Assessment of General Chemistry Course

Samar Ayesh, Ph.D.
Unit Level Liaison for Dept. of Physical Science

When I took over the Assessment Liaison role for the Chemistry courses within the Physical Science department, in fall of 2019, it was clear to me and others teaching CHEM 201 that student learning seems to be missing some important component. The results of the ACS assessment tool, that was previously used by the faculty, clearly indicated the areas that students are challenged. So, I started designing several “Learning Activities” which were meant to engage students in exploring the big ideas and concepts in order to develop the desired understandings, knowledge, and skills that they should come away knowing by taking CHEM 201. These activities were meant to be used in the classroom, and since we went back face-to-face instruction from fall 2021, I’ve been using them in my sections.

Along side the “Learning Activities”, I also decided to examine the course SLOs more closely. The first steps towards an effective assessment plan is to establish goals and develop specific measurable learning outcomes. It is very important to first determine what we faculty expect students to learn. The master syllabus for the course shows only 16 student learning outcomes. So, based on the topics/concepts that are taught in CHEM 201, I wrote a specific SLO for each topic/concept. This came to 56 SLOs covering 13 chapters. Then, using Wiggins and McTighe's "Understanding by Design", and with the help of faculty teaching CHEM 201, we classified the SLOs as critical, important, or desirable, based on the following definitions:

• Critical outcomes (CRO) are considered to be vital and of fundamental importance. They are outcomes in which an enduring understanding is needed, such that students will remember them long after the details have faded.

• Important outcomes (IMO) are more specific and pertain to ideas or skills that the student must know or be able to do. Student learning is incomplete without mastery of these essentials.

• Desirable outcomes (DO) are recognized as worth knowing, but the aim is exposure, not mastery.

Appendix 1 shows a list of these SLOs that are covered throughout CHEM 201. The first column is based on the survey conducted by Allan Wilson in 2017. It shows the number of faculty teaching a specific topic.

Designing and Conducting the Assessment (Spring 2022-Spring 2023)

Since we were able to classify our SLOs for CHEM 201, I wrote questions that should assess how much our students have learned during the semester for each of the SLOs. The initial assessment consisted of 25 multiple choice questions and was given online during spring/summer/fall of 2021. A total of 70 students in 4 different sections took this assessment. I revised the assessment in spring of 2022 and added 2 more questions. The revised assessment consisting now of 27 multiple choice questions was given in-person since spring 2022 semester. The data shown below summarizes the results of the assessment given over 4 different semesters. A total of 67 students in 5 different sections took this assessment. The data collected was studied and analyzed below.

Data Analysis

The following table summarizes the results for the studied SLOs. The table shows each of the SLO studied, it's classification as either: critical, important or desired outcome, the question number used from the Assessment tool (provided in Appendix 2 below), and the number of students who got the answer correct.

SLO	Classification	Question(s) #	% Correct
Understand the Nuclear Model of the Atom	CRO	4 5	61.2 61.2
Understand the nature and importance of isotopes.	DO	7	94.0
Apply derived units, such as volume and density, to perform calculations.	CRO	2	61.2
Apply Bohr's theory of the hydrogen atom to calculate energy levels.	CRO	8	46.3
Utilize rules of nomenclature to name the different types of compounds including: **ionic compounds**, covalent compounds, oxoacids, and hydrates.	CRO	1	61.2
Determine the empirical formula of a compound from **percent composition** or from combustion analysis data.	CRO	11	64.2

Identify the limiting reactant in a reaction.	CRO	12 13	41.8 71.6
Use the relationship between Avogadro's number, moles, molar mass, and grams to perform calculations.	CRO	9	74.6
Calculate the molarity of a solution and molarity of ions in solution.	CRO	16	73.1
Use the ideal gas equation to determine the pressure, volume, moles, or temperature of a given all of the other values.	CRO	25	55.2
Apply dimensional analysis toward solving problems with multiple steps or conversions.	CRO	26	88.1
Apply oxidation number rules toward determining the oxidation number of each element in a compound or polyatomic ion.	IMO	18	44.8
Define resonance and determine the resonance structures of a species.	CRO	19	6.0
Determine the Lewis structures of species that do not follow the octet rule, including radicals.	CRO	20	64.2
Use the valence-shell electron pair repulsion (VSEPR) model to determine the shape of a molecule.	CRO	21 22	44.8 37.3
Predict the hybridization of molecules to explain bonding in molecules.	CRO	24	77.6
Determine amounts of reactant required or product formed using stoichiometry.	CRO	14 **15**	88.0 7.5

Conclusion and Future Work:

Looking back at the results, it is clear that more work needs to be done to improve the results of the students learning outcomes that we classified as critical outcomes. Topics such as resonance structures, molecular geometry and hybridization, limiting reactant and stoichiometry, and oxidation numbers show a success of less than 60%. My plan is to further develop lessons to help students understand these topics better.

Appendix 1: SLO Classification as Critical, Important, or Desired

Student Learning Outcome	SLO Classification
1. Apply derived units, such as volume and density, to perform calculations.	**CRO**
2. Utilize conversion factors to conduct unit conversions.	**CRO**
3. Apply dimensional analysis toward solving problems with multiple steps or conversions.	**CRO**
4. Utilize SI unit prefixes.	**CRO**
Calculate the average atomic mass of an element given the atomic mass and relative abundance of each of its naturally occurring isotopes.	**DO**
1. Determine the empirical formula of a compound from percent composition or from combustion analysis data.	**CRO**

2. Determine the empirical formula of a compound using combustion analysis data.	**DO**
3. Utilize the empirical formula and molar mass to determine the molecular formula of a compound.	**IMO**
Identify weak and strong acids and bases.	**DO**
Apply oxidation number rules toward determining the oxidation number of each element in a compound or polyatomic ion.	**IMO**
Calculate the molarity of a solution and molarity of ions in solution.	**CRO**
Apply Bohr's theory of the hydrogen atom to calculate energy levels.	**CRO**

1. Use the ideal gas equation to determine the pressure, volume, moles, or temperature of a given all of the other values.	**CRO**
2. Use the ideal gas equation in stoichiometric calculations.	**IMO**

Appendix 2: Assessment Tool

1. Which is NOT named correctly?

A. SnO_2 tin(II) oxide

B. $CoSO_4$ cobalt(II) sulfate

C. K_3PO_4 potassium phosphate

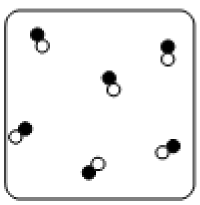
D. CaF_2 calcium fluoride

2. Which sample has the smallest volume? The density of aluminum is 2.70 g/cm^3, and the density of iron is 7.87 g/cm^3.

A. 1.0 g aluminum B. 5.0 g aluminum C. 1.0 g iron D. 5.0 g iron

3. Which microscopic representation best represents a diatomic gas only?

A.



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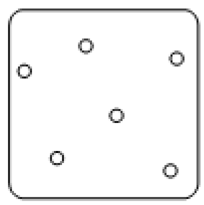

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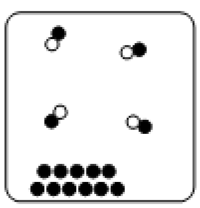

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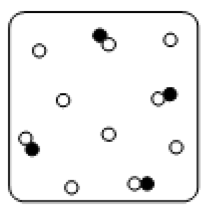


4. Which statement regarding the nucleus of an atom is correct?

A. The nucleus contains protons and neutrons and has no charge.
B. The nucleus contains protons and neutrons and is positively charged.
C. The nucleus contains protons and electrons and has no charge.
D. The nucleus contains protons and electrons and is positively charged.

5. How many protons, neutrons, and electrons are in the following isotope: $^{131}I^-$?

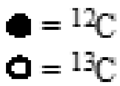
A. 131 protons, 53 neutrons and 54 electrons
B. 53 protons, 78 neutrons and 53 electrons
C. 53 protons, 78 neutrons and 54 electrons
D. 53 protons, 131 neutrons and 52 electrons
E. 78 protons, 53 neutrons and 72 electrons

6. Which pair of particles has the same number of electrons?

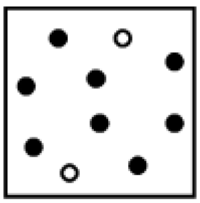
A. O^{2-} , Na^{+}　　B. N^{3-} , P^{3-}　　C. Br^{-}, Se　　D. Al^{3+}, P^{3-}

7. An enriched sample of carbon contains 20.0% ^{12}C and 80.0% ^{13}C. Which figure shows this sample?

Key:



A.



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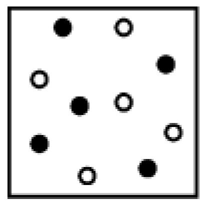
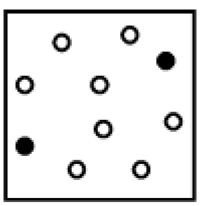
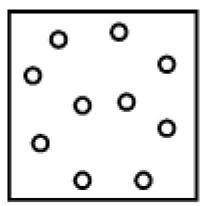


C.



D.



8. Which electronic transition in a hydrogen atom is associated with the smallest *emission* of energy?

$$\Delta E = R_H\left(\frac{1}{n_i^2} - \frac{1}{n_f^2}\right)$$

$R_H = 2.18\times10^{-18}$ J

A. $n = 2$ to $n = 1$　　B. $n = 1$ to $n = 2$　　C. $n = 2$ to $n = 3$
D. $n = 4$ to $n = 3$　　E. $n = 3$ to $n = 2$

9. What mass (in g) of oxygen is in 4.37×10^{-4} moles of $C_8H_{11}N_3O_3S$?

A. 2.10×10^{-2} g　　B. 3.12×10^{-2} g　　C. 4.20×10^{-2} g　　D. 1.84×10^{-2} g

10. What is the percent composition by mass of hydrogen in a 2.55 g sample of propanol, $CH_3CH_2CH_2OH$? The molar mass of propanol is 60.09 g·mol^{-1}.

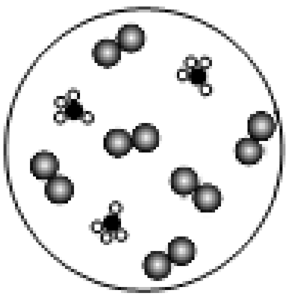
A. 11.7% H　　B. 33.9% H　　C. 13.4% H　　D. 60.0% H

11. A molecular compound is found to consist of 26.0% nitrogen and 74.0% oxygen. If the molecule contains 2 atoms of nitrogen, what is the molar mass of the molecule? (*Hint:* determine empirical formula of the compound)

A. 46 g/mol B. 92 g/mol C. 54 g/mol D. 108 g/mol

12. An initial state before reaction of CH_4 and Cl_2 is shown in the figure. Based on the balanced equation and the figure, what is the limiting reactant?

$$CH_4(g) + 4Cl_2(g) \rightarrow CCl_4(g) + 4HCl(g)$$



A. Cl_2 B. CCl_4 C. CH_4 D. not enough information is given.

13. What is the limiting reactant when 15.0 g of Fe and 15.0 g of carbon dioxide are allowed to react completely according to the following reaction:

$$2Fe(s) + 3CO_2(g) \rightarrow Fe_2O_3(s) + 3CO(g)$$

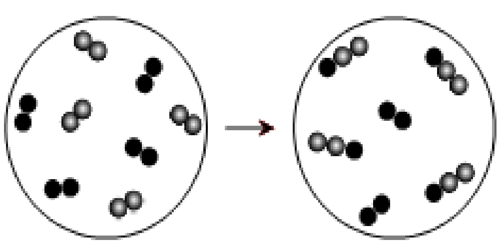
A. CO B. CO_2 C. Fe D. Fe_2O_3

14. What mass of CCl_4 (153.81 g/mol) is needed to produce 2.00 g of CCl_2F_2 (molar mass = 120.91 g/mol)?

$$3CCl_4 + 2SbF_3 \rightarrow 3CCl_2F_2 + 2SbCl_3$$

A. 2.54 g B. 0.848 g C. 7.63 g D. 1.69 g

15. What is a correct balanced equation for the reaction shown?



A. $N_2(g) + O_2(g) \rightarrow 2NO(g)$ B. $2N_2(g) + O_2(g) \rightarrow 2N_2O(g)$

C. $4N_2(g) + 4O_2(g) \rightarrow 4NO(g) + 2O_2(g)$ D. $4N_2(g) + 4O_2(g) \rightarrow 4N_2O(g) + 2O_2(g)$

16. What is the best procedure to prepare 0.750 L of a 0.500 M solution of Na_2SO_4? The molar mass of Na_2SO_4 is 142.05 g/mol.

A. Weigh 53.3 g of solute and add 0.750 L of water.
B. Weigh 142.05 g of solute and add sufficient water to obtain a final volume of 0.750 L.
C. Weigh 53.3 g of solute and add sufficient water to obtain a final volume of 0.750 L.
D. We do not have sufficient information.

17. What volume of 0.200 M $K_2C_2O_4$ is required to react completely with 30.0 mL of 0.100 M $Fe(NO_3)_3$?

$$2Fe(NO_3)_3 + 3K_2C_2O_4 \rightarrow Fe_2(C_2O_4)_3 + 6KNO_3$$

A. 10.0 mL   B. 15.0 mL   C. 22.5 mL   D. 30.0 mL

18. In which reaction is carbon oxidized?

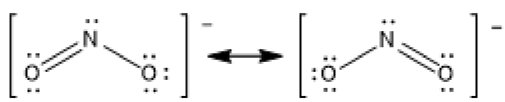
A. $CO_2(g) \rightarrow CO(g) + O_2(g)$

B. $H_2CO_3(aq) \rightarrow CO_2(g) + H_2O(l)$

C. $CO_2(g) + 2H_2O(l) \rightarrow CH_4(g) + 2O_2(g)$

D. $C_2H_4(g) \rightarrow C_2H_2(g) + H_2(g)$

19. Which statement best describes the bond length(s) in the nitrite ion (shown)? The bond length of N–O is 136 pm and N=O is 122 pm.

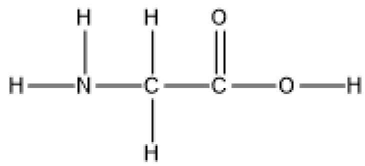


A. There is one bond length of 129 pm.
B. There is one bond length of 258 pm.
C. There are two bonds lengths where one bond is 136 pm, and the other is 122 pm.
D. There are two bonds lengths where the bonds oscillate between 122 pm and 136 pm.

20. Which is the best Lewis structure for nitrogen monoxide?

A.   B.   C.   D.

21. What is the molecular geometry around the N atom in the molecule depicted (lone pairs are not shown)?



A. t-shaped B. tetrahedral C. trigonal planar D. trigonal pyramidal

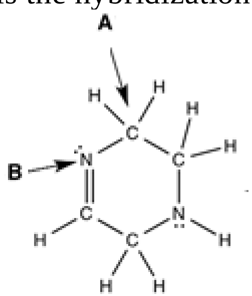
22. Which molecule has the smallest bond angle?

A. H_2O B. SO_4^{2-} C. SO_2 D. SO_3

23. Which molecule has polar bonds but is overall nonpolar?

A. SF_4 B. O_3 C. SO_2 D. NO_3^-

24. What is the hybridization of the indicated atoms below?



A. **A** is sp^3; **B** is sp^2 B. **A** is sp^2; **B** is sp^3

C. **A** is sp^2; **B** is sp^2 D. **A** is sp^3; **B** is sp^3

25. A 10.00 g sample of an unknown gas in a 20.0 L container at 75.0 °C exerted a pressure of 0.476 atm. What is the gas? $R = 0.08206$ (L·atm)/(mol·K)

A. NH_3 B. HCN C. NO D. NO_2

26. The average distance between the Earth and the Moon is 240,000 miles. Express this distance in kilometers. (1 mi = 1609 m)

A. 6.1×10^5 km B. 5.3×10^5 km C. 3.9×10^5 km D. 1.5×10^5 km

27. Given the following thermochemical reaction, how many grams of CaO must react in order to liberate 525 kJ of heat?

$$CaO(s) + H_2O(l) \rightarrow Ca(OH)_2(s) \qquad \Delta H^\circ_{rxn} = -64.8 \text{ kJ/mol}$$

A. 6.92 g B. 56.1 g C. 454 g D. 606 g E. 3.40×10^4 g