# Guidance for Developing & Teaching Inorganic Chemistry

### Why Is Inorganic Chemistry Required By The ACS Guidelines?

Inorganic chemistry uses the lens of periodicity to understand trends and predict the properties of elements and their compounds ranging from small molecules to extended solids. Students address fundamental ideas including periodicity, electronic structure, bonding theories, structure, and reactivity which requires them to apply and evaluate different models. A course in inorganic chemistry can help students make connections between chemical ideas across chemistry subdisciplines and deepen their understanding of chemistry.

Inorganic chemistry plays an important role in the broader chemical sciences. It contributes to many fields including material science, nanoscience, catalysis, green chemistry, organometallics, environmental science, medicine, and renewable energy.

### Meeting The Guidelines - Foundation Coursework

ACS Approved programs must offer, at minimum, **a foundation inorganic chemistry course** that builds on concepts taught in prior courses, including general chemistry. A general chemistry course or text cannot be used to meet this guideline. Typically the foundation course is a one semester course and carries the equivalent of 3 semester credit hours (approximately 45 hours of lecture). For programs on the quarter system, this translates to approximately two quarters.

The guidelines do not stipulate content for the one-semester foundation inorganic course, however a survey of existing courses shows that there are six topics that are addressed to some extent in many foundation level inorganic chemistry courses:

- Atoms & Electronic Structure
- Covalent Bonding & Molecular Orbital Theory
- Transition Metal Complexes & Coordination Chemistry
- Acids, Bases, & Solvents
- Symmetry & Group Theory
- Solids & Solid State Chemistry

A foundation course should be centered on these key inorganic chemistry concepts. Curricular coverage should build on introductory coursework and central ideas must be addressed at a higher level than is found in a general chemistry treatment. If these topics are not addressed in a foundation inorganic course, they should be addressed in an in-depth course (or in other courses in the curriculum).

Addressing the breadth of topics and the discussion of models that are treated in the inorganic course can be challenging to do in a single semester, particularly at the lower division level. In some curricula, these topics may be addressed in another foundation or in depth course. Programs should consider how topics traditionally associated with inorganic chemistry are addressed in their program. This is an important topic for department level conversations.

There is a tendency to use the foundation inorganic chemistry course as a catchall for stand alone topics that aren't covered elsewhere in a program's curriculum. This should not come at the expense of teaching central concepts in inorganic chemistry or the lens of periodicity. Nor should the course be used to supplement material that is omitted from an institution's general chemistry course.

## Meeting the Guidelines - In Depth Coursework

Programs may offer a second semester inorganic chemistry course that can serve as an in-depth course. One example of an in-depth course is a survey course that builds on ideas developed in the foundation level course. An alternative approach to an in-depth course that covers one of the subdivisions of inorganic chemistry including, but not limited to, Bioinorganic Chemistry, Coordination Chemistry, Main Group Chemistry, Nanoscience, Organometallic Chemistry, Solid State Chemistry, or Sustainable Energy & the Environment. An in-depth course in inorganic chemistry should build on knowledge developed in the foundation inorganic chemistry course.

Programs are not required to teach a second semester of inorganic chemistry, but are strongly encouraged to offer a second course in inorganic chemistry. Care must be taken to ensure that students receive the coursework that they need to pursue their desired career path.

## Standard Prerequisites for Inorganic Chemistry Courses

Beyond completion of the general chemistry coursework, the ACS Guidelines do not specify prerequisites for inorganic chemistry. The foundation course in inorganic chemistry represents a student's first exposure to the area beyond the concepts explored in general chemistry. The only prerequisite for the foundation inorganic chemistry course is coursework in general chemistry.

The prerequisites for inorganic chemistry vary greatly between approved programs because the placement of inorganic chemistry is institution specific. Prerequisites should be identified to prepare students for success in the context of the institution's course. Common prerequisites include

- General Chemistry
- General Chemistry and one or two semesters of Organic Chemistry
- General Chemistry, Organic Chemistry, and one semester of Physical Chemistry

The course should be tailored to the experiences of the students enrolled so that students work with models appropriate to their development as chemists.

## Suggested Content and Best Practices for Teaching Inorganic Chemistry

Inorganic is a broad field and it is not possible, or desirable, to cover all of the topics addressed by the field. To help students develop a deeper understanding of the field that can be applied to new systems when encountered, courses should focus on underlying themes such as periodicity, bonding, energetics, reactivity, structure property relationships across the periodic table. Inorganic chemistry deals with substances encompassing a range of scale, so it is critical that students be exposed not only to small molecules but also work with examples of nanoscale and extended systems.

Using different models, making predictions, and constructing chemical explanations should be a key outcome of inorganic coursework. A course in inorganic chemistry provides opportunities to engage with the modern chemical literature for examples and make connections to the numerous applications of inorganic chemistry.

## Laboratory Experiences

Laboratory experiences for inorganic chemistry should include the range of synthetic approaches and characterization tools used by inorganic chemists. While molecular chemistry has historically been the focus, students should have the opportunity to do work with diverse materials ranging from small molecules and supramolecular systems to extended solids. Students are expected to use observations and data from their laboratory experiences to construct chemical explanations and connect what they've learned to chemical principles. Inorganic laboratories should use multiple techniques to fully characterize systems.

Laboratory experiences should provide students with opportunities to build skills including experimental design, data analysis, chemical reasoning, critical thinking, and problem solving. While students should develop basic manipulative and characterization skills, ideally their lab experiences will relate to modern research problems. This includes lab experiences that have open-ended or incompletely defined questions and allow students to explore unfamiliar situations. Whenever possible, students should have the opportunity to participate in multi-week laboratory experiences where they can revise their ideas and build on prior findings.

The laboratory program may accompany the lectures or may be a completely separate course. The inorganic chemistry laboratory experience may also be integrated into a broader laboratory experience, but care should be taken to provide students with diverse experiences across inorganic chemistry. While a common theme is to connect the structure of compounds to their properties, another approach is to identify a course theme such as bioinorganic, catalysis, green chemistry, or materials chemistry. These examples are not proscriptive, and creativity in the pedagogy and teaching of inorganic chemistry concepts is encouraged.

Like the lecture course, the structure, content, and instrumentation used in the inorganic laboratory course is highly variable. A survey suggests the most common techniques used are NMR, IR, UV-VIS, and magnetic susceptibility. However, these techniques tend to focus on small molecule systems and neglect the nanoscience, supramolecular systems, and extended systems that are prevalent in inorganic research. Programs should think about how they can incorporate these systems into their laboratory program. The inorganic laboratory provides a natural home for these topics.

## Resources for Designing Inorganic Chemistry Courses and Illustrative Modes of Coverage

There are several community-informed resources that can be used by programs to design their inorganic chemistry curriculum. Through community workshops, the inorganic community identified inorganic articulations of the anchoring concepts in chemistry.[1] Several surveys contain information about what is taught and the methods of teaching in both inorganic lecture[2,3] and laboratory courses.[4] Based on these surveys, a framework for teaching inorganic chemistry was proposed.[5]

The Journal of Chemical Education and the Virtual Inorganic Pedagogical Electronic Resource (VIPEr) provide examples of courses and activities that can be used to support an inorganic curriculum.

## Resources

(1) Marek, K. A.; Raker, J. R.; Holme, T. A.; Murphy, K. L. The ACS Exams Institute Undergraduate Chemistry Anchoring Concepts Content Map III: Inorganic Chemistry. *J. Chem. Educ.* **2018**, *95* (2), 233–237. https://doi.org/10.1021/acs.jchemed.7b00498.

(2) Raker, J. R.; Reisner, B. A.; Smith, S. R.; Stewart, J. L.; Crane, J. L.; Pesterfield, L.; Sobel, S. G. Foundation Coursework in Undergraduate Inorganic Chemistry: Results from a National Survey of Inorganic Chemistry Faculty. *J. Chem. Educ.* **2015**, *92* (6), 973–979. https://doi.org/10.1021/ed500624t.

(3) Raker, J. R.; Reisner, B. A.; Smith, S. R.; Stewart, J. L.; Crane, J. L.; Pesterfield, L.; Sobel, S. G. In-Depth Coursework in Undergraduate Inorganic Chemistry: Results from a National Survey of Inorganic Chemistry Faculty. *J. Chem. Educ.* **2015**, *92* (6), 980–985. https://doi.org/10.1021/ed500625f.

(4) Raker, J. R.; Pratt, J. M.; Connor, M. C.; Smith, S. R.; Stewart, J. L.; Reisner, B. A.; Bentley, A. K.; Lin, S.; Nataro, C. The Postsecondary Inorganic Chemistry Instructional Laboratory Curriculum: Results from a National Survey. *J. Chem. Educ.* **2022**, *99 (5)*, 1971–1981. https://doi.org/10.1021/acs.jchemed.2c00092.

(5) Reisner, B. A.; Smith, S. R.; Stewart, J. L.; Raker, J. R.; Crane, J. L.; Sobel, S. G.; Pesterfield, L. L. Great Expectations: Using an Analysis of Current Practices To Propose a Framework for the Undergraduate Inorganic Curriculum. *Inorg. Chem.* **2015**, *54* (18), 8859–8868. https://doi.org/10.1021/acs.inorgchem.5b01320.