Designing Effective Multiple-Choice Items in Chemistry

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Information About Michael

- Teaching high school chemistry since 1998
- My teaching style is a combination of lectures, demonstrations, interactive discussions, and hands-on activities
- I give the practice quiz (and explanations) before the real quiz
- YouTube Videos (Search for Michael Farabaugh)
- Reader for the AP Chemistry Exam since 2011
- Item Writer for the AP Chemistry Exam since 2014
Instructor at the University of Colorado, Colorado Springs

Taught HS chemistry (regular, Honors and AP) for 14 years

Teaching style includes dynamic lecture, Socratic questioning, demonstrations, particle drawing, and POGIL

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Reader for the AP Chemistry Exam since 2013

Item writer for the AP Chemistry Exam since 2016

Item writer for the ACS HS 2019 Exam
Outline of Tonight’s Webinar

- The Components of a Multiple-Choice Item
- Guidelines for Writing Multiple-Choice Items
- Suggestions for Improving an Existing Item
- The Process of Writing an Original Item
- Items Submitted by Webinar Participants
The Components of a Multiple-Choice Item

- Learning objective or standard
- Stimulus (e.g., graph, diagram, data table, etc.)
- Stem (the question itself)
- Options (the correct answer and distractors)
The student can design, and/or interpret data from, an experiment that uses titration to determine the concentration of an analyte in a solution.

A student carries out the same titration, but uses an indicator instead of a pH meter. If the indicator changes color slightly past the equivalence point, what will the student obtain for the calculated concentration of the acid?

(A) Slightly less than 0.0800 M
(B) Slightly more than 0.0800 M
(C) Slightly less than 0.125 M
(D) Slightly more than 0.125 M
The Components of a Multiple–Choice Item

Learning objective 2.5 The student is able to refine multiple representations of a sample of matter in the gas phase to accurately represent the effect of changes in macroscopic properties on the sample.

Stem The figure above represents three sealed 1.0 L vessels, each containing a different inert gas at 298 K. The pressure of Ar in the first vessel is 2.0 atm. The ratio of the numbers of Ar, Ne, and He atoms in the vessels is 2:1:6, respectively. After all the gases are combined in a previously evacuated 2.0 L vessel, what is the total pressure of the gases at 298 K?

Options

(A) 3.0 atm
(B) 4.5 atm
(C) 9.0 atm
(D) 18 atm
Guidelines for Writing Multiple-Choice Items

Avoid making errors in spelling and/or grammar.
If options are numerical, arrange them in increasing order.

<table>
<thead>
<tr>
<th>Change of verb tense:</th>
<th>Subject-verb agreement:</th>
</tr>
</thead>
<tbody>
<tr>
<td>“is doing”</td>
<td>“results…is”</td>
</tr>
<tr>
<td>“was”</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Initial Volume of 1.0 ( M ) NaOH</th>
<th>2.50 mL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final Volume of 1.0 ( M ) NaOH</td>
<td>12.50 mL</td>
</tr>
</tbody>
</table>

A student is doing a titration experiment to determine the concentration of a 25 mL sample of aqueous hydrochloric acid (HCl). The titrant in this experiment was 1.0 \( M \) NaOH. The results of the experiment is shown above. What is the approximate value for the concentration of HCl(aq)?

(A) 0.40 \( M \)
(B) 2.50 \( M \)
(C) 0.20 \( M \)
(D) 0.80 \( M \)

Arrange the options from smallest to largest.
Guidelines for Writing Multiple–Choice Items

Try to avoid redundancy in the wording of the stem and/or options.

The atomic radius of calcium is equal to 174 pm, and the first ionization energy of calcium is equal to 590 kJ/mol. Which of the following statements concerning potassium is most likely to be true?

(A) The atomic radius of potassium is less than 174 pm, and the first ionization energy of potassium is less than 590 kJ/mol.

(B) The atomic radius of potassium is less than 174 pm, and the first ionization energy of potassium is greater than 590 kJ/mol.

(C) The atomic radius of potassium is greater than 174 pm, and the first ionization energy of potassium is less than 590 kJ/mol.

(D) The atomic radius of potassium is greater than 174 pm, and the first ionization energy of potassium is greater than 590 kJ/mol.
Guidelines for Writing Multiple-Choice Items

Here is an improved version of the same question.

<table>
<thead>
<tr>
<th>Element</th>
<th>Atomic Radius</th>
<th>First Ionization Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium</td>
<td>174 pm</td>
<td>590 kJ/mol</td>
</tr>
<tr>
<td>Potassium</td>
<td>?</td>
<td>?</td>
</tr>
</tbody>
</table>

Based on periodic trends and the data in the table above, which of the following are the most probable values of the atomic radius and the first ionization energy for potassium?

<table>
<thead>
<tr>
<th>Atomic Radius</th>
<th>First Ionization Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A) 144 pm</td>
<td>419 kJ/mol</td>
</tr>
<tr>
<td>(B) 144 pm</td>
<td>633 kJ/mol</td>
</tr>
<tr>
<td>(C) 196 pm</td>
<td>419 kJ/mol</td>
</tr>
<tr>
<td>(D) 196 pm</td>
<td>633 kJ/mol</td>
</tr>
</tbody>
</table>
Guidelines for Writing Multiple-Choice Items

Focus on one learning objective or chemistry concept.

The percentage of oxygen by mass for a pure substance is determined to be 20%. Which of the following is most likely to represent the identity of this substance?

(A) copper(II) oxide
(B) lithium oxide
(C) magnesium oxide
(D) calcium oxide
Here is an improved version of the same question.

The percentage of oxygen by mass for a pure substance is determined to be 20%. Which of the following is most likely to represent the identity of this substance?

(A) CuO
(B) Li₂O
(C) MgO
(D) CaO
Guidelines for Writing Multiple–Choice Items

Try to avoid “chemical trivia.”

Questions 1-4 refer to the following chemical compounds.

(A) CH₄  
(B) CCl₃F  
(C) H₂S  
(D) H₂O₂  
(E) K₂CrO₄

1. Commonly used as a disinfectant for minor skin wounds

2. A refrigerant implicated in the thinning of the stratospheric ozone layer

3. A major component of the fuel known as natural gas

4. A yellow solid at room temperature and 1 atm
Sometimes a multiple-choice item is actually just a true-false question. If so, it is probably based on factual recall instead of the application of knowledge.

Which of the following statements concerning the kinetic-molecular theory of gases is true for a sample of an ideal gas?

(A) The attractive forces between the gas particles are rather strong.
(B) The average kinetic energy of the gas particles is directly proportional to the volume of the container.
(C) The volume of the individual gas particles is much smaller than the volume occupied by the gas itself.
(D) An ideal gas consists of very small particles, each of which has a mass of zero.
Here is an improved version of the same question.

<table>
<thead>
<tr>
<th>Moles of CO₂(g)</th>
<th>Volume of Container</th>
<th>Gas Temperature</th>
<th>Pressure Calculated Using the Ideal Gas Law</th>
<th>Measured Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.500 mol</td>
<td>1.00 L</td>
<td>273 K</td>
<td>11.2 atm</td>
<td>10.5 atm</td>
</tr>
</tbody>
</table>

The data table above shows information for a pure sample of CO₂(g). Which of the following statements best helps to explain why the measured pressure is different than the pressure calculated using the ideal gas law?

(A) The attractive forces between CO₂ molecules cause them to collide with the walls of the container with less force.

(B) The average speed of the CO₂ molecules is relatively large, based on repulsive forces between CO₂ molecules.

(C) Two CO₂ molecules will occasionally decompose, producing two molecules of CO and one molecule of O₂.

(D) The volume occupied by the gas is much greater than the combined volume of the CO₂ molecules.
Guidelines for Writing Multiple-Choice Items

Avoid stems that are too short.

Water is
(A) a polar substance
(B) a nonpolar substance
(C) a metallic substance
(D) an ionic substance
Avoid stems that are too wordy.

Water is a substance that has a density of 1.0 g/mL in the liquid phase and a density of 0.92 g/mL in the solid phase. It has a rather high boiling point (100°C) despite the fact that the molecule has a relatively small size. In addition, water has a high specific heat capacity, a high melting point, and a high heat of vaporization. Which of the following statements provides the best explanation for the fact that water has these properties?

(A) Water molecules contain strong covalent bonds.

(B) Water molecules are able to dissolve a wide variety of solutes.

(C) Water molecules release a large amount of energy when they evaporate.

(D) Water molecules experience strong intermolecular forces.
Guidelines for Writing Multiple-Choice Items

Avoid negative words (e.g. not, never, etc.) in the stem.

Which of the following statements about atoms is NOT correct?

(A) Atoms are electrically neutral because they have the same number of protons and electrons.
(B) All atoms of a given element must have the same number of protons, neutrons, and electrons.
(C) Most of the volume of an atom contains only electrons.
(D) The nucleus is positively charged.
(E) Almost all of the mass of an atom is in the nucleus.
Guidelines for Writing Multiple-Choice Items

Avoid negative words (e.g. not, never, etc.) in the stem.

Which of the following does NOT behave as an electrolyte when it is dissolved in water?

(A) CH₃OH
(B) K₂CO₃
(C) NH₄Br
(D) HI
(E) Sodium acetate, CH₃COONa

The metal calcium reacts with molecular hydrogen to form a compound. All of the following statements concerning this compound are true EXCEPT:

(A) Its formula is CaH₂.
(B) It is ionic.
(C) It is a solid at room temperature.
(D) When added to water, it reacts to produce H₂ gas.
(E) When added to water, it forms an acidic solution.
Guidelines for Writing Multiple-Choice Items

The “complex multiple-choice” format is confusing for students.

\[ \text{Fe}^{3+}(aq) + \text{SCN}^{-}(aq) \rightleftharpoons \text{Fe(SCN)}^{2+}(aq) \]

For the reaction represented above, the value of the equilibrium constant, \( K_{eq} \), is 240 at 25°C. From this information, correct deductions about the reaction at 25°C include which of the following?

I. The reaction is quite rapid.
II. The product is favored over the reactants at equilibrium.
III. The reaction is endothermic.

(A) I only
(B) II only
(C) I and II only
(D) II and III only
(E) I, II, and III
Guidelines for Writing Multiple-Choice Items

Try to create unique options that can stand alone. Avoid using the phrase “___ of the above.”

The rate of a reaction depends on the ___ of the collisions between reactant molecules.

(A) frequency
(B) orientation
(C) energy
(D) all of the above

Which of the following substances behaves as a Brønsted-Lowry base when it reacts with water?

(A) H⁻
(B) NH₄⁺
(C) H₃O⁺
(D) none of the above
A student was performing a titration of a strong acid with a strong base using phenolphthalein as an indicator. At the endpoint of the titration, the color of the solution changes abruptly from colorless to pink. The reason for the abruptness of this color change is that

(A) a large change in pH occurs near the endpoint of the titration
(B) a buffer solution exists at the endpoint of the titration
(C) phenolphthalein is a strong Brønsted-Lowry acid
(D) phenolphthalein is a magical substance that is full of surprises
When the temperature of a reaction mixture is increased from 300 K to 350 K, the rate of the reaction increases. Which of the following statements best explains why the reaction rate is increased?

(A) The activation energy of the reaction is decreased.

(B) The value of ΔH for the reaction is decreased.

(C) The value of ΔS for the reaction is decreased.

(D) The average kinetic energy of the molecules increases, which increases the number of effective collisions between the molecules.
Suggestions for Improving an Existing Item

Make the stem more meaningful. Present a definite problem.

For a main group element, the valence electrons …?

What do you want students to KNOW about the valence electrons?

(A) increase in number when moving from top to bottom down a group
(B) are located in the energy level that has the lowest value of $n$
(C) require a relatively large amount of energy to remove from an atom
(D) are located in the outermost energy level of an atom
Suggestions for Improving an Existing Item

Here is an improved version of the same question.
The stem asks a specific question that is related to valence electrons.

Which of the following is the best reason to justify why two different elements belong in the same group on the periodic table?

(A) Each element is classified as nonmetal and exists as a gas at room temperature.
(B) Each element reacts with oxygen to form an ionic compound.
(C) Each element has the same number of electrons in its outermost energy level.
(D) The valence electrons of each element are located in an \( s \) orbital.
Suggestions for Improving an Existing Item

Emphasize conceptual understanding by making the math easier.

\[ 2 \text{C}_8\text{H}_{18} + 25 \text{O}_2 \rightarrow 16 \text{CO}_2 + 18 \text{H}_2\text{O} \]

In a certain experiment, 1.0 g of C\textsubscript{8}H\textsubscript{18} undergoes complete combustion according to the equation represented above. How many molecules of H\textsubscript{2}O would be formed if the reaction goes to completion?

(A) \(5.3 \times 10^{21}\) molecules H\textsubscript{2}O
(B) \(4.7 \times 10^{22}\) molecules H\textsubscript{2}O
(C) \(5.3 \times 10^{22}\) molecules H\textsubscript{2}O
(D) \(9.5 \times 10^{22}\) molecules H\textsubscript{2}O

\[
1.0 \text{ g C}_8\text{H}_{18} \times \frac{1 \text{ mol C}_8\text{H}_{18}}{114.224 \text{ g C}_8\text{H}_{18}} \times \frac{18 \text{ mol H}_2\text{O}}{2 \text{ mol C}_8\text{H}_{18}} \times \frac{6.02 \times 10^{23} \text{ molecules H}_2\text{O}}{1 \text{ mol H}_2\text{O}}
\]
Suggestions for Improving an Existing Item

Here is essentially the same question, but it can be solved without a calculator.

\[ \text{C}_3\text{H}_8 + 5 \text{O}_2 \rightarrow 3 \text{CO}_2 + 4 \text{H}_2\text{O} \]

In a certain experiment, 22 g of \( \text{C}_3\text{H}_8 \) undergoes complete combustion according to the equation represented above. How many molecules of \( \text{H}_2\text{O} \) would be formed if the reaction goes to completion?

(A) \( 3.0 \times 10^{23} \) molecules \( \text{H}_2\text{O} \)
(B) \( 6.0 \times 10^{23} \) molecules \( \text{H}_2\text{O} \)
(C) \( 1.2 \times 10^{24} \) molecules \( \text{H}_2\text{O} \)
(D) \( 2.4 \times 10^{24} \) molecules \( \text{H}_2\text{O} \)

1 mole of \( \text{C}_3\text{H}_8 = 44 \) g

22 g of \( \text{C}_3\text{H}_8 = 0.50 \) mol \( \text{C}_3\text{H}_8 \)

0.50 mol \( \text{C}_3\text{H}_8 \) would produce 2 mol \( \text{H}_2\text{O} \)

2 mol \( \text{H}_2\text{O} = (2)(6.0\times10^{23}) \) molecules
Here is another question that emphasizes conceptual understanding because the calculations are rather simple.

In a certain experiment, 1 mole of a hydrocarbon undergoes combustion in the presence of excess oxygen gas to produce 36 grams of water vapor. Which of the following represents the most likely chemical formula of this hydrocarbon?

(A) C₂H₂
(B) C₂H₄
(C) C₂H₆
(D) C₄H₈

\[
\text{C}_2\text{H}_4 + 3 \text{O}_2 \rightarrow 2 \text{CO}_2 + 2 \text{H}_2\text{O}
\]

36 g of H₂O = 2 mol H₂O

2 mol H₂O contains 4 moles of H atoms

1 mol CₓHᵧ contains 4 moles of H atoms
Suggestions for Improving an Existing Item

Ensure that all of the distractors are plausible.

Which of the following represents the empirical formula of a hydrocarbon that contains 75% carbon by mass?

(A) CH₂
(B) CH₄
(C) CH₆
(D) C₃H

A student might eliminate choices (C) and (D) because they seem unlikely or impossible. If students use a simple heuristic to eliminate some of the distractors, they might get the correct answer without fully understanding the concepts associated with the learning objective.
Suggestions for Improving an Existing Item

Ensure that all of the distractors are plausible.

Which of the following represents the empirical formula of a hydrocarbon that contains 75% carbon by mass?

(A) CH
(B) CH₂
(C) CH₃
(D) CH₄

The correct answer is (D) because CH₄ contains 12 g C and 4 g H.

The mass percent of C is equal to 12/16 = ¾ = 0.75 = 75% C
Suggestions for Improving an Existing Item

Move away from factual recall toward deeper conceptual understanding.

Which of the following is classified as a weak acid?

(A) HF  
(B) HCl  
(C) HNO₃  
(D) HClO₄
Suggestions for Improving an Existing Item

Move away from factual recall toward deeper conceptual understanding.

Which of the following provides the best justification that HF should be classified as a weak acid?

(A) Molecules of HF are only sparingly soluble in water.

(B) In 0.10 \( M \) HF\((aq)\), molecules of HF are only partially dissociated into ions.

(C) In 0.10 \( M \) HF\((aq)\), the concentration of \( \text{H}_3\text{O}^+(aq) \) is much less than the concentration of \( \text{F}^-(aq) \).

(D) The pH of 0.10 \( M \) HF\((aq)\) is equal to 1.00.
The Process of Writing an Original Item

- Start with a learning objective or standard
- Which comes first...the stem or the stimulus?
- If you use data, make sure it is accurate (or plausible)
- Misconceptions make great distractors
- There should be only one correct answer
The Process of Writing an Original Item

Start with a learning objective or standard

LO 3.4 The student is able to relate quantities (measured mass of substances, volumes of solutions, or volumes and pressures of gases) to identify stoichiometric relationships for a reaction, including situations involving limiting reactants and situations in which the reaction has not gone to completion. [See SP 2.2, 5.1, 6.4]
The Process of Writing an Original Item

Which comes first…the stem or the stimulus?

If you already have a good idea of what you want to ask the student, start writing the stem. Then you may choose to add a data table or a graph to help provide additional context to your question.

If you’re not exactly sure what the stem should look like, start with a data table, graph, or a laboratory situation. Then you can think about a question you might ask that is related to the stimulus.
I want to write a stoichiometry question. I decide to pick an easy chemical reaction with simple coefficients.

The synthesis of water: \( 2 \text{H}_2 + \text{O}_2 \rightarrow 2 \text{H}_2\text{O} \)

I want the math to be simple enough to be done without a calculator.
This question is going to involve the concept of a limiting reactant.

\[ 2 \text{H}_2 + \text{O}_2 \rightarrow 2 \text{H}_2\text{O} \]

2 mol H₂ = 4.0 g H₂  \quad 1 \text{mol O}_2 = 32 \text{g O}_2

If these quantities reacted together completely, 36 g of H₂O would be produced, and there would be no excess reactant left over at the end.

Some students might think that the limiting reactant is always the sample that has the smaller mass. Therefore, I want to use an example in which the limiting reactant is the sample that has the \textit{greater mass}. In this example, I will set it up so that the limiting reactant is oxygen.
### The Process of Writing an Original Item

\[
2 \text{H}_2 + \text{O}_2 \rightarrow 2 \text{H}_2\text{O}
\]

<table>
<thead>
<tr>
<th>Reaction</th>
<th>H₂</th>
<th>O₂</th>
<th>H₂O</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.0 g H₂</td>
<td>32.0 g O₂</td>
<td>36.0 g H₂O</td>
<td></td>
</tr>
<tr>
<td>6.0 g H₂</td>
<td>48.0 g O₂</td>
<td>54.0 g H₂O</td>
<td></td>
</tr>
<tr>
<td>24.0 g H₂</td>
<td>48.0 g O₂</td>
<td>54.0 g H₂O</td>
<td></td>
</tr>
</tbody>
</table>

- 4.0 g H₂ is (2 mol) and 32.0 g O₂ is (1 mol); theoretical yield is 36.0 g H₂O.
- 6.0 g H₂ is (3 mol) and 48.0 g O₂ is (1.5 mol); theoretical yield is 54.0 g H₂O.
- 24.0 g H₂ is excess reactant and 48.0 g O₂ is limiting reactant; theoretical yield is 54.0 g H₂O.

**Note:** There will be 18.0 g H₂ left over.
H₂ reacts with O₂ according to the equation shown above. In a certain experiment, 24.0 grams of H₂ reacted with 48.0 grams of O₂ until one of the reactants was completely consumed. What is the theoretical yield of H₂O?

The correct answer is **54.0 g H₂O**.

One of the distractors could be the sum of the reactants, which is equal to **72.0 g H₂O**.

48.0 g O₂ is equal to 1.50 mol O₂. If a student thinks that 1.50 mol H₂O is produced, they would choose \((1.50) \times (18.0)\). This is equal to **27.0 g H₂O**.

There are 2 moles of H₂O in the balanced equation, so one of the distractors could be **36.0 g H₂O**, because that represents 2 mol H₂O.
H₂ reacts with O₂ according to the equation shown above. In a certain experiment, 24.0 grams of H₂ reacted with 48.0 grams of O₂ until one of the reactants was completely consumed. What is the theoretical yield of H₂O?

(A) 27.0 g

(B) 36.0 g

(C) 54.0 g

(D) 72.0 g
Another way to ask this question is to have students choose which reactant, hydrogen, or oxygen, should be identified as the limiting reactant.

With 4 options, you can split them up into 2 groups of 2.

You can have two options for the mass of $\text{H}_2\text{O}$ produced as the theoretical yield from this experiment.
H₂ reacts with O₂ according to the equation shown above. In a certain experiment, 24.0 grams of H₂ reacted with 48.0 grams of O₂ until one of the reactants was completely consumed. Which of the following correctly identifies both the limiting reactant in this experiment and the theoretical yield of H₂O?

<table>
<thead>
<tr>
<th>Limiting Reactant</th>
<th>Theoretical Yield of H₂O</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A) H₂</td>
<td>54.0 g</td>
</tr>
<tr>
<td>(B) H₂</td>
<td>72.0 g</td>
</tr>
<tr>
<td>(C) O₂</td>
<td>54.0 g</td>
</tr>
<tr>
<td>(D) O₂</td>
<td>72.0 g</td>
</tr>
</tbody>
</table>
The Process of Writing an Original Item

Start with a learning objective or standard

LO 2.11 The student is able to explain the trends in properties and/or predict properties of samples consisting of particles with no permanent dipole on the basis of London dispersion forces. [See SP 6.2, 6.4]

Which comes first...the stem or the stimulus?

ethane

butane
The Process of Writing an Original Item

- Misconceptions make great distractors

  Students often confuse INTERmolecular forces with INTRAmolecular forces (aka covalent bonds)

  Some students think that any molecule that contains hydrogen atoms can experience hydrogen bonding attractive forces.

  Some students have trouble deciding if a molecule is polar or nonpolar.

Chemical structures:
- Ethane: $\text{H-C-C-H}$
  - Boiling point = 185 K
- Butane: $\text{H-C-C-C-C-H}$
  - Boiling point = 273 K
The structural formulas and the boiling points for ethane and butane are shown above. Which of the following provides the best explanation for the fact that butane has a higher boiling point than ethane?

(A) Butane has a larger electron cloud than ethane. Butane has greater polarizability and stronger dispersion forces.

(B) Butane has more hydrogen atoms than ethane. There are more opportunities for butane molecules to form hydrogen bonds with neighboring molecules.

(C) Butane requires a greater amount of energy to break up the covalent bonds between its atoms.

(D) Butane is polar, whereas ethane is nonpolar. The dipole-dipole forces in butane are stronger than the dispersion forces in ethane.
The Process of Writing an Original Item

Start with a learning objective or standard

LO 6.13 The student can interpret titration data for monoprotic or polyprotic acids involving titration of a weak or strong acid by a strong base (or a weak or strong base by a strong acid) to determine the concentration of the titrant and the $pK_a$ for a weak acid, or the $pK_b$ for a weak base. [See SP 5.1, 6.4, connects to 1.E.2]

Which comes first...the stem or the stimulus?

There are many concepts associated with this LO. I decided that I wanted to assess the student’s ability to find the equivalence point on a titration curve. So I decided to start with the stimulus...the titration curve.
I used the “advanced image search” feature of Google to find an image. Under “usage rights,” I selected “free to use, share or modify.” This will ensure that I am not violating copyright.

I chose a simple image. I prefer a black and white image without a lot of distracting text. This image has red curves that will print black. The equivalence point, 25 mL, is clear for both curves.
I decided to address the misconception that a weak acid will require less (or more) of the titrant (base) than a strong acid in order to be neutralized.

I wrote the following stem:
In two separate experiments, a student titrated 25 mL of a strong acid and 25 mL of a weak acid. The titrant in both experiments was 0.100 \( M \) NaOH. Based on the two titration curves shown above, which of the following statements correctly compares the relative concentrations of the weak acid and the strong acid and provides the correct justification?
In two separate experiments, a student titrated 25 mL of a strong acid and 25 mL of a weak acid. The titrant in both experiments was 0.100 M NaOH. Based on the two titration curves shown above, which of the following statements correctly compares the relative concentrations of the weak acid and the strong acid and provides the correct justification?

(A) The weak acid has the same concentration as the strong acid because each acid sample requires the same volume of titrant to reach the equivalence point.

(B) The weak acid has a higher concentration than the strong acid because the pH at the equivalence point of the weak acid titration is higher than the pH at the equivalence point of the strong acid titration.

(C) The weak acid has a higher concentration than the strong acid because the percent ionization of a weak acid in water is greater than the percent ionization of a strong acid in water.

(D) The weak acid has a lower concentration than the strong acid because the percent ionization of a weak acid in water is less than the percent ionization of a strong acid in water.
In two separate experiments, 0.100M NaOH was used to titrate 25 mL of a strong acid and 25 mL of a weak acid. Based on the titration curves shown above, which of the following statements correctly compares the relative concentrations of the two acids with the correct justification?

<table>
<thead>
<tr>
<th>The weak acid has</th>
<th>because</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A) the same concentration as the strong acid</td>
<td>each acid sample required the same volume of titrant to reach the equivalence point.</td>
</tr>
<tr>
<td>(B) a higher concentration than the weak acid</td>
<td>the pH at the equivalence point is higher for the weak acid than the strong acid.</td>
</tr>
<tr>
<td>(C) a higher concentration than the strong acid</td>
<td>a weak acid has a higher percent ionization than a strong acid in water.</td>
</tr>
<tr>
<td>(D) a lower concentration that the strong acid</td>
<td>a weak acid has a lower percent ionization than a strong acid in water.</td>
</tr>
</tbody>
</table>
On the 2018 AP Chemistry Exam (Form 0), Free Response Question #2(a) featured a particle-level diagram for the following reaction:

\[ 2 \text{NO}(g) + \text{O}_2(g) \rightarrow 2 \text{NO}_2(g) \]
2. A student investigates the reactions of nitrogen oxides. One of the reactions in the investigation requires an equimolar mixture of NO\(_{(g)}\) and NO\(_2(g)\), which the student produces by using the reaction represented above.

(a) The particle-level representation of the equimolar mixture of NO\(_{(g)}\) and NO\(_2(g)\) in the flask at the completion of the reaction between NO\(_{(g)}\) and O\(_2(g)\) is shown below in the box on the right. In the box below on the left, draw the particle-level representation of the reactant mixture of NO\(_{(g)}\) and O\(_2(g)\) that would yield the product mixture shown in the box on the right. In your drawing, represent oxygen atoms and nitrogen atoms as indicated below.
I wrote the following stimulus:

\[
2 \text{NO}(g) + \text{O}_2(g) \rightarrow 2 \text{NO}_2(g)
\]

NO(g) and O\(_2\)(g) react to form NO\(_2\)(g) according to the equation above. The diagram below represents a particle-level representation of the contents of the flask at the completion of the reaction.
The Process of Writing an Original Item

\[ 2 \text{NO}(g) + O_2(g) \rightarrow 2 \text{NO}_2(g) \]

NO(g) and O\(_2\)(g) react to form NO\(_2\)(g) according to the equation above. The diagram below represents a particle-level representation of the contents of the flask at the completion of the reaction.

I wrote the following stem:

Which of the following diagrams best represents the particle-level representation of the reactant mixture of NO(g) and O\(_2\)(g) that would yield the product shown in the diagram above?
2 NO(g) + O_2(g) \rightarrow 2 NO_2(g)

NO(g) and O_2(g) react to form NO_2(g) according to the equation above. The diagram below represents a particle-level representation of the contents of the flask at the completion of the reaction.

Which of the following diagrams best represents the particle-level representation of the reactant mixture of NO(g) and O_2(g) that would yield the product shown in the diagram above?

The correct particle diagram should contain the following.

- 4 NO(g) molecules
- 2 O_2(g) molecules
The Process of Writing an Original Item

2 NO(g) + O₂(g) → 2 NO₂(g)

NO(g) and O₂(g) react to form NO₂(g) according to the equation above. The diagram below represents a particle-level representation of the contents of the flask at the completion of the reaction.

Which of the following diagrams best represents the particle-level representation of the reactant mixture of NO(g) and O₂(g) that would yield the product shown in the diagram above?

(A)  
(B)  
(C)  
(D)
Which of the following is a true statement about a 1.00-mol sample of aluminum and a 1.00-mol sample of selenium?

(A) They have the same number of atoms and the same mass.

(B) They have the same number of atoms, but the aluminum sample has more mass.

(C) They have the same number of atoms, but the selenium sample has more mass.

(D) They have the same mass, but the selenium sample has more atoms.

(E) They have the same mass, but the aluminum sample has more atoms.
Which of the following particle diagrams best represents what happens when aqueous MgCl₂ reacts with aqueous AgNO₃?

Note: Water is not included in these particle diagrams.

(A)  

(B)  

(C)  

(D)
Items Submitted by Webinar Participants

The person who submitted the following question commented that there needs to be more clarification regarding the concept of bond strength.

Which of the following represents the formula of a molecule in which the intramolecular forces are the strongest?

(A) BeCl₂
(B) SO₂
(C) N₂
(D) O₂

The phrase “intramolecular forces” is synonymous with “covalent bonds.”

The correct answer is (C) because the N≡N bond is the strongest.
Which of the following arranges the molecules N₂, O₂, and F₂ in order of their bond enthalpies, from least to greatest?

(A) F₂ < O₂ < N₂
(B) O₂ < N₂ < F₂
(C) N₂ < O₂ < F₂
(D) N₂ < F₂ < O₂
Here is another option that also focuses on the comparison of bond strength for a single bond, a double bond, and a triple bond.

Which of the following molecules contains a carbon-carbon bond that has the greatest bond enthalpy?

(A) $\text{C}_2\text{H}_2$

(B) $\text{C}_2\text{H}_4$

(C) $\text{C}_2\text{H}_6$

(D) $\text{C}_3\text{H}_8$
The person who submitted the following question commented that students tend to jump quickly to choosing an answer and ignore the fact that the equation is not balanced. “How do I make it more clear that the student needs to balance the equation without telling them to do it?”

What is a mole ratio in the following unbalanced chemical equation?

\[ \text{CO} + \text{O}_2 \rightarrow \text{CO}_2 \]

(A) 2 mol CO : 2 mol CO₂
(B) 1 mol CO : 1 mol O₂
(C) 2 mol O₂ : 1 mol CO₂
(D) 2 mol O₂ : 2 mol CO₂
Here is one option for writing a similar question. It focuses on the fact that the equation has not yet been balanced.

\[ \text{NH}_3 + \text{O}_2 \rightarrow \text{NO} + \text{H}_2\text{O} \]

When the equation shown above has been balanced using the lowest possible whole number coefficients, the coefficient for \( \text{H}_2\text{O} \) is

(A) 2  
(B) 3  
(C) 4  
(D) 6
The person who submitted the following question would like it to be edited so that it emphasizes a conceptual understanding of Hammond’s postulate instead of just recalling the definition.

According to Hammond’s postulate, the transition state in an exothermic reaction looks more like

(A) the reactants

(B) the products

(C) neither the reactants nor the products
The energy diagram shown above represents a chemical process that converts A into B. According to Hammond’s postulate, the structure of the transition state at point X in the diagram should be structurally similar to

(A) A, because the conversion of A to B is an endothermic process.
(B) A, because the conversion of A to B is an exothermic process.
(C) B, because the conversion of A to B is an endothermic process.
(D) B, because the conversion of A to B is an exothermic process.
Additional Resources

How Can We Construct Good Multiple Choice Items?
Derek Cheung and Robert Bucat

The Development of Multiple-Choice Items Consistent with the AP Chemistry Curriculum Framework To More Accurately Assess Deeper Understanding
https://pubs.acs.org/doi/abs/10.1021/ed5000185

Guide to Developing High-Quality, Reliable, and Valid Multiple-Choice Assessments
https://pubs.acs.org/doi/abs/10.1021/ed500076x

AACT members receive 50 complimentary downloads from the Journal of Chemical Education and other ACS Publications
https://teachchemistry.org/about-us/acs-publications-access
Additional Resources

Good, Better Best: Multiple Choice Exam Construction
http://www.duq.edu/about/centers-and-institutes/center-for-teaching-excellence/teaching-and-learning/multiple-choice-exam-construction

14 Rules for Writing Multiple-Choice Questions
https://testing.byu.edu/handbooks/14%20Rules%20for%20Writing%20Multiple-Choice%20Questions.pdf

Writing Good Multiple-Choice Exams

Writing Good Multiple Choice Test Questions
https://cft.vanderbilt.edu/guides-sub-pages/writing-good-multiple-choice-test-questions/
If you have additional questions, contact us.

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