

Adapting Advanced Inorganic Chemistry Lecture and Laboratory Instruction for a Legally Blind Student

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ABSTRACT: In this article, the strategies and techniques used to successfully teach advanced inorganic chemistry, in the lecture and laboratory, to a legally blind student are described. At Fairfield University, these separate courses, which have a physical chemistry corequisite or a prerequisite, are taught for junior and senior chemistry and biochemistry majors. A student earns a separate grade in each the lecture (three credits) and the laboratory course (two credits). An overview of the course topics is given, followed by general accommodations and specific approaches that were used. Student assistants were very helpful and provided extra support for the blind student. Student assistants were utilized for the laboratory course, problem sets, and exams. Specific examples and detailed explanations of approaches that were helpful to the legally blind student throughout the entire course are provided. The legally blind student benefited from extensive, verbal description of complexes, figures, and diagrams. In addition, the student benefited from tactile description of figures and models. The student assistants and extra office hours were essential for the blind student to succeed and excel in advanced inorganic chemistry. The approaches discussed in this paper are the product of immediate and continual feedback from the student over the course of the semester. The student would frequently comment after class that he followed the lesson or was confused, and the latter comment elicited experimentation with different approaches.

KEYWORDS: *Upper-Division Undergraduate, First-Year Undergraduate/General, Second-Year Undergraduate, Graduate Education/Research, Inorganic Chemistry, Laboratory Instruction, Collaborative/Cooperative Learning, Coordination Compounds, MO Theory, Group Theory/Symmetry*

INTRODUCTION

The visual observations and representations often used to explore and explain chemical phenomena must be translated for a legally blind student to comprehend and appreciate the ideas being demonstrated or discussed. The blind student is a coauthor of this manuscript. Several recent articles have stressed the importance of making science learning accessible to blind students or students who have low vision.^{1–4} In a sense, the translation of topics to a blind student is akin to a classic vaudeville act in which an assistant, beholding an object, describes it in such a way that the blindfolded entertainer can positively identify it. As in this act, visual chemical information must be encoded (primarily verbally) so the blind student can form an accurate picture in his or her mind's eye.

This “translation topic” has not seen much attention in the literature to date. Some of the articles are dedicated toward laboratory adaptations.^{5–14} There have been several recent articles that address using tactile representations to make chemistry more accessible to blind and low-vision students.^{15,16} In addition, Tantillo and co-workers reported accommodations that have been made in a computational–theoretical chemistry laboratory for blind students.¹⁷ Pereira and co-workers reported using sonified infrared spectra and how they were interpreted by blind and low-vision students.¹⁸ Pereira and co-workers also reported a web portal, which blind students can use to process molecular structures.¹⁹

Those that address the difficulty of making lectures accessible are generally dedicated to logistical as opposed to content-specific matters (e.g., the need to provide course materials in

alternate formats or to allow sufficient time for their acquisition).^{16,17,20,21} A notable example is Cary Supalo's report of strategies for the classroom and laboratory, as their use to understand specific chemical topics is not detailed.²² Two important exceptions are Boyd-Kimball's report on instructional aids developed for a general chemistry course for nonmajors and Harshman et al.'s exploratory study of helpful representations of gas laws at the introductory level.^{8,20} These examples, however, and others^{15–19} underscore the absence of reports on content-specific, field-tested accommodations in more advanced chemistry courses.

In this article, the strategies and techniques used to successfully teach advanced inorganic chemistry, in the lecture and laboratory, to a legally blind student are described. An overview of the course topics is given, followed by general accommodations and specific approaches that were used. While these methods will not work for every legally blind student due to his or her particular, individual capability to mentally manipulate spatial relationships, they constitute suggestions that, for one student at least, proved helpful. The primary need of a legally blind student that our methods address is access to advanced inorganic chemistry concepts. Our methods attempt to make each step in the logical progression from Lewis structures to molecular geometry, symmetry operations, point group assignments, and qualitative molecular orbital diagrams intelligible to a visually impaired student. We believe that instructors of sighted students will learn from the approaches

Published: March 11, 2015

we followed in the teaching of the legally blind student and could use some of the methods we describe as an alternate way of describing topics.

COURSE OVERVIEW

At Fairfield University, advanced inorganic chemistry is intended for junior and senior chemistry and biochemistry majors. Students receive separate grades for the lecture (three credits) and laboratory (two credits) courses. The laboratory course, which meets for 4 h each week, was optional, although most students register for the laboratory. The courses have physical chemistry lecture and laboratory as a corequisite or a prerequisite. The course was designed to introduce the interdependence of chemical bonding, spectroscopic characteristics, and reactivity properties of coordination compounds and complexes using the fundamental concept of symmetry. After reviewing atomic and molecular structure, periodic trends, Lewis structures, and valence shell electron pair repulsion (VSEPR) theory, symmetry and group theory were introduced. These approaches were used to understand central atom hybridization, ligand group orbitals, and the construction of qualitative molecular orbital (MO) energy diagrams with a view to interpret the spectrochemical series. Electronic spectroscopy as well as the use of correlation and Tanabe-Sugano diagrams was also introduced.

The laboratory course focuses on the syntheses and characterization of coordination and organometallic complexes. For the laboratory portion of advanced inorganic chemistry, students write either extensive laboratory reports or give an oral presentation for each experiment. For all of the laboratory experiments, students work in groups of two or three.

GENERAL ACCOMMODATIONS

A week before the first class, a presemester conference was attended by the instructor, student, and the director of the University's Disability Service Office. It was arranged that the student would actively take notes on a Braille hand-held computer and also be provided with an electronic version of the instructor's notes either before or after class. The lecture notes were only referred to by the student in cases where his own notes were unclear. In those cases, the text of electronic lecture notes was reviewed using the Job Access with Speech (JAWS) screen reader, with Greek symbols having been added to the reader's dictionary by the student previously. When drawings were insufficiently described in the student's notes, they were either explained from the electronic notes by the student's homework assistant, or the student asked about the relevant material during office hours. The student was thereby able to independently and actively engage with lecture material and at the same time, know that ambiguities, omissions, and other problems with the student's notes could be resolved by checking the instructor's version. The laboratory manual, authored by the instructor, was also provided in an electronic format. Handouts were either posted electronically for the course or given as physical photocopies. Most handouts had been submitted to the University's Disability Services Office and the State of Connecticut's Vocational Rehabilitation Department five months prior to the start of the semester for braille transcription. For the course textbook, the student relied on an audio recording from Learning Alley (formerly recording for the blind and dyslexic) on which volunteers for the organization read the text and attempted to describe the figures.

The student is legally blind. He has low usable vision in his right eye with an acuity of 20/800 and cannot see out of his left eye. He can see colors, large shapes, and sizable objects. He cannot read print either on the board or in a text book.

Student assistants formed an important support team for the blind student. These assistants were compensated for their services and were recommended by the course instructor beforehand. There was an assistant in the laboratory course, an assistant for the completion of problem sets, and an assistant for completion of exams. Specifically, one assistant helped with weekly laboratory experiments to ensure that prelab diagrams were understood, physical manipulations performed, and observations vividly described. The assistant also drew structures and energy diagrams, as directed, on lab reports prepared by the student using the JAWS screen reader application, Microsoft Word, and Microsoft Excel. Another assistant helped with the drawing of energy diagrams and chemical structures, under the student's instruction, on weekly problem sets. A third assistant read exams and took down by dictation the blind student's responses after they had been worked through on his Braille computer. The instructor made molecular models of structures depicted on exams beforehand. The assistants for assignments and exams had not taken the course but knew chemistry sufficiently well for their roles. The assistants for problem sets and exams were senior biology majors. These two biology majors were strong students who had the instructor previously. There were two senior chemistry and biochemistry majors who had taken the course as juniors, and only one was available to assist. She assisted in the laboratory. All these arrangements were set forth at the presemester meeting. Additionally, extended time was offered on lab reports if needed, but the student never utilized this.

SPECIFIC APPROACHES FOR COURSE CONTENT

In the American Chemical Society's publication *Teaching Chemistry to Students with Disabilities: A Manual for High Schools, Colleges, and Graduate Programs*, instructors are directed to "Verbally describe or explain charts, diagrams, graphs, and other information being presented in a visual format."¹⁰ However, best practices for how to describe visual concepts or representations (e.g., symmetry properties, character tables, MO diagrams) are not provided for instructors in any known reference. Furthermore, Cary Supalo emphasizes the construction of tactile diagrams over verbal descriptions.^{15,16} The question naturally arises, "When are verbal descriptions or tactile representations more appropriate?" While depending on the student's ability to form mental pictures to an extent, the answer also depends on the quality of the description. It is the aim of this section to illustrate cases in which tactile diagrams or molecular models were more useful.

It is worthwhile to note that Cary Supalo usefully extends the advice of the ACS manual to encompass chemical and mathematical expressions and illustrates how to avoid verbal ambiguities. With these expressions, literalness in one's description is helpful. To read the formula $\text{trans-K}[\text{Mn}(\text{C}_2\text{O}_4)_2(\text{H}_2\text{O})_2]$, for example, one could say "K open bracket Mn open parentheses C_2O_4 close parentheses taken twice open parentheses H_2O close parentheses taken twice close bracket." This works for a student familiar with the notational convention of subscripting numbers immediately preceding element symbols. As a general rule, it is also useful to be

mindful in avoiding directional pronouns (e.g., this, that, here, there) in descriptions.

Atomic and Molecular Structure

Understanding the chemistry of coordination compounds and complexes requires learning about the shapes of the d-orbitals. The student knew the shapes of s- and p-orbitals at the start of the course, but those of d-orbitals were only vaguely familiar. Learning their shapes was facilitated by styrofoam models that had the x-, y-, and z-axes indicated with metal wires.

The student was also familiar with the concept of Lewis structures. It was sufficient to state which was the central atom, which were terminal, the number of lone pairs on each atom, and the atoms between which there were multiple bonds. In describing the structure of $[\text{IO}_4]^-$, for example, the instructor said, "Place I in the center, surrounded by four O connected to it, each O having three lone pairs." (Figure 1). Then, in

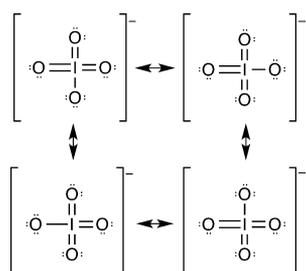


Figure 1. Lewis Structures for $[\text{IO}_4]^-$.

explaining the need to minimize formal charges, the instructor continued, "Move one of the lone pairs from an O to between I and O to form a double bond." The formal charge of each "singly bonded" and "doubly-bonded" O was then calculated, and the process was repeated two more times. Each resonance structure was included within brackets, with the charge indicated outside at the upper right.

Two particularly challenging to describe molecular structures, the porphyrin and corrin ring systems, were encountered in a prelab lecture for an experiment designed to synthesize and characterize a Vitamin-B12 model complex (Figure 2). Though

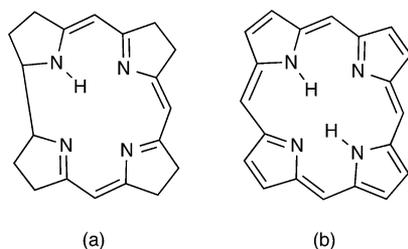


Figure 2. (a) Corrin and (b) Porphyrin rings.

descriptions were attempted during the lecture, the student was unable to follow them. Consequently, the assistant methodically described the structures after the talk, while the instructor helped teams of students start the experiment. The verbal description for Porphyrin is reproduced here.

"Imagine a square, and at each corner of the square is a pentagon. Each pentagon consists of four Cs and one N. The N of each pentagon points towards the center of the square and will be referred to as the number 1 position in each pentagon. The others will be numbered in a clockwise fashion. For the pentagon in the upper left hand corner of the macrocyclic

molecule, there is a double bond at the base of the pentagon between positions 3 and 4. Position 2 has a substituent to which we'll return. Position 5 is doubly bonded to a CH, which in turn is singly bonded to the second position of the pentagon in the upper right hand corner of the molecule. In this pentagon, the N is doubly bonded to position 2. There is again a double bond between positions 3 and 4, and a double bond from position 5 to a bridging CH that connects to the lower right hand corner pentagon at position 2. This pentagon is different. It has double bonds between positions 2 and 3, and 4 and 5. Position 5 is singly bonded to a CH, which is doubly bonded to position 2 of the lower left hand corner pentagon. This fourth pentagon has a double bond between positions 3 and 4, like the first two. It also has a double bond between positions 1, the N, and 5. A single bond leads from position 5 to the fourth and final bridging CH in the molecule, which is doubly bonded to position 2 of the first pentagon at the upper left hand corner. This CH connecting the fourth to the first pentagon was the substituent that was originally skipped over. Finally, the Ns of the first and third pentagons were protonated." A total of 298 words were used to describe a porphyrin ring. In general, a chemical structure has a lot of meaning.

This description was accompanied by the student attempting to trace in air the molecule as it was explained position-by-position. Movement helped the student picture the molecule mentally and also permitted the assistant to correct or confirm the student's understanding of the description. Once the structure of porphyrin was understood, that of corrin was much easier to explain. Though the position of double bonds was explained in a similar manner as that for porphyrin, it was only necessary for purposes of the experiment for the assistant to describe the corrin ring system as I lacking the fourth bridging CH group, having instead a direct single bond between position 5 of the fourth pentagon and position 2 of the first one, and II being less unsaturated than porphyrin. Since each description is rather lengthy, understanding one of the structures, and then contrasting it with the other, was the most effective approach. The contrasting was accomplished by comparing the text descriptions.

When molecular geometry was considered, molecular models were often useful to understand the basic shapes predicted by VSEPR theory. Since the student was familiar with an analogue clock, simple shapes, such as trigonal and square planar, could be verbally described using the face of a clock as a frame of reference. For example, " BF_3 is trigonal planar, meaning that it has a boron at the center, with fluorine's at the 12, 4, and 8 o'clock positions." For more complex shapes, such as trigonal bipyramidal and octahedral, molecular models were needed. They are particularly convenient for considering possible, alternate structures, for example, whether none, one, or both of the lone pairs on Cl in ClF_3 should reside in an equatorial position. In this case, a model of each possible structure was built using a giant-sized, ball-and-stick model kit that consisted of differently colored spheres for atoms and lobes for lone pairs. Each model was shown to the class and when presented to the blind student, held over his desk directly in front of him, or simply handed to him. The student sat in the front row in a position illuminated by panels of fluorescent lights on either side. With his limited perception of light, color, and shapes, this meant that models held aloft to show the class on either side of his desk were mostly obscured by glare. The tactile representation of each molecule allowed the student to count

the number of bonding pair–bonding pair, lone pair–lone pair, and bonding pair–lone pair interactions. Comparison of these counts recorded on his Braille computer allowed for correct identification of the observed structure.

Types of Coordination Complex Isomerism

Molecular models, furthermore, were essential for understanding stereo or configurational isomers (e.g., *cis* versus *trans*, *mer* versus *fac*). They were useful in finding all the possible isomers for a given complex and which of these were chiral. The procedure used for this operation was also helpful and is illustrated for the complex $[\text{CoBrCl}(\text{H}_2\text{O})_2(\text{NH}_3)_2]^+$.

First, the ligands were assigned letters such that H_2O was called A; NH_3 , B; Br, C; and Cl, D. A given isomer was specified by indicating which pairs of ligands were trans to each other. For example, AABBCD meant that the two waters (AA) were trans to each other, the two ammonias (BB) were trans to each other, and the Br (C) and Cl (D) ligands had a trans configuration. Different isomers in this case are AABCBD, ACADBB, ABACBD, ABABCD, and ABADBC. This notation, while generally convenient, was especially so for the blind student, because it provided a way to nonvisually record an isomer in his notes so that he could build the model at a later time in the course of studying. For models in and outside of class, the student benefited from the differently colored parts of the model kit. As long as a convention was specified to or by the student (e.g., ligated waters are represented with white balls), there was no confusion. Before chirality was defined in terms of certain point groups in the course, the student occasionally built a model and its mirror image to resolve whether the molecule was chiral. As the student became more comfortable with identifying the presence or absence of symmetry elements, however, this was mostly unnecessary.

In contrast to the need of models to examine stereoisomers, examples of ionization, solvent, coordination, and linkage isomers were all adequately handled by explicitly reading chemical formulas, as illustrated previously.

Crystal Field Theory

The orientation of the d-orbitals was first reviewed by emphasizing that three (d_{xy} , d_{xz} , and d_{yz}) had lobes between axes, and the other two ($d_{x^2-y^2}$ and d_z^2), on them. The torus of d_z^2 in the xy -plane was also noted. This preface made the following geometric explanation of crystal field theory (CFT) understandable to the blind student.

A free metal ion was envisioned with its five degenerate d-orbitals at a certain energy. The accompanying energy diagram for the d-orbitals was described as consisting of five orbitals, all at the same level. The metal ion was assumed to have an n^+ charge, and it was imagined that a spherical charge of 6^- was then applied. All five orbital slots on the diagram were said to rise in energy. The next step was to imagine, instead of a spherical field, the presence of negative point charges at the opposite ends of the x -, y -, and z -axes. Three slots, representing the d-orbitals oriented between axes, were said to move to lower energy, while the remaining two, with lobes on the axes, rose in energy. Though the symmetry unit had not yet been covered, the triply and doubly degenerate sets of d-orbitals were labeled T_{2g} and E_g , respectively, for ease of reference (Figure 3).

The difference between them was defined as $10D_q$. The position of the d-orbitals in a spherical field (the result of the second step in this procedure) was labeled the bary center. It was initially difficult for the blind student to reconcile the

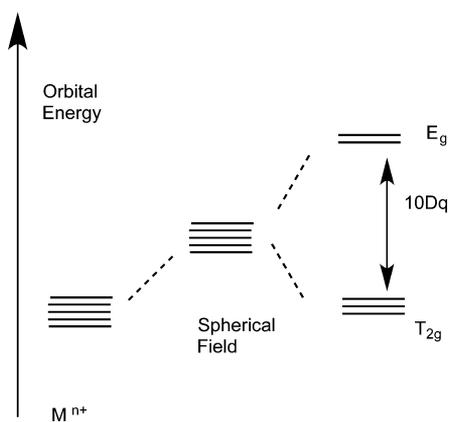


Figure 3. Crystal field theory and d-orbital splittings in a complex with octahedral symmetry.

description of the T_{2g} set as being closer to the bary center than the E_g set, with the statement that the amount of stabilization and destabilization canceled one another. This was resolved by explaining that each of the three T_{2g} orbitals was $-0.4\Delta_o$ below the bary center, and each of the two E_g sets was $0.6\Delta_o$ above it, meaning that either set differed by a total of $1.2\Delta_o$ from the bary center.

The d-orbital electron configurations for the 2^+ and 3^+ oxidation states of Ti, Cr, and Fe were illustrated using the energy diagram thus derived. The examples, covering d^1 through d^6 configurations, were used to systematically add electrons. The configurations were described by stating how many of the T_{2g} or E_g slots contained “one” or “a pair”. For example, the high-spin d^5 configuration was described as “one in each of the orbitals”, whereas the d^5 low-spin state had “two paired sets and one unpaired in T_{2g} ”. With this information, the student was able to visualize the number of electrons in the T_{2g} and E_g sets, the number of pairing interactions, and the possible electronic exchanges. As a result, the blind student was able to express the total energy of a given d-electron configuration as the sum of the crystal field stabilization energy, exchange energy, and pairing energy. By knowing the number of unpaired electrons, the student was also able to calculate the effective magnetic moment, the formula for which had been read explicitly as explained earlier.

CFT d-orbital splitting diagrams for tetrahedral and square planar complexes were treated in much the same fashion. For the former, the negative point charges were envisioned at opposite corners of a cube, coming closer to the d-orbitals directed toward the cube’s edges than those with lobes lying on the axes. The orbital overlap for either set was said to be not as direct as for the octahedral complex, which thereby explains in part the smaller energetic splitting of the d-orbital sets. For the latter, the point charges on the z -axis of the octahedral complex were envisioned as being pulled away and causing the d-orbitals containing a z -component to fall in energy. For both cases, the orbital slots on the diagrams were labeled and read sequentially from lowest to highest energy.

Symmetry and Group Theory

Again, molecular models played a pivotal role in demonstrating the elements of symmetry to the blind student, who, prior to the course, found the relevant chapter in the textbook incomprehensible. It was generally helpful to hold the molecule in one hand directly in front of the student while indicating the location of a mirror plane or inversion center with the other.

Axes of rotation were shown by rotating the molecule about each by the hand that held the model. A given symmetry property was either first shown to the class or to the blind student so as to not give any additional special attention to the student.

The most difficult symmetry element to visualize was an improper axis of rotation. The example given to the class was the S_4 axis of methane and is given in Figure 4. Though

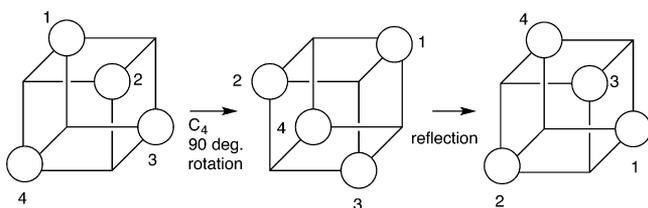


Figure 4. Tetrahedron inscribed in a cube to represent a S_4 axis.

manipulation of a model would perhaps have been the easiest approach to demonstrate this property, a verbal description was attempted. "Picture a tetrahedron inscribed in a cube. Spheres at opposite corners of a cube—front upper left and back upper right, back lower left and front lower right—form a tetrahedron. Number these spheres 1 through 4, respectively. If the molecule is rotated by 90° and then inverted, so the spheres at the bottom of the cube are brought upstairs and vice versa, the molecule in its original orientation is reproduced."

Notwithstanding the clarity of this description, it was helpful for the student to come to the board after class. His index finger (with guidance) was used to trace the dimensions of the cube, and to point out the numbering pattern. Then the 90° rotation was illustrated by positioning two of the student's fingers at opposite corners and indicating to which corner each finger would move. The same approach was used to show the outcome of the reflection operation.

Second only to the usefulness of molecular models for the blind student to visualize the symmetry properties of a molecule was exhaustive practice with models on his part.

Point groups of molecules were assigned by examining molecular models according to a flowchart that was presented during lectures as a series of questions about the presence of certain symmetry elements.

When character tables were discussed, the column headings, characters of the irreducible representations (in rows), and corresponding information about orbitals were read row-by-row.

Molecular Orbital Theory

The MO theory was explained through the linear combination of atomic orbitals method to form bonding, antibonding, and nonbonding orbitals. Each was described based on its effect on electron density in the internuclear region. The simplest case was the addition of "two spherical s -orbitals of positive symmetry" to form "a bigger, oval lobe of positive symmetry," and their subtraction to yield "spherical lobes of opposite symmetry separated by a node." (Figure 5).

Every change in sign was understood to imply the presence of a node. The addition of two p -orbitals on the internuclear axis was described as "negative positive plus positive negative" and resulted in "two outer negative lobes and a middle positive lobe roughly double in size". Their subtraction yielded a four lobed antibonding orbital described as "negative positive negative positive". Combination of either pair of the

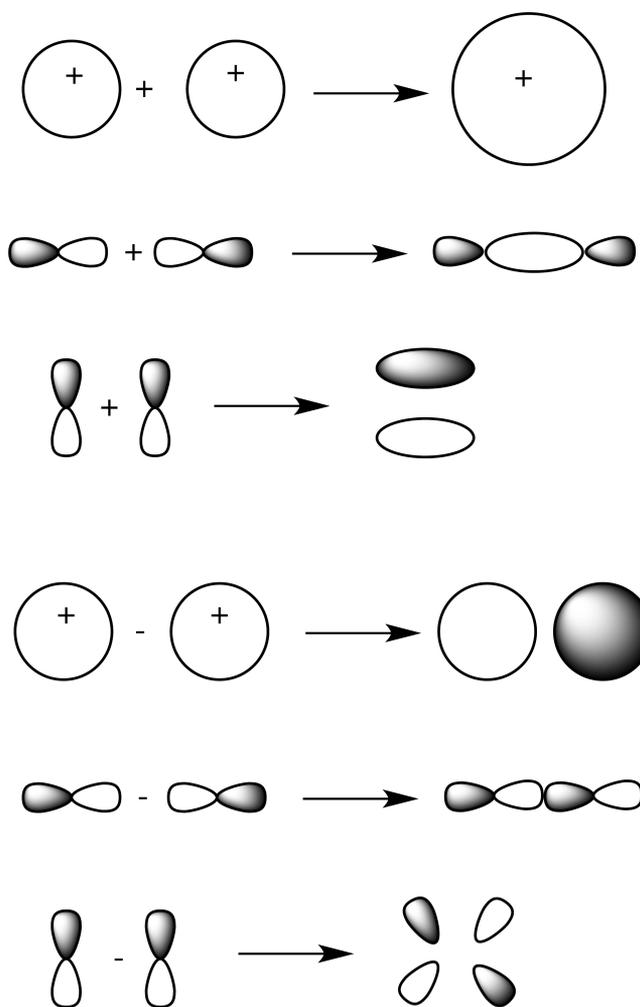


Figure 5. Linear combination of atomic orbitals showing both bonding and antibonding orbitals.

perpendicular p -orbitals was described similarly. For example, one set was drawn vertically and described as "positive-negative, top-bottom for each". The resulting bonding orbital consisted of "a positive lobe on top, negative on bottom", and the antibonding, "positive-negative, top-bottom on the left, and negative-positive, right".

Description of MO energy diagrams consisted of stating the atomic orbitals on the left- and right-hand sides, the MOs in the middle, and from and to where tie lines were drawn. Orbital occupancy was read from lowest to highest energy as for CFT d -orbital splitting diagrams. A sense of the spacing in these diagrams was conveyed by stating the orbital energies in electron volts. The description of the MO diagram for O_2 is given as an example (Figure 6).

Atomic orbitals for oxygen are on the left and right. On each side, there is one $2s$ atomic orbital at -32.38 eV and above it, three $2p$ orbitals at -15.58 eV. Both $2s$ orbitals interact, which gives $\sigma(2s)$ in the middle beneath their level and a $\sigma^*(2s)$ above their level. The vertical or energetic difference between $\sigma^*(2s)$ and the $2s$ orbitals on either side is greater than that between them and $\sigma(2s)$. Tie lines connect the $2s$ orbitals to these MOs. In addition, one $2p$ orbital from the left and right interact to form $\sigma(2p)$ below their vertical position. The other two $2p$ orbitals from each side form two $\pi(2p)$ below and two $\pi^*(2p)$ above their level. The

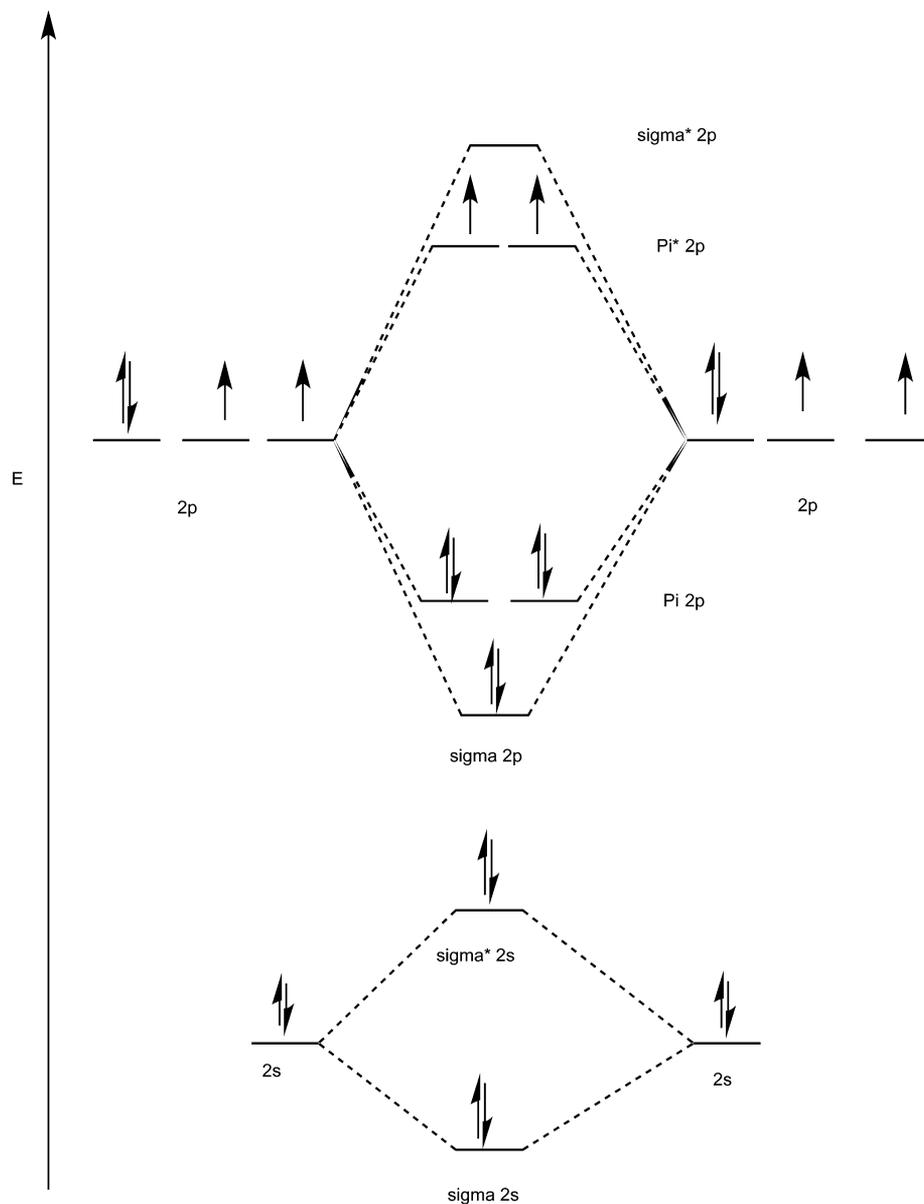


Figure 6. Molecular orbital diagram for O_2 .

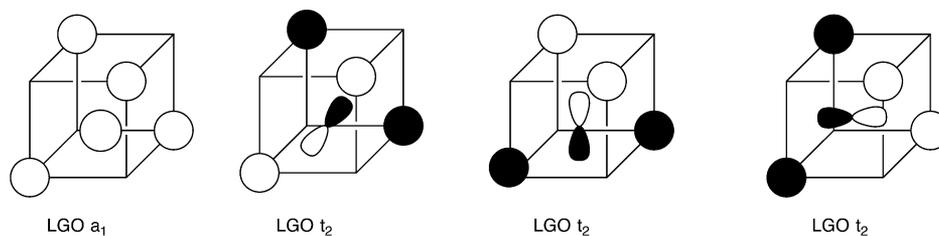


Figure 7. Ligand group orbitals and their overlap with the atomic orbitals of carbon.

p-orbitals that formed $\sigma(2p)$ also form $\sigma^*(2p)$, which is the highest energy MO. As before, tie lines connect the atomic orbitals to the bonding and antibonding MOs they form. The electron configuration on each side is “two s two, two p four.” For the MOs in the middle, it is “sigma two s two, sigma star two s two, sigma two p two, pi two p four, with a pair in each of the two degenerate orbitals of this kind, and pi star two p two, with one up in each degenerate orbital of this kind.”

Once the energy ordering of the MOs for a given system is clearly stated, an alternative way to summarize their occupancy is by identifying the highest occupied molecular orbital (HOMO) and the lowest occupied molecular orbital (LUMO) and the number of electrons in the former.

For systems other than homo- or heteronuclear diatomics, the method of constructing ligand group orbitals by inspection was employed, as described for methane (Figure 7).

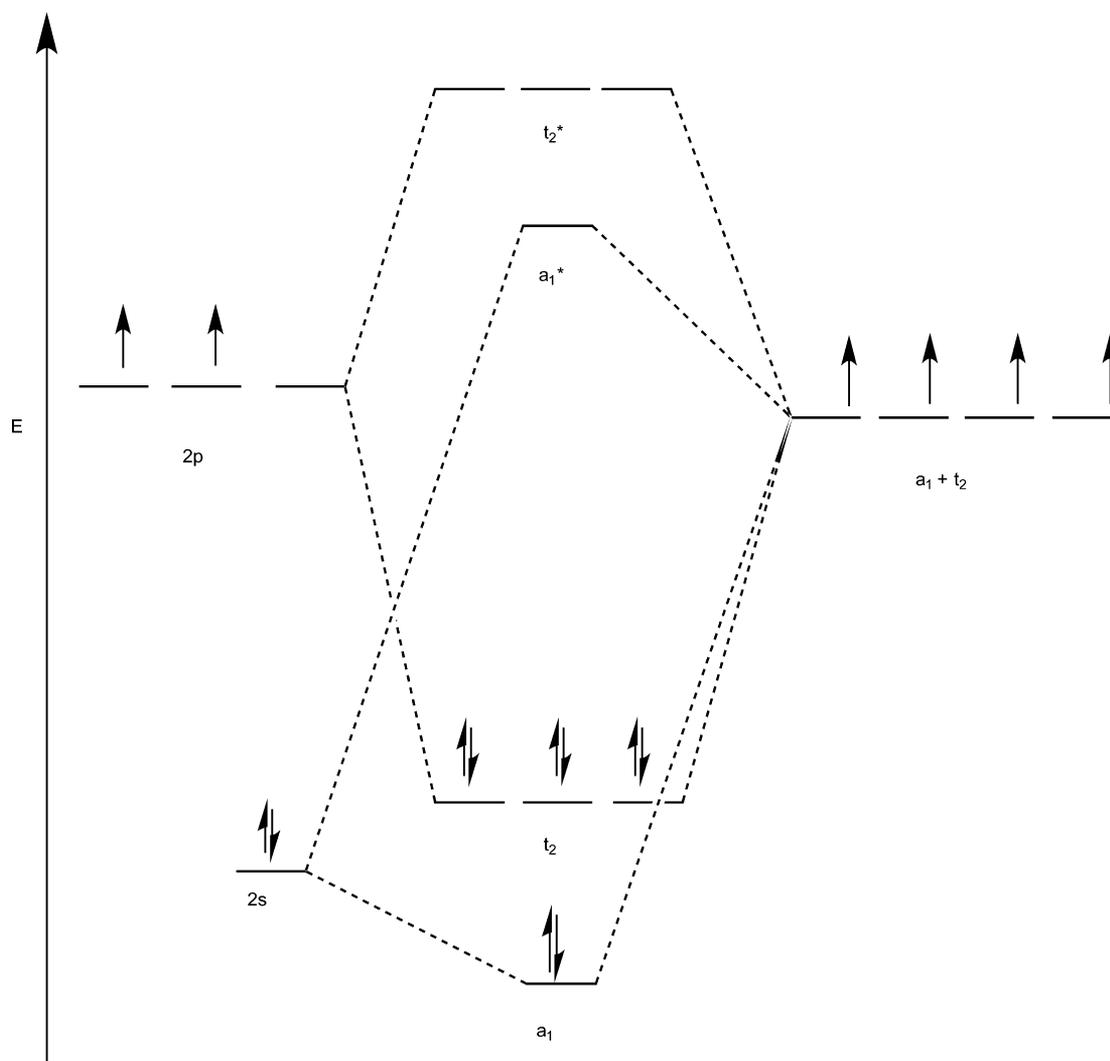


Figure 8. Qualitative molecular orbital diagram for CH_4 .

Draw four cubes. At their center, put an s - or p_x - or p_y - or p_z -orbital. Axes: z , vertical; y , left-to-right; and x , into-and-out of the board. The positive symmetry part of the p_x orbital is open toward you, and the hatched or negative symmetry part is behind. The positive symmetry part of the p_y is open to the right, and the negative symmetry part is on the left. The positive symmetry part of the p_z is open up, and the negative symmetry part is down. Numbered corners: upper right-hand ligand group orbital (LGO), 1; lower right-hand LGO, 2; lower left-hand LGO, 3; upper left LGO, 4. LGOs 1 and 3 form face of the cube facing the class; LGOs 2 and 4 form the other face going into the board. For overlap with p_x , LGOs 2 and 4 need negative symmetry; LGOs 1 and 3 require positive symmetry phasing. For p_y overlap, LGOs 3 and 4 require negative symmetry, and LGOs 1 and 2 require positive symmetry. For p_z overlap, LGOs 1 and 4 require positive symmetry, and LGOs 2 and 3 require negative symmetry.

For the MO diagram (Figure 8), the $2s$ - (-19.43 eV) and $2p$ - (-10.66 eV) orbitals from the central C were drawn on the left, and the $1s$ LGOs from H (-13.6 eV) were drawn on the right. The $2s$ orbital from C interacts with the $1s$ orbital from H to form MO A_1 . The three $2p$ orbitals on C interact with the LGOs from H to give a degenerate set of three T_2 MOs. The next MO is A_1^* , which comes from $2s$ on the left and $1s$ on the

right, and the highest energy MO is T_2^* , which comes from the $2p$ orbitals on the left and the $1s$ LGOs of H. The HOMO is T_2 , with three pairs, and the LUMO is A_1^* .

The approach used for methane was extended to explain pi-acceptor, sigma-donor, and pi-donor octahedral complexes. The atomic orbitals on the central metal ion were drawn in boxes in an analogous fashion to those of C in methane. For this case, however, the axes were defined somewhat differently. The z -axis was said to be vertical, with the top labeled position 1 and the bottom, 6. The y -axis extended from the bottom right, labeled position 3, to top left, labeled 5. The x -axis extended from the top right, position 2, to bottom left, position 4. The construction of LGOs and the MO diagrams, were otherwise described similarly. It was helpful for the instructor to compare the relative size of the HOMO–LUMO gap among the three MO diagrams for octahedral complexes to explain the ordering of the spectrochemical series.

Tanabe–Sugano Diagrams

MO diagrams were used as a starting point for understanding electronic spectra. In addition, Tanabe–Sugano diagrams were utilized to interpret UV–vis spectra for first-row octahedral metal complexes. The following steps were helpful for the blind student in interpreting Tanabe–Sugano diagrams:

- (1) Read the ground state and then the excited states of the same multiplicity.
- (2) Enumerate each transition, from lowest to highest energy, by stating the ground state and then a given excited state.
- (3) Read the energy of the transitions from spectral data.
- (4) Describe drawing a vertical line at a test value on the Dq/B axis that intersects with each of the curves of the same multiplicity as the ground state.
- (5) Describe drawing horizontal lines from the points of intersection to get their y -coordinates (E/B).
- (6) Calculate the ratio of the y -values for a given transition. Compare each to the ratios found from the spectral data.
- (7) This method was easy for the blind student to follow in class and work through on an exam. (e.g., If the blind student asked reader, "If you draw a line at $Dq/B = 2$, where about does it intersect curves with a multiplicity of 4?" The reader would say, "it intersects $4T_2$ at 19," and so on.)

Laboratory Considerations

The laboratory course was designed as a synthetic inorganic chemistry laboratory with an emphasis on characterization. The students prepare a variety of coordination and organometallic complexes including one air-sensitive complex.

The blind student prepared his notebook using Microsoft Word before the laboratory. This entry included a bullet-point version of the procedure with calculated quantities for reagents. In the laboratory, the physical manipulations and measurements were accomplished by other group members or the laboratory assistant. The solutions were prepared and placed in the instruments (UV-vis spectrometer, NMR spectrometer, magnetic susceptibility balance, polarimeter, or ATR-IR spectrometer) by other laboratory group members or the laboratory assistant.

While in the laboratory, the student provided direction to the assistant. The student was allowed to provide as much direction as possible. Usually, this consisted of conveying the instructions from the procedure that the student had outlined in his notebook prior to the experiment. The student, for example, provided instruction as to the quantities of reagents and the type of glassware to be used. Meanwhile, the assistant provided observational feedback to the student as to what was transpiring in the laboratory. Observation of color changes during the course of reactions was critical to the laboratory experience. The assistant provided vivid and detailed descriptions of these phenomena. An example of this is given in the following for the preparation of pentaamminechlorocobalt(III) chloride, which was synthesized in the laboratory.

$\text{CoCl}_2 \cdot 6\text{H}_2\text{O}$ (10.001 g, 42.033 mmol) was added to a solution in which NH_4Cl (5.0136, 93.727 mmol) had been dissolved with stirring in 30 mL of NH_4OH . The resulting brownish-pink solution, which contained some solid material, transitioned to a blackish-pink, or raspberry jelly color, with some bubbling upon the dropwise addition of 10 mL of H_2O_2 over a period of 10 min. Subsequent addition of 30 mL of concentrated HCl to this solution resulted in the vigorous evolution of gas and heat and a wine-colored solution. After the reaction mixture was heated for 20 min at 85 °C, the solid present in the solution changed from rose to deep lilac in color. The mixture was then cooled to room temperature, and gooey, purple crystals were collected on a Buchner funnel from an indigo solution.

Feedback to the student was frequent and continual to assure that the student knew what the assistant was doing and observing unless the assistant needed to have their undivided attention on the task at hand. At these times, the student was informed that the flow of descriptive feedback would be stopped for a few moments.

SUMMARY

This article provides the strategies and techniques used to successfully teach advanced inorganic chemistry, in the lecture and laboratory, to a blind student. Student assistants were very helpful and provided extra support for the blind student. We provided specific examples and detailed explanations from the entire course that were helpful to the blind student. In general, we have given examples where two-dimensional energy diagrams, MO energy diagrams, nomenclature, and two-dimensional structures were handled well by verbal descriptions. We have also given examples where spatial relationships, three-dimensional structures, and Tanabe-Sugano diagrams were handled well by three-dimensional tactile representations. Instructors of sighted students will learn from the approaches we followed in the teaching of the legally blind student and could use some of the methods we described as an alternate method of describing topics.

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Notes

The authors declare no competing financial interest.

ACKNOWLEDGMENTS

The authors are grateful for all of the assistance that the Office of Disability Support Services at Fairfield University provided for the blind student. The authors would like to thank Professor L. Craig Steffen for the helpful suggestions.

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