult's Law	3
	6.3.5.8.	Boiling point elevation	3
	6.3.5.9.	Freezing point depression	3
	6.3.5.10.	Osmotic pressure	3
	6.3.5.11.	Partition coefficient	3
	6.3.5.12.	Solvent extraction	3
6.3.6.	Multiple		
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	6.3.6.2.	Calculation of pH for weak acid mixtures	3
6.4.	*Electrochemistry*		
6.4.1.	Electromotive force (definition)		1
6.4.2.	First kind electrodes		1
6.4.3.	Standard electrode potential		1
6.4.4.	Nernst equation		3
6.4.5.	Second kind electrodes		3
6.4.6.	Relationship between D*G* and electromotive force		3

7. Chemical kinetics (Homogeneous reactions)

7.1.	*Introduction*		
7.1.1.	Factors affecting reaction rate		1
7.1.2.	Reaction coordinates and the basic idea of a transition state		1
7.2.	*Rate law*		
7.2.1.	Differential rate law		2
7.2.2.	Concept of reaction order		2
7.2.3.	Rate constant definition		2
7.2.4.	First order reactions		
	7.2.4.1.	Dependence of concentration on time	3
	7.2.4.2.	Concept of half life	3
	7.2.4.3.	Relationship between half life and rate constant	3
	7.2.4.4.	Calculation of first order rate constant from	
		a. differential rate law	3
		b. integrated rate law	3
	7.2.4.5.	Rate constant for second and third order reactions	3

7.3. Reaction mechanisms

7.3.1.	Concept of molecularity	3
7.3.2.	Rate-determining step	3
7.3.3.	Basic concepts of collision theory	3
7.3.4.	Opposing parallel and consecutive reactions	3
7.3.5.	Arrhenius's law	3
7.3.5.1.	Definition of activation energy	3
7.3.5.2.	Calculation of activation energy	3

8. Spectroscopy

8.1. UV/visible

8.1.1.	Identification of aromatic compound	3
8.1.2.	Identification of chromophore	3
8.1.3.	Dyes: colour *vs.* structure	3
8.1.4.	Beer's Law	3

8.2. Infrared

8.2.1.	Interpretation using a table of frequencies	3
8.2.2.	Recognition of hydrogen bonds	3

8.3. x-Ray

8.3.1.	Bragg's Law	3
8.3.2.	Concept of	
8.3.2.1.	coordination number	3
8.3.2.2.	unit cell	3
8.3.3.	Solid structures	
8.3.3.1.	NaCl	3
8.3.3.2.	CsCl	3
8.3.3.3.	metals	3

8.4. NMR

8.4.1.	General Concepts	
8.4.1.1.	chemical shift	3
8.4.1.2.	spin-spin coupling and coupling constants	3
8.4.1.3.	integration	3
8.4.2.	Interpretation of a simple 1H spectrum (like ethanol)	3
8.4.3.	Identification of *o*- and *p*-disubstituted benzene	3
8.4.4.	Interpretation of simple spectra of 13C (proton decoupled) and other 1/2 spin nuclei	3

8.5. Mass spectrometry

8.5.1.1.	Recognition of molecular ion	3
8.5.1.2.	Recognition of fragments with the help of a table	3
8.5.1.3.	Recognition of typical isotope distribution	3

9. Organic Chemistry

9.1. Introduction

9.1.1.	(3.1.1) Alkane naming (IUPAC)	1
9.1.2.	Trends in boiling points of	
9.1.2.1.	(3.1.3) alkanes with structure	1
9.1.2.2.	(3.7.1) alcohols *vs* ethers due to hydrogen-bonding	1
9.1.3.	(3.3.1, 3.4.1) Geometry at singly, doubly, and triply bonded carbon	1
9.1.4.	Identification of common functional groups	1
9.1.5.	Isomerism of alkenes	
9.1.5.1.	*cis-trans*	1
9.1.5.2.	*E*/*Z*	3

9.1.6. Enantiomers
- 9.1.6.1. Optical activity 2
- 9.1.6.2. *R*/*S* nomenclature 3

9.2. Reactivity

9.2.1. Alkanes
- 9.2.1.1. reaction with halogens
  - a. products 1
  - b. free radical mechanism (initiation, termination) 2
- 9.2.1.2. Cycloalkanes
  - a. names 2
  - b. Strain in small rings 3
  - c. chair/boat conformations of cyclohexane 3

9.2.2. Alkenes
- 9.2.2.1. Products from Br_2, HBr and H_2O/H^+ 1
- 9.2.2.2. Markownikoff's rule 2
- 9.2.2.3. Mechanism involving carbocation intermediates 3
- 9.2.2.4. Relative stability of carbocations 3
- 9.2.2.5. 1,4 addition to dienes 3

9.2.3. Alkynes
- 9.2.3.1. Acidity relative to alkenes 3
- 9.2.3.2. Differences in chemical properties from alkenes 2

9.2.4. Benzene
- 9.2.4.1. formula 1
- 9.2.4.2. stabilization by resonance 1
- 9.2.4.3. electrophilic substitution (nitration, halogenation)
  - a. directing effect of first substituent 3
  - b. effect of first substituent on reactivity 3
  - c. explanation of substituent effects 3

9.2.5. Halogen compounds
- 9.2.5.1. Nomenclature of monofunctional 1
- 9.2.5.2. Substitution reactions
  - a. giving alcohols 3
  - b. in which halogen is exchanged 3
  - c. reactivity
    - i. primary *vs* secondary *vs* tertiary 3
    - ii. aliphatic *vs* aromatic 3
  - d. S_N1 and S_N2 mechanisms 3
- 9.2.5.3. Elimination reactions 2
- 9.2.5.4. Competition of elimination and substitution 2

9.2.6. Alcohols
- 9.2.6.1. Nomenclature of monofunctional 1
- 9.2.6.2. Comparison of acidity of alcohols and phenols 2
- 9.2.6.3. Dehydration to alkenes 1
- 9.2.6.4. Esters with inorganic acid 2
- 9.2.6.5. Oxidation reactions 1

9.2.7. Aldehydes and ketones
- 9.2.7.1. Nomenclature of monofunctional 1
- 9.2.7.2. Oxidation of aldehydes 1
- 9.2.7.3. Reduction to alcohols ($LiAlH_4$, $NaBH_4$) 3
- 9.2.7.4. Keto/enol tautomerism 3
- 9.2.7.5. Nucleophilic addition reactions with
  - a. HCN 3

b. RNH_2 (R = alkyl, HO, NH_2) 3
c. enolate anions (aldol condensation) 3
d. alcohols to form acetals/ketals 3
e. Grignard reagents 3

9.2.8. Carboxylic acids and their derivatives

9.2.8.1. Nomenclature of carboxylic acids and their derivatives (esters, acid halides, amides) 2

9.2.8.2. Acidity strength related to inductive effects 3

9.2.8.3. Preparation of carboxylic acids by hydrolysis of

a. esters (including soaps) 1
b. amides 2
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9.2.8.4. Reaction of carboxylic acids

a. with alcohols to form esters 1
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9.2.8.5. Reaction of acid chlorides to form amides 3

9.2.8.6. Mechanism of esterification 3

9.2.8.7. Multifunctional acids (hydroxyacids, ketoacids) 3

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9.2.9. Amines

9.2.9.1. Nomenclature

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b. recognition of primary, secondary, tertiary 1

9.2.9.2. Basicity

a. As a property of an amine 1
b. Comparison of basicity of aliphatic and aromatic 3
c. Comparison of basicity of amines and amides 3
d. Preparation of amines
i. from halides 3
ii. from aromatic nitro compounds 3
iii. from amides (by hydrolysis) 3

9.2.9.3. Diazotization

a. of aliphatic amines 3
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10. Polymers

10.1. Synthetic

10.1.1. Addition polymers

10.1.1.1. polystyrene 2
10.1.1.2. polyethene 1
10.1.1.3. chain mechanism of formation 2

10.1.2. Condensation polymers

10.1.2.1. polyesters 2
10.1.2.2. polyamides 2

10.1.3. Silicones 3

10.1.4. Concept of cross-linking and its affect on properties 3

10.2. Natural

10.2.1. Silicates 3

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11. Biochemistry

11.1. Carbohydrates

- 11.1.1. Glucose and fructose
  - 11.1.1.1. chain formulae — 1
  - 11.1.1.2. Fischer projections — 2
  - 11.1.1.3. Haworth formulae — 3
- 11.1.2. Difference between starch and cellulose — 2
- 11.1.3. Difference between a- and b- D glucose — 2

11.2. Fats

- 11.2.1. Structure of fats in relationship to properties — 2
- 11.2.2. Formula of glycerol — 1

11.3. Nitrogen-containing Compounds of Biological Importance

- 11.3.1. Amino acids
  - 11.3.1.1. Ionic structure — 1
  - 11.3.1.2. Isoelectric point — 3
  - 11.3.1.3. 20 amino acids (classification with structures provided) — 2
  - 11.3.1.4. Separation by electrophoresis — 3
  - 11.3.1.5. The peptide linkage — 1
- 11.3.2. Proteins
  - 11.3.2.1. Primary structure — 1
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  - 11.3.2.3. Sequence analysis — 3
  - 11.3.2.4. Secondary structure — 3
  - 11.3.2.5. Details of alpha-helix structure — 3
  - 11.3.2.6. Tertiary structure — 3
  - 11.3.2.7. Denaturation (change in pH, temperature, metals, ethanol) — 2
- 11.3.3. Nuclei Acids and Protein Synthesis
  - 11.3.3.1. Pyrimidine and purine — 3
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  - 11.3.3.3. Formulae of pyrimidine and purine bases — 3
  - 11.3.3.4. Difference between ribose and 2-deoxyribose — 3
  - 11.3.3.5. Base combination CG and AT (hydrogen-bonding) — 3
  - 11.3.3.6. Difference between DNA and RNA — 3
  - 11.3.3.7. Difference between mRNA and tRNA — 3

11.4. Enzymes

- 11.4.1.1. General properties, active centers — 3
- 11.4.1.2. Nomenclature, kinetics, coenzymes, function of ATP — 3

12. Analytical chemistry

12.1. Titrations

- 12.1.1. acid-base
  - 12.1.1.1. Titration curve; pH (strong and weak acid) — 2
  - 12.1.1.2. Choice of indicators for acidimetry — 2
- 12.1.2. Redox titration — 3

12.2. Qualitative analysis

- 12.2.1. Ions (Inorganic)

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