Course information:
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1. Course name: Modern Chemical Principles I
2. Department: CHM
3. Number: 155
4. Cluster requirement: Science of the Natural World

Faculty information:
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Required components:
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8. Master syllabus: http:///webroots/www.umassd.edu/genedchecklist/holding/chm155universitystudies.pdf
9. Course overview statement:
The main purpose of the course is to learn the fundamental principles of chemical sciences, any examination of which begins with the process of scientific inquiry and the scientific method. These principles are dealt with in a conceptual context first, and then the concepts are applied to problem solving in a computational manner. In addition, these concepts are examined in the context of real world applications and problems, including but not limited to fuels and energy sources, global warming, pollutants and pharmaceuticals. Through homework, quizzes and exams that are not simple multiple choice but rather short answer and multi-step computations, all of the University Studies Learning Outcomes are tested and reinforced.
10. Signed faculty and chair sponsor sheet: sent separately.
11. Official course catalog description for the course:
CHM 155 - Modern Chemical Principles I
3 credits S
4 hours lecture and recitation
Prerequisites: High school chemistry and algebra; and satisfactory score on departmental placement examination
Corequisites: MTH 131 or 111, CHM 163
Physical and chemical principles pertaining to the structure of chemical species and the nature, extent, and rates of chemical reactions. The details of stoichiometry, energy changes associated with chemical reactions, atomic and molecular structure, chemical bonding, and the phenomenon of chemical periodicity are emphasized and discussed in light of modern scientific theories. For science and engineering majors. Non-honors sections are offered.

MASTER SYLLABUS

Course Overview:

The course covers units and dimensional analysis, significant figures, atomic theory, isotopes, the periodic table, the mole, formulas, stoichiometry, balancing equations, limiting reagents, states of matter, solutions, precipitation, acid-base reactions, oxidation-reduction reactions, gas laws, the ideal gas law, kinetic theory of gases, non-ideal gases, energy, enthalpy, Hess's law, bond dissociation energy, fuels, light, quantum theory, atomic orbitals, electron configuration, periodic trends, bonding, Lewis structures, valence shell electron pair repulsion, hybridization, and molecular orbitals among other topics.

The course stresses the scientific method and the application of scientific principles in complex problem solving with an emphasis on computations. Real world concepts like fuel and energy sources, global warming, pollutants, pharmaceuticals, etc. are discussed in the context of basic theories, with a particular emphasis on common misconceptions from the science illiterate. The assignments across the various sections of the course are largely problem-based homework, quizzes and exams.

Learning Outcomes:

Course Specific Learning Outcomes:

For students to gain a firm understanding of the fundamental principles of chemistry, including the scientific method, stoichiometry, chemical reactions, thermodynamics, atomic and molecular structure and bonding.

University Studies Learning Outcomes:

A. Science of the Natural World

After completing this course, students will be able to:

1. Recount the fundamental concepts and methods in one or more specific fields of science.
2. Explain how the scientific method is used to produce knowledge.
3. Successfully use quantitative information to communicate their understanding of scientific knowledge.
4. Use appropriate scientific knowledge to solve problems.

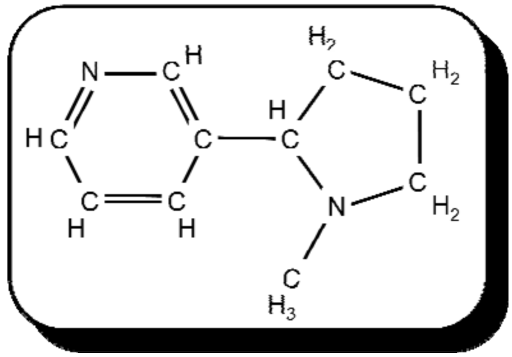
Texts:

General Chemistry by Darrell D. Ebbing and Steven D. Gammon, Houghton Mifflin, Boston, MA 02116, 9th edition, 2009.
Chemistry: The Central Science by Theodore L. Brown, H. Eugene LeMay, Jr., Bruce E. Bursten, Catherine J. Murphy, Patrick M. Woodward, Prentice Hall, New York, 12th edition, 2012.
General Chemistry by John E. McMurray and Robert C. Fay, Prentice Hall, New York, 2010.

Example Assignments:

Through homework, quizzes and exams that are not simple multiple choice but rather short answer and multi-step computations, all of the University Studies Learning Outcomes are tested and reinforced. Many examples of problems from homework, quizzes and exams are attached. To limit cheating over the course of years, these problems will not be reproduced exactly but similar problems will be utilized in the course. The course assessment is tied to the American Chemical Society (ACS) exam which is an inclusive multiple choice exam covering all aspects of the course. See the following pages for sample problems.

3. The molecule shown to the right is nicotine.
Based upon this molecular structure:



a. What is the **molecular formula** of nicotine?

$C_{10}H_{14}N_2$

b. What is the **empirical formula** of nicotine?

C_5H_7N

c. What is the **molar mass** of nicotine?

162.2 g/mol

d. How many nicotine **molecules** are there in 1.00 g of nicotine?

$$1.00 \text{ g nicotine} \times \frac{1 \text{ mol nicotine}}{162.2 \text{ g nicotine}} \times \frac{6.022 \times 10^{23} \text{ molecules nicotine}}{1 \text{ mol nicotine}} = 3.71 \times 10^{21} \text{ molecules nicotine}$$

e. How many **hydrogen atoms** are there in 1.00 g of nicotine?

$$3.71 \times 10^{21} \text{ molecules nicotine} \times \frac{14 \text{ atoms H}}{1 \text{ molecule nicotine}} = 5.20 \times 10^{22} \text{ atoms H}$$

f. What is the **% composition** of hydrogen in nicotine?

14.11 g/14 mol H ÷ 162.2 g/mol nicotine × 100 = 8.6 %

8. The Haber-Bosch process is the most important industrial chemical process in the world. It is used to produce fertilizer, without which, there would only be enough food to feed about half of the global population. The process takes dinitrogen (N_2) and dihydrogen (H_2) and converts them to ammonia (NH_3). If this reaction is performed utilizing 3.50 g of N_2 and 0.60 g of H_2, resulting in 2.70 g of NH_3. What was the percent yield of the reaction?

(Molar Mass: N_2 = 28.0 g/mol; H_2 = 2.0 g/mol; NH_3 = 17.0 g/mol)

___ N_2 (g) + _3_ H_2 (g) → _2_ NH_3 (g)

3.50 g N_2 × (1 mol/28.0 g) = 0.125 mol N_2 ÷ 1 = 0.125

0.60 g H_2 × (1mol/2.0 g) = 0.30 mol H_2 ÷ 3 = 0.100 → **H_2 is Limiting**

0.300 mol H_2 × (2 mol NH_3/3 mol H_2) × (17.0 g/mol) = 3.40 g NH_3

2.70/3.40 × 100 = **79.4 % Yield**

3. (For the past 100+ years, gases have been an important component in refrigeration systems. They are known as refrigerants, and must possess specific properties (densities, boiling points, etc.)

   a. At the turn of the twentieth century, the most common refrigerant was ammonia (NH_3). The use of ammonia as a refrigerant was eventually phased out because of its toxicity. 0.273 moles of ammonia was confined in a volume of 1.75 liters at a temperature of 300K. (Mol Wt: NH_3 = 0.01703 **kg**/mol)

      i. What is the pressure of NH_3?

$$P = nRT/V = \frac{(0.273\text{ mol})(0.08206\text{ Latm/molK})(300\text{K})}{(1.75\text{ L})} = 3.84\text{ atm}$$

      ii. What is the speed of a NH_3 molecule in m/s?

$3/2\ RT/N_A = ½\ mv^2$

$3/2\ RT = ½\ Mv^2$

$v = \sqrt{(3(8.314\text{ J/molK})(300\text{ K})/(0.01703\text{ kg/mol})}$

$v =$ **663 m/s**

   b. To avoid the toxicity of early refrigerants, DuPont developed a series of compounds known as Freons. Freon-12 (CF_2Cl_2) was the most commonly used. Freon-12 stored at a pressure of 46.0 kPa and a temperature of 45 °C occupies 3.94 L. How many moles of Freon-12 are present? (Mol Wt: CF_2Cl_2 = 120.91 g/mol)

$$n = PV/RT = \frac{((46.0/101.3)\text{ atm})(3.94\text{ L})}{(0.08206\text{ Latm/molK})(318\text{K})} = 0.0686\text{ mol}$$

c. The use of Freon-12 was discontinued because it is a chlorofluorocarbon (CFC) and it depletes the ozone layer. The most commonly used refrigerant today is Freon-23 (CHF_3). 140.0 g of Freon-23 is stored at a pressure of 1.00 atm and takes up a volume of 0.0500 m^3.
(Mol Wt: CHF_3 = 70.01 g/mol)

i. What temperature is the Freon-23 stored at?

140.0 g × (1 mol/70.01 g) = 2.00 mol
0.0500 m^3 × (10^3/L) = 50.0 L

$$T = PV/nR = \frac{(1.00 \text{ atm})(50.0 \text{ L})}{(2.00 \text{ mol})(0.08206 \text{ Latm/molK})} = 305 \text{ K}$$

ii. What is the relative rate of effusion of Freon-23 to Freon-12?

1. ^{99}Tc is a radioactive isotope of Technetium that emits low-energy gamma rays which are used to image the heart. The gamma rays emitted by ^{99}Tc have an energy of 2.24×10^{-15} J.

    a. What is the frequency of this radiation?

    $E = h\nu$

    $\nu = E/h = 2.24 \times 10^{-15}\ J/6.626 \times 10^{-34}\ Js =$ **3.39×10^{18} Hz**

    b. What is the wavelength (in m) of this photon?

    $\lambda\nu = c$

    $\lambda = c/\nu = 3.0 \times 10^{8}/3.38 \times 10^{18} =$ **8.9×10^{-11} m**

5. Arrange the following atoms from lowest to highest ionization energy

Sb, Rb, Xe, Te, Ar, Cs, Sr

Cs < **Rb** < **Sr** < **Sb** < **Te** < **Xe** < **Ar**

6. Electron affinities for Group 13 to Group17 elements are shown below.

Gp	**13**	kJ/mol	**14**	kJ/mol	**15**	kJ/mol	**16**	kJ/mol	**17**	kJ/mol
	B	37	**C**	122	**N**	-7	**O**	141	**F**	328
	Al	43	**Si**	134	**P**	72	**S**	200	**Cl**	349
	Ga	29	**Ge**	116	**As**	78	**Se**	195	**Br**	325
	In	29	**Sn**	116	**Sb**	103	**Te**	190	**I**	295
	Tl	19	**Pb**	35	**Bi**	91	**Po**	183	**At**	279

a. Note the general trend as you go across (left to right) the periodic table and explain it

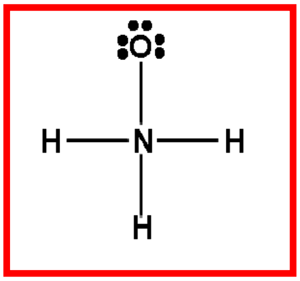
The electron affinity generally increases across the periodic table. This is because the effective nuclear charge (Z_{eff}) increases from left to right. This is because of an increase in the number of valence electrons, which shield poorly. The higher Z_{eff} results in a greater attraction for electrons, and makes it easier for the atom to form an anion.

b. Note instances that go against this trend and explain them.

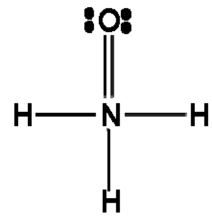
There is often a drop in electron affinity when moving from group 14 to group 15, which goes against the general trend. Adding an electron to an atom in group 15 would result in a p^4 configuration. The p^4 configuration brings the additional destabilization from the pairing of two electrons in a single orbital. This is the coulombic energy of repulsion (Π_c).

7. For each formula below, determine which Lewis structure is preferred and circle it? Briefly explain why you chose that Lewis structure.

a. H_3NO

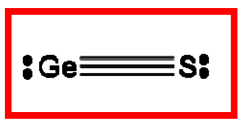


vs.



The structure on the left is the preferred structure. The structure on the right has zero formal charge, but nitrogen has 10 electrons. Second row elements cannot have an expanded shell of more than eight electrons.

b. GeS



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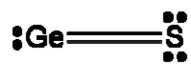
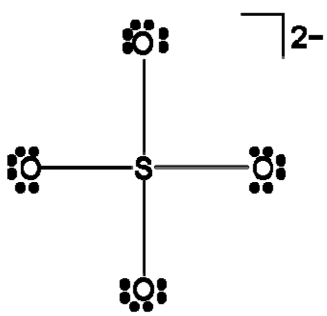
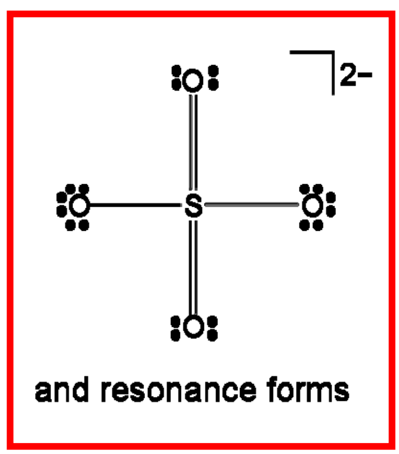


The structure on the left is the preferred structure. The structure on the right has zero formal charge, but the germanium atom only has six electrons around it. The structure on the right satisfies the octet rule.

c. SO_4^{2-}



vs.



The structure on the right has zero formal charge. The expanded shell of the central atom is acceptable in this case because sulfur is in the third row.

Chlorine trifluoride ($ClF_3(g)$) is prepared by the reaction of chlorine ($Cl_2(g)$) and fluorine ($F_2(g)$).

a. Write a balanced equation for this reaction. Label the oxidation state of every atom in the equation, and label which compound is the oxidant and which is the reductant.

$Cl_2(g)$ (reductant) + 3 $F_2(g)$ (oxidant) → 2 $ClF_3(g)$

Oxidation States: Reactants – Cl = 0 F = 0; Products – Cl = +3 F = –1

b. Chlorine trifluoride is used to treat "spent" fuel rods from nuclear plants, by treating uranium (U(s)) with chlorine trifluoride to generate uranium hexafluoride ($UF_6(g)$) and chlorine fluoride (ClF(g)).

i. Write a balanced equation for this reaction.

U(s)+ 3 $ClF_3(g)$ → $UF_6(g)$ + 3 ClF(g)

ii. 390 mL of fluorine gas (P = 345 torr and T = 286 K) is treated with excess chlorine to generate chlorine trifluoride (reaction in part a.). All the generated chlorine trifluoride is used to treat 500 mg of uranium (reaction from part b.). What volume of uranium hexafluoride is generated at 350K and 1.75atm? (assume 100% yield on all reactions)

345 torr × (1 atm/760 torr) = 0.454 atm

n = PV/RT = (0.454 atm)(0.390 L)/(0.08206)(286 K) = 7.54×10^{-3} mol F_2

7.54×10^{-3} mol F_2 × (2 mol ClF_3/3 mol F_2) = 5.03×10^{-3} mol ClF_3 ÷ 3 = 1.68×10^{-3}

0.500 g U × (1 mol U/238.0 g U) = 2.10×10^{-3} mol U

ClF_3 limiting

5.03×10^{-3} mol ClF_3 × (1 mol UF_6/3 mol ClF_3) = 1.68×10^{-3}mol UF_6

V = nRT/P = (1.68×10^{-3}mol)(0.08206)(350K)/(1.75 atm) = **0.0276 L UF_6**

Old black and white photography used film consisting of celluloid strips containing grains of silver bromide. When light hits the grains of silver bromide, it facilitated the following reaction.

$$AgBr \rightarrow Ag + \tfrac{1}{2}\, Br_2 \qquad \Delta H^\circ = 100 \text{ kJ/mol}$$

The silver was then treated to generate the picture that is observed. What is the minimum frequency that light must possess for the formation of silver metal to occur?

$E = 100 \text{ kJ/mol} \times (1 \text{ mol}/6.022 \times 10^{23} \text{ molecules}) = 1.66 \times 10^{-22} \text{ kJ} = 1.66 \times 10^{-19} \text{ J}$

$E = h\nu$

$\nu = E/h = (1.66 \times 10^{-19} \text{ J})/(6.626 \times 10^{-34} \text{ Js}) =$ **2.50×10^{14} Hz**

Sample Course Outline:

Lecture 1	Units and Dimensional Analysis
Lecture 2	Significant Figures and Atomic Theory
Lecture 3	Isotopes and Simple Bonding
Lecture 4	Periodic Table
Lecture 5	Mole and Formula
Lecture 6	Stoichiometry
Lecture 7	Balancing Equations
Lecture 8	Limiting Reagents
Lecture 9	States of Matter and Solutions
Lecture 10	Precipitation and Solubility
Lecture 11	Acid-Base Reactions
Lecture 12	Acid-Base Reactions
Lecture 13	Oxidation/Reduction Reactions
Lecture 14	Oxidation/Reduction Reactions
Lecture 15	Gas Laws
Lecture 16	Ideal Gas Law
Lecture 17	Ideal Gas Law
Lecture 18	Kinetic Theory of Gases
Lecture 19	Non-Ideal Gases
Lecture 20	Energy
Lecture 21	Heat Transfer
Lecture 22	Enthalpy
Lecture 23	Hess's Law
Lecture 24	Standard Enthalpy
Lecture 25	Bond Dissociation Energy
Lecture 26	Fuels
Lecture 27	Light
Lecture 28	Bohr Atom and Uncertainty Principle
Lecture 29	Quantum Theory
Lecture 30	Quantum Theory
Lecture 31	Atomic Orbitals
Lecture 32	Aufbau Principle and Hund's Rule
Lecture 33	Electron Configuration
Lecture 34	Periodic Trends
Lecture 35	Periodic Trends
Lecture 36	Bonding
Lecture 37	Lewis Structures
Lecture 38	Valence Shell Electron Pair Repulsion
Lecture 39	Electronic and Molecular Geometry
Lecture 40	Hybridization
Lecture 41	Molecular Orbitals
Lecture 42	Molecular Orbitals