Draft of a new IChO syllabus

The Steering Committee of the IChO has started working on the improvement of the syllabus found in the appendix of the IChO regulations. A draft is included in this document.

The Steering Committee is planning to finalize this draft in December 2007. We would like to invite any comments and suggestions to Gabor Magyarfalvi at gmagyarf@chem.elte.hu. The new rules and the syllabus would be discussed and voted on by the International Jury at the 40th IChO in Budapest.

Rationale for restructuring the syllabus of the IChO

It is a fact that the practice at the olympiads had not always been completely in line with the letter of the regulations with respect to the material expected from the students.

One aspect of this was the eagerness of the organizers to incorporate up-to-date science into the tasks. Definitely there should be less material at the olympiads not usually taught in secondary education.

However, it must not be forgotten that it is almost impossible to differentiate between the best students, if we exactly define the knowledge that will be tested in the exams. If the problem authors would stick to the letter of a set syllabus, then the problems would be boring. The best results would go to students who are good at reproducing exactly what they learned, instead of the brightest and most creative students.

The present syllabus might already be too restrictive in some aspects, so it is no wonder that organizers have not kept the letter of the rules.

E.g.: if there is a problem concerning the pH of carbon-dioxide solution, that would exhaust all possibilities for the organizers to include questions not explicitly listed as allowed. (pH of multiprotic acids, equilibrium constants in partial pressures and Henry’s law are all listed as level 3.)

The purpose of the syllabi and the preparatory problems is twofold. They should limit the organizers to keep the questions within the reach of the students. On the other hand, if the international jury would have a free hand in editing the problems without any guidelines, the most interesting tasks could also be left out by majority vote.

The points listed in the present syllabus are typically of two kind:

-skills and concepts that the students should be able to use,

-factual knowledge that is expected to be known.

The beauty of chemistry is that one needs both facts and concepts to solve problems and understand phenomena, but these two categories would require rather different rules.

The first type of required knowledge (concepts and skills) is much more easy to list and limit in the syllabus. We attempt to list the ones supposed to be known by all students in Appendix C.

The number of new concepts or fields is definitely an area where the problem authors should be restricted from including too many in the exam. Our recommendation is no more than 6 such topics (including lab. skills) in a preparatory problem set. If each topic can be taught and example problems can be practiced in a few hour long session to talented students, then the training could be well within the present limits of two weeks.

The preparatory problems can even explicitly list these fields in their preamble.

We include a list (obviously not comprehensive) of some possible new topics in the appendix.

The second type of knowledge (facts) is the more sensitive one. Luckily, if a problem is based on the knowledge of a fact, then it is usually a bad problem. There have not been many such problems at the Olympiads.

This is the aspect of the syllabus that needs to be rather strictly confined. However, it is quite tedious to list all facts that are supposed to be known so we can only define a broad outline.

If the problem authors need to use facts possibly unfamiliar to many students, they should be conveyed in some way in the problem itself, or they can alternatively be included and demonstrated in the preparatory problems, as the content and solutions of the preparatory problems is supposed to be known by all participants. Obviously the extent of the preparatory problems does not give much space to include lots of such ‘facts’. We do not think that there could be explicit limits on these in the regulations. The authors should be aware that the International Jury will probably remove those questions from the exam which are only based on hidden information.

The proposed new regulations:

Paragraph 10 of the regulations

(1) The organizer distributes a set of preparatory tasks written in English to all participating countries in the January of the competition year. The preparatory tasks are intended to give students a good idea of the type and difficulty of the competition tasks, including safety aspects (see §12 and Appendix “B”). SI units must be used throughout the preparatory tasks.

(2) The total number of theoretical and experimental tasks in the set of preparatory problems cannot be lower than 25 and 5, respectively. The total number of tasks in the set can not be more than 50, and the number of characters in the complete preparatory set (problems and solutions) must be less than 200,000.

(3) Appendix C of the regulations contains a list of concepts and skills expected to be mastered by the participants. Organizers may freely include questions and tasks in the theoretical or experimental competition based on the knowledge listed there.

The organizer can include problems in the exams based on the use of concepts and skills (theoretical or practical) from not more than 6 fields outside this list, if a minimum of 2 tasks from each field is included and the necessary skills demonstrated in the set of preparatory problems. Examples of such external fields are also listed in Appendix C. Fields not already listed should have a breadth similar to the examples.

(4) Appendix D contains an outline of the factual knowledge supposedly familiar to the competitors. If specific facts not included here are required for the solution of the exam questions, then these should be included in the exam text or in the preparatory problems and their solutions.

The number of such facts should obviously be limited, but there is no explicit restriction. The problem authors must be aware that the International Jury will discuss and probably eliminate questions that only test factual knowledge.

Appendix C

Concepts and skills expected to be familiar for all participants:

Estimation of experimental errors, use of significant figures;
Nucleons, isotopes, radioactive decay and nuclear reactions (alpha, beta, gamma);
Quantum numbers (n,l,m) and orbitals (s,p,d) in hydrogen-like atoms;
Hund's rule, Pauli principle;
Electronic configuration of main group and transition metal atoms and ions;
Periodic table and trends (electronegativity, electronaffinity, ionization energy, atomic and ionic size, melting points, metallic character, reactivity);
Bond types (covalent, ionic, metallic), intermolecular forces and relation to properties;
Molecular structures and simple VSEPR theory (up to 4 e pairs);

Balancing equations, empirical formulae, mole concept and Avogadro's number, stoichiometric calculations, density, calculations with different concentration units;
Chemical equilibrium, Le Chatelier's principle, equilibrium constants in terms of concentrations, pressures and mole fractions;
Arrhenius and Bronsted acid-base theory, pH, self ionization of water, acid and base dissociation constants, pH of weak acid solutions, pH of very dilute solutions and simple buffer solutions, hydrolyis of salts;
Solubility product and solubility;

Complexation reactions, definition of coordination number, complex formation constants;

Electromotive force, electrodes of the first and second kind, Nernst's equation;
Electrolysis, Faraday's laws;

Rate of chemical reactions, elementary reactions, factors affecting the reaction rate, rate law for homogeneous and heterogeneous reactions, rate constant, reaction order, reaction energy profile, activation energy, catalysis, influence of a catalyst on thermodynamical and kinetic characteristics of a reaction;

Energy, heat and work, enthalpy and energy, heat capacity, Hess' law, standard formation enthalpies, solution, solvation and bond energies;
Definition and concept of entropy and Gibbs' energy, second law of TD, direction of change;
Ideal gas law, partial pressures, boiling point elevation and freezing point depression, determination of molar mass;

Principles of direct and indirect tiration (back titration);
Acidi and alkalimetry, acidimetric titration curves, choice and colour of indicators for acidimetry;
Redox titrations (permanganometric and iodometric;
Simple complexometric titrations;
Basic principles of inorganic qualitative analysis, group reactions and specific reactions for common ions, flame tests;
Lambert-Beer law;

Organic structure-reactivity relations (polarity, electrophilicity, nucleophilicity, inductive effects, relative stability)
Structure-property relations (*e.g.* boiling point, acidity, basicity);
Simple organic nomenclature;
Hybridization and geometry at carbon centers;
Sigma and pi bonds, delocalization, aromaticity, mesomeric structures;
Isomerism (constitution, configuration, conformation, tautomerism)
Stereochemistry (*E-Z*, cis-trans, and syn-anti isomers, chirality, optical activity, Cahn-Ingold-Prelog system);
Hydrophilic and hydrophobic groups, micelle formation;
Polymers and monomers, crosslinking, chain polymerizations, polyaddition and polycondensation;

Laboratory skills:

Heating in the laboratory, heating under reflux;

Mass and volume measurement (with electronic balance, measuring cylinder, pipette and burette, volumetric flask);
Preparation and dilution of solutions and standard solutions;
Operation of a magnetic stirrer;
Filtration through flat or folded filter paper, Büchner-funnel or glass filter;
Operation of a water vacuum pump;
Decanting, washing and drying of precipitates on the filter;
Recrystallization from given solvents;
Carrying out of test tube reactions;
Qualitative testing for organic functional groups (using a given procedure);
Volumetric determination, titrations, use of a pipette bulb

Examples of concepts and skills allowed in the exam only if included and demonstrated in the preparatory problems

6 of these or other topics of similar breadth are allowed in a preparatory problem set. It is intended that a topic can be introduced and discussed in a lecture of 2-3 hours before a prepared audience.

- VSEPR theory in detail (with more than 4 ligands);
- Inorganic stereochemistry, isomerism in complexes;
- Solid state structures (metals, NaCl, CsCl) and Bragg's law;
- Relation of equilibrium constants, electromotive force and standard Gibbs energy;
- Integrated rate law for first order reactions, half-life, Arrhenius equation, determination of activation energy;
- Analysis of complex reactions using steady-state and quasi-equilibrium approximations, mechanisms of catalytic reactions, determination of reaction order and activation energy for complex reactions;
- Collision theory
- Simple phase diagrams and the Clausius-Clapeyron equation, triple and critical points;
- Pericyclic reactions
- Catalysis (homogeneous, heterogeneous, organo-)
- Stereoselective transformations (diastereoselective, enantioselective), optical purity
- Conformational analysis, use of Newman projections, anomeric effect
- Aromatic nucleophilic substitution, electrophilic addition on polycyclic aromatic compounds and heterocycles
- Supramolecular chemistry

- Advanced polymers, rubbers, copolymers, thermosetting polymers. Polymerization types, stages and kinetics of polymerization;
- Amino acid side groups, reactions and separation of amino acids, protein sequencing;
- Higher than primary structure of proteins, non-covalent interactions, stability and denaturation, protein purification by precipitation, chromatography and electrophoresis, enzymes and classification according to reaction types, active sites, coenzymes and cofactors, mechanism of catalysis
- Monosaccharides, equilibrium between linear and cyclic forms, pyranoses and furanoses, Haworth projection and conformational formulae;
- Chemistry of carbohydrates, oligo and polysaccharides, glycosides, determination of structure;
- Bases, nucleotides and nucleosides with formulae, Functional nucleotides, DNA and RNA, hydrogen bonding between bases, replication, transcription and translation, DNA based applications;
- Complex solubility calculations (with hydrolysing anions, complex formation);
- Simple Schrödinger equations and spectroscopic calculations;
- Simple MO theory;
- Basics of mass spectrometry (molecular ions, isotope distributions);
- Interpretation of simple proton NMR spectra (chemical shift, multiplicity, integrals);
- Synthesis in microscale equipment;
- Advanced inorganic qualitative analysis;
- Gravimetric analysis;
- Titrations based on precipitation reactions;
- Use of a spectrophotometer;
- Theory and practice of extraction with immiscible solvents;;
- Thin layer chromatography;
- Column chromatography (including cartridges);

Appendix D

Outline of the factual knowledge supposed to be known by the competitors:

Reactions of s-block elements with water, oxygen and halogens, their color in flame tests;
Stoichiometry, reactions and properties of simple non-metal hydrides;

Reactions and equilibria of common nitrogen and sulphur oxides and oxoacids (NO, NO_2, N_2O_4,SO_2, SO_3);
Common oxidation states of p-block elements, stoichometry of common halogenides and oxoacids (HNO_2, HNO_3, H_2CO_3, H_3PO_4, H_3PO_3, H_2SO_3, H_2SO_4, $HOCl$, $HClO_3$, $HClO_4$);
Reaction of halogens with water;
Common oxidation states of first row transition metals (Cr(III), Cr(VI), Mn(II), Mn(IV), Mn(VII), Fe(II), Fe(III), Co(II), Ni(II), Cu(I), Cu(II), Ag(I), Zn(II), Hg(I), and Hg(II))and the color of these ions;
Dissolution of these metals and Al, amphoteric hydroxides ($Al(OH)_3$, $Cr(OH)_3$, $Zn(OH)_2$);
Permanganate, chromate, dichromate ions and their redox reactions;
Iodometry (reaction of thiosulphate and iodine);
Identification of Ag^+, Ba^{2+}, Cl^-, SO_4^{2-} ;

Common electrophiles and nucleophiles
Electrophilic addition: addition to double and triple bonds, regioselectivity (Markovnikoff’s rule), stereochemistry
Electrophilic substitution: substitution on aromatic rings, influence of substituents on the reactivity and regioselectivity, electrophilic species;
Elimination: E1 and E2 reactions at sp^3 carbon centers, stereochemistry, acid-base catalysis, common leaving groups;
Nucleophilic substitution: S_N1 and S_N2 reactions at sp^3 carbon centers (including allylic compounds), stereochemistry;
Nucleophilic addition: addition to carbon-carbon and carbon-hetero atom double and triple bonds including conjugate addition, addition-elimination reactions, acid-base catalysis;
Radical substitution: reaction of halogens and alkanes;
Oxidations and reductions: switching between the different oxidation states of carbon (alkine – alkene – alkane – alkyl halide, alcohol – aldehydes, ketone – acid, ester, amide, nitrile – carbonic acid derivatives)
Cyclohexane conformations;
Grignard reaction, Fehling and Tollens reaction;

Simple polymers and their preparation (polystyrene, polyethylene, polyamides, polyesters);
Amino acids and their classification in groups, isoelectric point, peptide bond, peptides and proteins; Carbohydrates: aldoses and ketoses, alpha and beta anomers, oxidation and reduction of carbohydrates, Fisher projections, glucose and fructose, maltose, starch and cellulose; Lipids: general formulae of triacyl glycerides and phospholipids, saturated and unsaturated fatty acids; Bases: nucleosides and nucleotides (without formulae), difference between DNA and RNA