

**Title: Improving Student's Summative Knowledge of Introductory Chemistry through the Forward Testing Effect: Examining the role of Retrieval Practice Quizzes.**

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This document contains a sampling of questions used for each Retrieval Practice Quiz (RQ) compared to the During-term exams and the Final exam. The "Topics" are the RQ short names from Table 1 of the article, followed by the full topic list covered in the RQ.

A significant portion of the questions were multiple choice format; a few were numerical entries or select-all-that-apply formats.

All answer choices follow the question. The correct answer is highlighted in yellow and is listed first.

Permission to release a sample of questions from the DTEs and Final was obtained from the course instructor, Christopher Brewer.

Unit 1 material:

Topic: Dimensional (Dimensional analysis, density, significant figures, scientific notation)

During-term Exam question	Rewrite the following value in scientific notation: 0.000123 Answer options: <b>1.23 10<sup>4</sup></b> , 1.23 x10 <sup>6</sup> , 1.23 x10 <sup>4</sup> , 1.23 x10 <sup>-3</sup> , 1.23 x10 <sup>-6</sup>
Retrieval Quiz question	Express 9.13 x10 <sup>-2</sup> in decimal form. Answer options: <b>0.09130</b> , 0.0913, 0.00913, 913, 913.0  Which of the following metric conversions is incorrect? Answer options: <b>1 gram = 10<sup>3</sup> kilograms</b> , 1 mL = 1 cm <sup>3</sup> , 10 <sup>-3</sup> liters = 1 mL, 10 <sup>6</sup> microliters = 1 liter
Final Exam question	How many significant figures are in the measured value 0.12300 grams? Answer options: <b>5</b> , 2, 3, 4, 6

Topic: Properties (Chemical vs physical properties, states of matter)

During-term Exam question	A substance that has a definite volume, but no defined shape would be classified by which state of matter? Answer options: <b>Liquid</b> , Solid, Gas
Retrieval Quiz question	Which state of matter for an object has both definite shape and definite volume? Answer options: <b>solid state</b> , gas state, plasma state, liquid state  Which of the following would be classified as a nonmetal based on its position on the periodic table? A. Iron B. Sulfur C. Lithium D. Neon E. Thorium. Answer options: <b>B and D</b> , all are nonmetals, B only, D only, A C and E
Final Exam question	Combustion of a balloon containing hydrogen and oxygen to generate heat and water vapor would be a... Answer options: <b>Chemical Change</b> , Physical Change

Topic: Isotopes (Isotopes, protons, electrons, neutrons)

<p>During-term Exam question</p>	<p>Which of the following isotopes has the greatest number of neutrons (with respect to the other choices)?            Answer options: <math>^{134}\text{Xe}</math>, <math>^{128}\text{Te}</math>, <math>^{131}\text{I}</math>, <math>^{134}\text{Cs}</math>, <math>^{134}\text{Ba}</math></p> <p>How many protons are in a single (neutral) atom of <math>^{114}\text{Cd}</math>?            Answer options: 48, 64, 66, 112, 114</p> <p>How many neutrons are in a single (neutral) atom of <math>^{114}\text{Cd}</math>?            Answer options: 66, 48, 64, 112, 114</p> <p>How many electrons are in a single (neutral) atom of <math>^{114}\text{Cd}</math>?            Answer options: 48, 64, 66, 112, 114</p>
<p>Retrieval Quiz question</p>	<p>Which of the following is not a possible isotope?            Answer options: <math>^{27}_{14}\text{Al}</math>, <math>^{165}_{67}\text{Ho}</math>, <math>^{23}_{11}\text{Na}</math>, <math>^{41}_{19}\text{K}</math></p> <p>Oxygen has three main isotopes, <math>^{16}\text{O}</math> <math>^{17}\text{O}</math> <math>^{18}\text{O}</math>. How many total neutrons are there in the three isotopes?            Answer options: 27, 24, 51, 48</p> <p>How many protons, neutrons, and electrons (respectively) are in a molecule of <math>\text{H}_2\text{O}_2</math>?            Answer options: 18 16 18, 18 18 18, 18 34 18, 16 18 16, 16 16 16</p>
<p>Final Exam question</p>	<p>How many neutrons would be in a single (neutral) atom of <math>^{60}\text{Co}</math> isotope?            Answer options: 33, 60, 27, 58, 31</p>

Unit 2 material:

Topic: Naming (Nomenclature and chemical formulas)

During-term Exam question	<p>Provide the best name for <math>\text{Cd}(\text{ClO}_4)_2</math> Answer options: <b>Cadmium perchlorate</b>, Cadmium chloride, Cadmium (II) perchlorate, Cadmium (II) chloride, Cadmium (II) chlorate</p> <p>Provide the best name for <math>\text{KMnO}_4</math> Answer options: <b>Potassium permanganate</b>, Permanganic acid, Potassium manganite, Potassium permangan(VII) ate, Potassium monomanganese tetroxide</p> <p>Provide the best formula for hydrosulfuric acid Answer options: <b><math>\text{H}_2\text{S}</math></b>, <math>\text{H}_2\text{SO}_3</math>, <math>\text{H}_2\text{SO}_5</math>, <math>\text{H}_2\text{SO}_4</math>, <math>\text{H}_2\text{SO}</math></p> <p>Provide the best formula for chlorous acid Answer options: <b><math>\text{HClO}_2</math></b>, <math>\text{HClO}</math>, <math>\text{HCl}</math>, <math>\text{HClO}_4</math>, <math>\text{HClO}_3</math></p>
Retrieval Quiz question	<p>Which chemical formula represents silver phosphate? Answer options: <b><math>\text{Ag}_3\text{PO}_4</math></b>, <math>\text{Ag}_3\text{P}</math>, <math>\text{Ag}(\text{PO}_4)_3</math>, <math>\text{Ag}_3\text{PO}_3</math></p> <p>What is the correct name from <math>\text{SnCl}_2</math> ? Answer options: <b>Tin (II) chloride</b>, Tin (II) chlorite, Tin chloride, Tin dichloride</p> <p>What is the correct name for <math>\text{N}_2\text{O}_4</math> ? Answer options: <b>Dinitrogen tetroxide</b>, Nitrogen (IV) oxide, Nitrogen tetraoxide, Nitrogen oxide</p>
Final Exam question	<p>Provide the best name for <math>\text{ZrH}_2</math> Answer options: <b>Zirconium (II) hydride</b>, Hydrozirconic acid, Zirconium (I) hydride, Zirconium hydride, Hydrogen zirconide</p> <p>Provide the best chemical formula for copper (II) phosphide Answer options: <b><math>\text{Cu}_3\text{P}_2</math></b>, <math>\text{Cu}_3(\text{PO}_4)_2</math>, <math>\text{Cu}_3(\text{PO}_3)_2</math>, <math>\text{CuP}</math>, <math>\text{CuPO}_4</math></p>

\*\*Combined topics of Moles and Solutions:

During-term Exam question	<p>What mass of copper (II) acetate would be needed to prepare 800 mL of 0.36 M aqueous copper (II) acetate? Answer options: <b>52.3 g</b>, 35.3 g, 182 g, 403 g, 81.7 g</p>
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Topic: Moles (Empirical/molecular formulas, molecular mass, moles, molecules)

During-term Exam question	<p>How many molecules of carbon disulfide would be found in a 30 g sample of carbon disulfide?</p> <p>Answer options: <b>2.37 x10<sup>23</sup></b>, 4.10 x10<sup>23</sup>, 4.74 x10<sup>23</sup>, 7.12 x10<sup>23</sup>, 8.20 x10<sup>23</sup></p>
Retrieval Quiz question	<p>Which of the following is not a true relationship to 1 mole of Fe(NO<sub>3</sub>)<sub>2</sub> ?</p> <p>Answer options: <b>3 moles of ions</b>, 6 moles of oxygen, 179.87 g of iron (III) nitrate, 1.807 x10<sup>24</sup> molecules of iron (III) nitrate</p> <p>How many grams of Chlorine gas (Cl<sub>2</sub>) are required to react completely with 56.7 grams of sodium to produce NaCl? Hint: write a balanced reaction</p> <p>Answer – <i>students entered a numerical answer</i></p> <p>A rhenium and chloride compound is composed of 63.6% rhenium. What is the formula for this compound?</p> <p>Answer options: <b>ReCl<sub>3</sub></b>, ReCl, ReCl<sub>5</sub>, Re<sub>2</sub>Cl<sub>3</sub></p>
Final Exam question	<p>Homer Simpson has come up with his own refreshment, which he calls the Flaming Homer. Everyone enjoys it and everyone wants the recipe. In order to trick folks, he tells them the secret ingredient is an organic compound with a molar mass of 956.03 g/mol and provides a combustions analysis of 69.10% C and 5.80% H. what is the integer value that relates the empirical formula to the molecular formula?</p> <p>Answer options: <b>5</b>, 1, 2, 3, 4</p>

Topic: Solutions (Solutions and molarity calculations)

During-term Exam question	<p>Given a 2 M aqueous solution of cadmium chloride, what is the concentration of chloride anions in the solution?</p> <p>Answer options: <b>4 M</b>, 0.5 M, 1 M, 2 M, 3 M</p>
Retrieval Quiz question	<p>What volume in mL of 6.86 M CuSO<sub>4</sub> stock solution is needed to prepare a 0.9 L of 1.99 M CuSO<sub>4</sub> ?</p> <p>Answer – <i>students entered a numerical answer</i></p>
Final Exam question	<p>You have a large supply of 0.526 M aqueous sulfuric acid. You would like to prepare 834 mL of 0.444 M sulfuric acid. What volume of your 0.526 M sulfuric acid solution could you dilute to prepare you 834 mL of 0.444 M sulfuric acid?</p> <p>Answer options: <b>704 mL</b>, 755 mL, 666 mL, 594 mL, 280 mL</p>

Unit 3 material:

Topic: Trends (Periodic table trends, electron configurations and orbital notation)

<p>During-term Exam question</p>	<p>Which of the following ions has the smallest radius?            Answer options: <math>\text{Mg}^{2+}</math>, <math>\text{P}^{3-}</math>, <math>\text{F}^-</math>, <math>\text{N}^{3-}</math>, <math>\text{O}^{2-}</math></p> <p>Which of the following would be the best electron configuration for a neutral atom of scandium?            Answer options: <math>[\text{Ar}] 4s^2 3d^1</math>, <math>[\text{Ar}] 3d^1 4s^2</math>, <math>[\text{Ne}] 3s^2 3p^6 3d^2 4s^1</math>, <math>[\text{Ar}] 4s^3</math>, <math>[\text{Ne}] 3s^2 3d^1 3p^6 4s^1</math></p>
<p>Retrieval Quiz question</p>	<p>Which ion has the largest atomic radius?            Answer options: <math>\text{Se}^{2-}</math>, <math>\text{Sr}^{2+}</math>, <math>\text{Li}^+</math>, <math>\text{N}^{3-}</math></p> <p>Which of the following is the best ground state electron configuration for a neutral atom with an atomic number of 33?            Answer options: <math>1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^3</math>, <math>1s^2 2s^2 2p^6 3s^2</math>, <math>1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^3</math>, <math>[\text{Kr}] 4s^2 3d^{10} 3p^3</math></p>
<p>Final Exam question</p>	<p>Which of the following neutral atoms would you expect to have the most metallic character?            Answer options: <math>\text{Cs}</math>, <math>\text{P}</math>, <math>\text{Na}</math>, <math>\text{V}</math>, <math>\text{C}</math></p> <p>Which of these is the best ground state electron configurations for a neutral atom with an atomic number of 28?            Answer options: <math>[\text{Ar}] 4s^2 3d^8</math>, <math>[\text{Ne}] 3s^2 3p^6 3d^8 4s^2</math>, <math>[\text{Kr}] 4s^2 3d^8</math>, <math>[\text{Ar}] 4s^0 3d^{10}</math>, <math>[\text{Ar}] 4s^2 4d^8</math></p>

Topic: Redox (Redox reactions and oxidation numbers)

<p>During-term Exam question</p>	<p>For the next 2 questions, use this information: Let's say that you have a yellow solution of vanadium where all of your vanadium ions in solution are <math>\text{V}^{5+}</math> (+5 oxidation state). You dump into it a handful of granular zinc and the solution changed color to purple and all of the vanadium ions in solution are now <math>\text{V}^{2+}</math> (+2 oxidation state).            In this reaction, are the vanadium ions oxidized or reduced?            Answer options: <b>Reduced</b>, Oxidized</p> <p>How would you classify the zinc that was added to the solution?            Answer options: <b>Reducing agent</b>, Oxidizing agent</p>
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	<p>What is the oxidation number of a Phosphorus atom in <math>\text{POCl}_3</math> ?</p> <p>Answer options: +5, +2, +4, +3, -3</p>
Retrieval Quiz question	<p>Considering the molecule of aluminum dichromate, which of the following statements is false?</p> <p>Answer options: The aluminum atom has an oxidation state of +2, Each oxygen atom has an oxidation state of -2, The dichromate ion has a -2 charge, Each chromium atom has an oxidation state of +6</p> <p>In a molecule of Hydrogen peroxide, the oxidation state of a single hydrogen atom is {blank1} and the oxidation state of a single oxygen atoms is {blank2}. Be sure to include the sign of the value (example +3).</p> <p>Answer – <i>students entered a numerical answer</i></p>
Final Exam question	<p>Consider the reaction of europium metal with hydrochloric acid to generate hydrogen gas and europium (III) chloride. Which of the following atoms represents the reducing agent for this reaction?</p> <p>Answer options: Eu, Cl, H, None-This is not a redox reaction</p>

Topic: Solubility (Solubility and reaction types)

During-term Exam question	<p>Consider the reaction of aqueous solutions of sodium carbonate and hydrochloric acid. Write the net ionic equation. Which of the following would NOT be a spectator ion for this reaction?</p> <p>Answer options: <math>\text{CO}_3^{2-}</math>, <math>\text{Na}^+</math>, <math>\text{Cl}^-</math>, There are no spectator ions</p> <p><math>\text{Cu}(\text{ClO}_3)_2</math> would be...</p> <p>Answer options: Soluble, Insoluble</p>
Retrieval Quiz question	<p>A calcium nitrate solution is added to a sodium sulfate solution. What precipitate forms?</p> <p>Answer options: Calcium sulfate, Sodium nitrate, Sodium calcium, Nitrate sulfate, No precipitate</p>
Final Exam question	<p>Based on the solubility rules from lecture, <math>\text{AgCl}</math> would be ...</p> <p>Answer options: NOT soluble (in water), Soluble (in water)</p>

Unit 4 material:

Topic: Geometry (Geometry and formal charges)

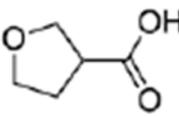
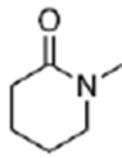
<p>During-term Exam question</p>	<p>What is the electron geometry from the carbon atom contained in box “i”? Answer options: <b>Tetrahedral</b>, Linear, Bent, Trigonal pyramidal, Trigonal planar</p> <p>What is the electron geometry of the carbon atom in box “ii”? Answer options: <b>Trigonal planar</b>, Linear, Bent, Trigonal pyramidal, Tetrahedral</p> <p>For the carbon atom contained in box “ii”, would your answer for the molecular shape be the same as the answer you indicated for electron geometry? Answer options: <b>Yes</b>, No</p>  <p>The image shows two Lewis structures of acetone (CH<sub>3</sub>-C(=O)-CH<sub>3</sub>). In the first structure, the methyl carbon atom is enclosed in a red box and labeled 'i.'. In the second structure, the carbonyl carbon atom is enclosed in a red box and labeled 'ii.'. Lone pairs are shown on the oxygen atom in both structures.</p>
<p>Retrieval Quiz question</p>	<p>What is the electron geometry of phosphorus trichloride? Answer options: <b>Tetrahedral</b>, Trigonal pyramidal, Trigonal planar, Bent, Trigonal bipyramidal</p> <p>What is the molecular shape of each carbon in ethanol (CH<sub>3</sub> – CH<sub>2</sub> – OH)? Answer options: <b>Tetrahedral/tetrahedral</b>, Tetrahedral/bent, Linear/linear, Trigonal planar/tetrahedral, Trigonal planar/trigonal planar, Tetrahedral/trigonal planar</p>
<p>Final Exam question</p>	<p>What is the molecular shape of a single molecule of PF<sub>3</sub>? Answer options: <b>trigonal pyramidal</b>, linear, trigonal planar, tetrahedral, bent</p>

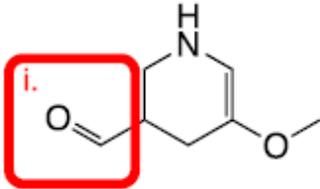


Topic: Acids (Acids, bases, buffers, electrolyte strength)

<p>During-term Exam question</p>	<p>Consider the acid/base reaction of nitric acid with water. Which species represents the conjugate acid?            Answer options: <math>\text{H}_3\text{O}^+</math>, <math>\text{HNO}_3</math>, <math>\text{H}_2\text{O}</math>, <math>\text{NO}_3^-</math></p> <p>Which of the following best classifies potassium nitrate when dissolved in water?            Answer options: <b>Strong electrolyte</b>, Weak electrolyte, Nonelectrolyte</p> <p>Which of the following classifies ammonia (<math>\text{NH}_3</math>)?            Answer options: <b>Weak base</b>, Strong acid, Strong base, Weak acid</p>
<p>Retrieval Quiz question</p>	<p>Which of the following are classified as a strong electrolyte? Select all that apply.            Answer options: <b>Strong acids, Strong bases, Salts</b>, Weak acids, Weak bases</p> <p>Which of the following compounds is the conjugate base of sulfuric acid?            Answer options: <b><math>\text{HSO}_4^-</math></b>, <math>\text{SO}_4^{2-}</math>, <math>\text{HS}^-</math>, <math>\text{S}^{2-}</math></p> <p>Which of the following species is amphoteric? Select all that apply.            Answer options: <b>Water, <math>\text{HSO}_4^-</math>, <math>\text{H}_2\text{PO}_4^-</math></b>, <math>\text{HNO}_3</math></p>
<p>Final Exam question</p>	<p>Which of the following compounds could you classify as a weak acid?            Answer options: <b><math>\text{HNO}_2</math></b>, <math>\text{HBr}</math>, <math>\text{HCl}</math>, <math>\text{HClO}_4</math>, <math>\text{H}_2\text{SO}_4</math></p>

Topic: Polarity (Intermolecular forces, polarity, functional groups)

<p>During-term Exam question</p>	<p>Which of the following contains an ester functionality?            Answer options:</p> <div style="display: flex; justify-content: space-around; align-items: center;">      </div> <p>Which of the following best classifies the C-Si interaction?            Answer options: <b>Polar covalent</b>, Ionic, Nonpolar covalent</p> <p>Which of the following best classifies the Te-Se interaction?            Answer options: <b>Nonpolar covalent</b>, Polar covalent, Ionic</p>
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<p>Retrieval Quiz question</p>	<p>Which of the following molecules are polar? Select all that apply.          Answer options: <b>Ammonia, Water</b>, Octane, Carbon disulfide</p> <p>What functional group does the molecule <math>\text{CH}_3 - \text{CH}_2 - \text{O} - \text{CH}_2 - \text{CH}_3</math> contain?          Answer options: <b>Ether</b>, Carbonyl, Ketone, Aldehyde, Alcohol</p> <p>What term best describes Iron (II) chloride?          Answer options: <b>Ionic</b>, Nonpolar covalent, Polar covalent, Hydrogen bonding</p>
<p>Final Exam question</p>	<p>Which of the following best represents the boxed functional group “i”?</p>  <p>Answer options: <b>aldehyde</b>, alcohol, ketone, carboxylic acid, ester</p>