

Teaching Descriptive Inorganic Chemistry Through the “Chemical of the Week”

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Abstract: Many general chemistry courses spend little time on descriptive inorganic chemistry. An approach used, which has met with considerable interest by students, is to select a different chemical each week as the *Chemical of the Week*. A 15 minutes presentation of this chemical is given at the end of the last lecture of the week. Compounds are chosen which appeal to students based on health, environmental, or current media interest. The chemicals discussed, in order, are ozone, Freons, nitrogen dioxide, sulfur dioxide, sulfuric acid, ammonia, nitric acid, phosphoric acid, lead, mercury, and cisplatin. The presentations are arranged so that later chemicals build on information from earlier chemicals. Each presentation usually follows a general format of the chemical's synthesis, its environmental impact, practical applications, and personal relevance. Details of each presentation are given.

Many articles have been written about teaching descriptive inorganic chemistry in both general chemistry courses and specialized courses [1]. Although contemporary general chemistry texts have chapters dealing with various aspects of the main group elements and of other inorganic compounds, often these are not covered due to lack of time or interest. In order to help bridge the interest gap, many books have introduced short descriptive chemistry articles under a title such as “Chemical Impact” [2].

A helpful approach I have used the last few years is what I call *Chemical of the Week*. In the first general chemistry course, I present the *Chemical of the Week* over 10-15 minutes at the end of the last lecture of each week. Using this approach, I discuss eleven chemicals during the semester. This is the students' first chemistry course in English; the course and textbook [2] are typical for a North American general chemistry course. The students come from secondary-school backgrounds that stress memorization, and they are weak in conceptual-skill development and laboratory practice. The students in this first course are science, secondary science-education, and premedical majors. They find these presentations interesting and often ask for more information after the lecture. The key to generating this interest seems to lie in choosing chemicals of current media interest (e.g., Freons and the ozone layer), chemicals that are environmental hazards (e.g., lead and mercury), or that are of health interest (e.g., cisplatin). Included are some major industrial inorganic chemicals of which I think a first-year chemistry student should be aware. The chemicals discussed, in order, are ozone, Freons, nitrogen dioxide, sulfur dioxide, sulfuric acid, ammonia, nitric acid, phosphoric acid, lead, mercury, and cisplatin. The presentations are arranged so that the later discussions build on information from chemicals discussed earlier. In the presentations, relationships between the chemical and everyday life are stressed along with humor and personal anecdotes. There are numerous chemicals one could discuss, depending on the lecturer's interest and background. The key is choosing ones that appeal to students' interests and/or are applicable to their future careers and lives.

At the beginning of each lecture, I write *Chemical of the Week* on the board and the name of the chemical that will be discussed that week. This gives the interested student an opportunity to do outside reading during the week; some students do take advantage of this. During the final 10 to 15 minutes of the last lecture of the week, the chemical is discussed. The presentation generally includes how the chemical is produced, its environmental impact as well as practical applications, and personal relevance. There are many inorganic references that one can use but much of the information has been drawn from two textbooks [3]. Information from articles in *Chemical and Engineering News* is also adapted and used for these presentations. Given below are the salient points of each chemical discussed during the semester.

Ozone

Ozone is discussed at the end of the first week [4]. All students have heard or read something about ozone, probably know its formula, and even may be concerned about the ozone hole. However, for these students, their knowledge ends with that. Its structure compared to dioxygen is given and its production from dioxygen by electric discharge is discussed. This leads into a discussion of ozone's production during lightning storms (not common in Oman, but spectacular when they do occur) and its sharp smell, which led to its detection in 1840 (the word *ozone* is derived from the Greek word for *smell*). Because of its unstable explosive properties when a liquid or solid, it is prepared industrially at its site of use. Its toxicity (1 ppm for 10 minutes) is mentioned.

The main chemical property of ozone, an oxidizing agent, yields negative and positive effects. As a pollutant, its deleterious oxidizing effects on trees, tires, and other materials can cause severe damage. However, these same oxidizing properties can be harnessed and used in water-purification processes. This has benefits over the chlorination process in that chlorinated organic compounds are not made. However, the ozone must be generated on site and does not have the

continuing purification properties that chlorine does after the water leaves the purification plant. As a pollutant at ground level, one finds it highly objectionable whereas at a level of 25 km in the stratosphere, it is highly desirable. Its production and decomposition in the upper atmosphere are mentioned, which leads into how it is a moderator of UV radiation. This sets the stage for a discussion of Freons and the ozone hole the following week.

Freons

Most students have heard of Freon but may not associate it with CFCs [5]. The general formula CF_xCl_{4-x} is mentioned along with, if time or interest allows, the numbering of Freons using the Rule of 90. Freon 12, formerly used commonly in air conditioning systems (and still widely used in developing countries like Oman) has the formula CF_2Cl_2 .

Why are these compounds desirable from a chemical viewpoint? Before they were discovered, compounds like SO_2 and NH_3 were the compounds of choice for refrigerants. Then in 1928, Midgley et al. first synthesized Freons, which seemed to be miracle compounds. They had the proper physical properties for compression and expansion and thus could be used as refrigerants. Moreover, they were colorless, odorless (unlike NH_3 and SO_2 !), nonflammable, noncorrosive, nontoxic, and nonreactive. Because of these ideal properties, they were manufactured in huge quantities and used as refrigerants, in aerosols, and in making foams without any thought to possible deleterious effects. The two questions "Where do they go?" and "What do they do when they get there?" were not asked until much later [6].

Although the chemicals seemed to be unreactive at ground level, a different story takes place at altitudes of 20–40 km. The equations describing the catalytic decomposition of ozone by chlorine atoms are discussed, with the mention that one chlorine atom can decompose up to 10^5 ozone molecules. Mention is made of a 1993 British study showing that two-thirds of the ozone shield over the Antarctic had been destroyed by September 1993, and how this is reflected in the increased incidence of skin cancer [7]. The lecture closes with a description of the Montreal agreement to phase out CFCs, and to substitute HCFCs for CFCs.

Nitrogen Dioxide

The brown haze in large cities, experienced by many citizens worldwide (though not much in Oman), is the platform for discussion of the chemical nitrogen dioxide [8]. Other oxides of nitrogen are mentioned but the discussion focuses on the formation of colorless nitrogen monoxide in internal combustion engines and its subsequent conversion to brown nitrogen dioxide, one of the culprits in the brown haze. A second involvement of nitrogen dioxide is in photochemical smog that results from the photodecomposition of nitrogen dioxide. This in turn leads to the production of ozone as oxygen atoms react with dioxygen molecules. Previously, students had seen that ozone in the stratosphere was beneficial; now they learn that ozone at ground level has very deleterious effects.

The third area of nitrogen dioxide's involvement in pollution is in the production of acid rain. This discussion leads into information on the industrial production of nitric

acid. The basic reactions are presented, but detailed discussion takes place four weeks later when nitric acid is formally covered.

Sulfur Dioxide

Continuing with the theme of chemicals contributing to air pollution, sulfur dioxide is discussed in the fourth week [9]. The synthesis of the compound, its common physical properties, its use as an antibacterial agent (e.g., in dried fruit), a bleaching agent, and a refrigerant, and its main use (in the production of sulfuric acid) are mentioned. Natural sources from volcanoes are mentioned (ca. 300 millions tons/year) but a major source since the Industrial Revolution has been human activities (ca. 200 million tons/year). Although this is less than the amount from natural sources, the major problem with human-made SO_2 production is its release over populated areas.

The sources of SO_2 emissions in the USA and Europe are 60% from coal combustion (electricity production), 25% from oil refineries and oil combustion, and 12% from copper smelting [9, 10]. Special mention is made of the burning of soft coal for heating in some countries and the effect it has on air pollution during the winter months (e.g., in Istanbul). On the local front, coal deposits recently discovered in eastern Oman were hailed as a great local energy source without mentioning the high sulfur content of the coal and the concomitant increase in sulfur dioxide emissions if this source were to be exploited.

Acid rain in industrial areas in the form of sulfuric acid is mentioned along with the necessary reactions. One way that some countries have abated the problem has been to build higher power-plant stacks. This does have an effect at lowering the emissions in the host country but not in adjacent ones downwind. Sweden is a prime example; it is estimated that 10% of its SO_2 burden is generated in the country, 10% comes from the UK, and 80% blows in from Northern Europe [9].

Sulfuric Acid

May his rest be long and placid / He poured the water in the acid. With this poem and a drawing of a tombstone, I begin the presentation on *Chemical of the Week* sulfuric acid [11]. The previous week's discussion of sulfur dioxide has given the necessary background information for this chemical. As the number one chemical produced in the world [12], its major uses are mentioned: 60% in the manufacture of phosphoric acid (which is then used in making fertilizer), and the remaining amount in steel manufacturing, the oil and chemical industries, and in automobile batteries.

The production process, starting from sulfur to SO_2 , to SO_3 , to $H_2S_2O_7$ and finally to H_2SO_4 , is mentioned along with the need for the vanadium(V) oxide catalyst and the intermediate production of $H_2S_2O_7$. Because 40% of the SO_2 produced worldwide comes from the roasting of sulfide ores, the need to locate sulfuric acid plants near roasting plants is mentioned. This communicates to the students the interrelationship of one industry with another.

At the end of the lecture, some of sulfuric acid's physical properties are mentioned: its viscosity, heat of solution, and avidity for water, and thus its dehydrating properties. This is a

place where a demonstration dehydrating sugar can be performed if ventilation is available.

Ammonia

Although sulfuric acid on a mass basis is the number one produced chemical in the world, ammonia wins the award on a mole basis although it is the number five chemical on a mass basis [12, 13]. Although ΔH_f° for ammonia is -46.1 kJ/mol, the slowness of the reaction forming it is related to the triple bond of the dinitrogen molecule and thus the need for a catalyst. The Haber process is discussed along with Haber's winning of the 1918 Nobel Prize for the discovery of the process. The reaction is presented along with material on how the other starting material, dihydrogen, is produced from natural gas, which is plentiful in Oman!

The discussion of ammonia gives an opportunity to give the first "Rich and Famous" lecture. The Haber process produces ammonia industrially at 200 atm and 400 °C. However, bacteria containing the enzyme nitrogenase are able to fix nitrogen at ambient temperature and 0.8 atm. Energetically this is much more favorable and would be welcomed industrially. The key to designing the new and wonderful catalyst may lie in understanding the structure and function of nitrogenase. The challenge is that "all" students have to do is make a model system of nitrogenase that would fix nitrogen at ambient conditions and they would be rewarded with riches and fame. Though tongue-in-cheek, this discussion communicates some currently active areas of research and their potential benefits. A model of the proposed active site of nitrogenase is shown [14] and a brief summary of the progress that has been made over the last twenty years is given.

The remaining time is spent describing the uses of ammonia in the production nitric acid, fibers, and plastics and its use as a fertilizer. Relating the cost of fertilizers to the cost of ammonia, which is related to the cost of natural gas, the feedstock for H_2 , shows the interrelationship of various world commodities.

Nitric Acid

After the discussion of ammonia, nitric acid is the Chemical of the Week, ranking number twelve by mass on world production charts [12, 15]. Although its ΔH_f° is quite negative (-174.1 kJ/mol), it is never made from the elements because of the inertness of the dinitrogen molecule. Otherwise, the world's oceans would be converted to dilute nitric acid as dinitrogen reacted with dioxygen. The older synthetic method using sulfuric acid and sodium nitrate is mentioned, but the synthesis of nitric acid by the Ostwald process is briefly detailed. Physical properties are mentioned and briefly compared to sulfuric acid. Nitric acid's oxidizing properties and reactions with all metals except the noble metals are mentioned, along with the production of *aqua regia*. Due to these oxidizing properties HNO_3 , able to dissolve the various metal fission products, is used in reprocessing nuclear fuel rods. Its use in explosives such as nitroglycerin and TNT is briefly mentioned, including the discovery of dynamite by Alfred Nobel.

Phosphoric Acid

Clear, syrupy phosphoric acid is the seventh most produced chemical in the world; its precursor is calcium phosphate [16]. Reactions are given for obtaining P_4 , P_4O_{10} , and finally H_3PO_4 . This gives opportunity to read the humorous description of how phosphorus was first prepared by Brandt of Hamburg, Germany in 1669: "Take a Quantity of Urine (not less for one Experiment than 50 or 60 Pails full); let it lie steeping in one or more Tubs, ... till it putrefy and breed Worms, as it will do in 14 or 15 days...." [17]. Students are greatly amused by this synthetic method and see that experimental chemistry has come a long way in 300 years!

The heating of phosphoric acid to make pyrophosphoric acid and triphosphoric acid is mentioned, along with their anions, $P_2O_7^{3-}$ and $P_3O_{10}^{5-}$. Use of phosphates in detergents is mentioned along with the resulting environmental problems. Use of phosphates in the body, such as hydroxyapatite in tooth enamel, are discussed along with the substitution of the hydroxyl group with fluoride to make the compound fluorapatite, which is much more resistant to decay. The main uses of phosphoric acid in the production of fertilizer and in the food industry are noted. Most students are surprised to find that it is used extensively in carbonated beverages where the concentration may be as high as 0.05% in various cola drinks. (Another reason for fluorapatite in the tooth enamel—so one's teeth don't dissolve!)

Lead

Everyone is familiar with the element lead but few of the students are aware of some of its toxic properties or its ubiquity in modern life [18]. After mentioning lead's physical properties, the two steps of its production, roasting and then reduction with a reducing agent like carbon, are discussed. The main uses of lead in batteries, gasoline, and chemicals like paints are discussed. This leads to a discussion of leaded gasoline. Although most western countries have stopped the use of lead in gasoline, most developing countries (Oman included) are still using leaded gasoline. Widespread use of the gasoline additive tetraethyllead, discovered in the early 1920s, has caused the ubiquitous distribution of lead in modern life. Again, the two questions: "Where does it go?" and "What does it do when it gets there?" are asked. The repetition of these questions causes the students to ask themselves these questions regarding more local issues such as dumping of toxic wastes in the desert and the nonrecycling of aluminum cans.

The second week's discussion focuses on lead poisoning and the effects of elevated blood lead levels. Due to increased knowledge about the effects of lead, the maximum recommended blood lead level has decreased considerably to a value of <10 $\mu\text{g/dL}$ [19] compared to the maximum recommended value twenty-five years ago of 40 $\mu\text{g/dL}$. Discussion moves to a folk medicine practice in Oman and other Gulf states where 2–4-month-old infants are given small amounts of the ground up, golden-colored mineral *Bint Al-Dhahab* (Daughter of Gold) to help cure colic and other stomach ailments. Many students are aware of this practice, which is diminishing in Oman. What they don't realize is that *Bint Al-Dhahab* is 91% PbO [20]! In one study done on Omani

infants, blood lead levels ranging from 73 to 953 $\mu\text{g}/\text{dL}$ were found [21].

A second area of potential lead poisoning is from pottery with lead based glazes. A fascinating story is told of how supposedly innocuous Italian pottery caused lead poisoning of an air force officer and his wife [22]. The essence of this story is that the cause of severe body pain was at first diagnosed as a blood disorder, acute intermittent porphyria, but was later found to be lead poisoning. The source of the lead was traced to the dishes they had purchased in southern Italy. In tests, all of the pottery released lead but hot coffee in the pottery cups released 8 mg/dL of lead and each patient had drunk 8 cups of coffee per day! Since many of the students are premedical students, they find the story very germane to their futures.

Mercury

Mercury is another familiar element but few realize the toxicity of its vapor and its compounds [23]. The properties of the element are given along with its production from cinnabar, which is another potential example of SO_2 pollution. A primitive method of preparing the element is mentioned: cinnabar is heated in a fire of brushwood, the mercury vapor condenses on the brush, falls to the ground, and is then collected. Uses of mercury in dental and other amalgams, fluorescent bulbs, and mercury-vapor lights are mentioned.

The second week is used to talk about the toxicity of mercury [24]. The high vapor pressure is mentioned and the danger from breathing the fumes as evidenced by people like Isaac Newton and Alfred Stock who suffered from mercury poisoning. The use of mercury(I) chloride as a treatment for syphilis and other ailments is mentioned and is contrasted with the deadly poison mercury(II) chloride. The symptoms of mercury poisoning are mentioned such as headache, tremors, loss of memory, reason, and motor control. This leads to the expression "mad as a hatter" since felt hat makers used mercury compounds to soften the fur and thus showed symptoms of mercury poisoning.

The topic of mercury poisoning has special interest in Oman since there is a widely observed folk medicine practice where people drink small amounts of liquid mercury to protect themselves from curses and sorcery. Everyone seems to have heard of people who practice sorcery and know of people who have drunk mercury as a means of protection. It is common to be able to buy 5-mL vials in the *souks* (markets) in the interior of the country. Thirty years ago it was common to treat various illnesses by putting the patient in a closed room with a small fire and placing mercury in the fire so that the person could breathe the vapor and thus be cured of the disease [25]. It is stressed that all compounds of mercury are toxic, easily absorbed, and hard to eliminate from the body.

Some time is spent on methylation of mercury by bacteria to form methylmercury [26]. A diagram of the mercury cycle is shown and how supposedly "inert" liquid mercury from industrial processes in the sediment of lakes can be methylated and thus be taken up by fish [23]. Reports of the mercury disaster in Minamata, Japan in 1952 is mentioned along with poisonings of people in Iraq and the United States who had eaten seeds which had been coated with a mercury based fungicide.

Cisplatin

The last chemical, cisplatin, presents an opportunity to discuss the idea of serendipity in chemical discovery [27]. Since most students believe that science always follows a systematically planned approach, this gives a chance to mention how often discoveries of great importance have been serendipitous. Goodyear's vulcanization process in 1839 and Plunkett's discovery of Teflon in 1938 are examples that have had great practical importance [28]. The structures of the cis and trans isomers of diamminedichloroplatinum(II) are shown and it is mentioned that only the cis isomer is active as an anticancer drug. This leads into a brief history of the use of metal compounds of mercury, arsenic, and antimony in the treatment of disease and bacterial infections.

Barnett Rosenberg had been fascinated by the visual similarity of cell division and magnetic fields generated by a flowing current. This led him to conduct experiments where electric current was passed through *E. coli* cells, using electrodes of "inert" platinum [29]. To his amazement, the cells became elongated but cell division was stopped, a process called filamentous growth (an uncommon but known cell behavior). This led to a laborious investigation to find out what active agent was inhibiting cell division, which was discovered to be cis diamminedichloroplatinum(II), a compound known since 1845. However, there was no reason to test it as an anticancer drug until Rosenberg's unusual experiment and subsequent discovery. Students find it a fascinating story of how science often works. The proposed reason for the cis isomer's activity is discussed, namely the ability of the cis isomer to bind to adjacent guanine bases along one DNA strand and the subsequent disruption of DNA replication [30].

Super-Cooled Protein-Lipid-Saccharose Globules

Another chemical discussed, if time permits, is super-cooled protein-lipid-saccharose globules or ice cream. This demonstration/hands-on student activity is best done two-thirds of the way through the semester, which allows one to build on the enthusiasm generated through the activity. The first part of the lecture involves traditional demonstrations with liquid nitrogen: frozen flowers, bananas, erasers, and balls that shatter when dropped. This moves into a time where each student makes a small amount of ice cream in a styrofoam cup [31]. The liquid nitrogen acts as both a coolant and a source of fine bubbles of gas, which makes a good quality ice cream. We have found that 2 liters of the milk-cream mixture will allow up to 35 students to each make some ice cream. The ice cream mixture is pre-made and brought into the lecture with the other materials.

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