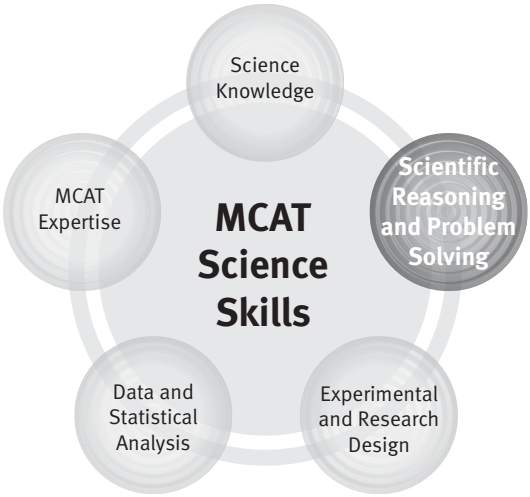
Skill 2 (Critical Thinking) Basics

In this lesson, you'll learn to:

- Recall relevant scientific concepts with limited or no clues in the question stem or answer choices
- Apply known scientific principles to novel and/or complicated situations



Science Topics

- Electrochemistry
- Circuit Elements
- Thermochemistry (General Chemistry)
- Thermodynamics (General Chemistry)

LESSON 2.1, LEARNING GOALS 1 AND 2:

- Recall relevant scientific concepts with limited or no clues in the question stem or answer choices
- Apply known scientific principles to novel and/or complicated situations

The Question Behind the Question

1. The Haber process for the production of ammonia is represented by the equation below:

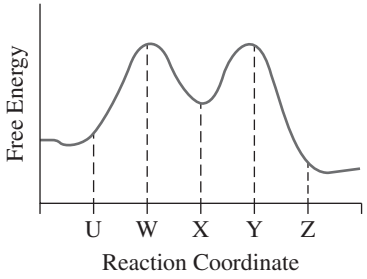
$$N_2(g) + 3H_2(g) \leftrightarrow 2NH_3(g) + 22 \text{ kcal}$$

Which of the following will decrease the yield of ammonia?

A. A decrease in temperature and an energy release
B. A decrease in temperature and energy absorption
C. An increase in temperature and an energy release
D. An increase in temperature and energy absorption

What is the relevant science concept?

2. Which of the following statements is true regarding the diagram below?



A. Going from U to W requires less energy than going from X to Y.
B. Going from U to X occurs more readily than going from X to Z.
C. Y will be more easily isolated in solution than X or W.
D. The reaction U to X releases energy while the reaction X to Z would absorb it.

What is the relevant science concept?

The Question Behind the Question

3. Which of the following statements is NOT true of melting ice?

A. The reaction happens spontaneously at 298 K.
B. The molecules become more ordered.
C. The reaction requires energy.
D. The volume of the substance decreases.

What is the relevant science concept?

4. The distance separating the two strands that make up DNA is about 1 nm. The magnitude of the force between the hydrogen-bonded bases will:

A. decrease as the distance decreases to 0.3 nm.
B. exhibit no change as the distance decreases.
C. increase as the distance increases to 2 nm.
D. decrease as the distance increases to 2 nm.

What is the relevant science concept?

5. A certain biological reaction requires two ATP (adenosine triphosphate) molecules to work within close proximity. Which of the following is true?

A. Work needs to be done on the molecules by an external force to bring them close because they repel each other.
B. No external force is needed in order to bring the two molecules together because they attract each other.
C. Work needs to be done on the molecules by an external force to bring them close because they attract each other.
D. The potential energy of the molecules is unaffected by bringing them close together.

What is the relevant science concept?

KAPLAN TIP

Clues or "buzzwords" in the question stem *or* the answer choices can help you identify the relevant science topic and get closer to points on Test Day.

LESSON 2.1 REVIEW

Critical Thinking Basics

The question and the answer choices

- Contain valuable clues
- Are linked conceptually
- Indicate relevant basic science concepts

Critical Thinking on the MCAT

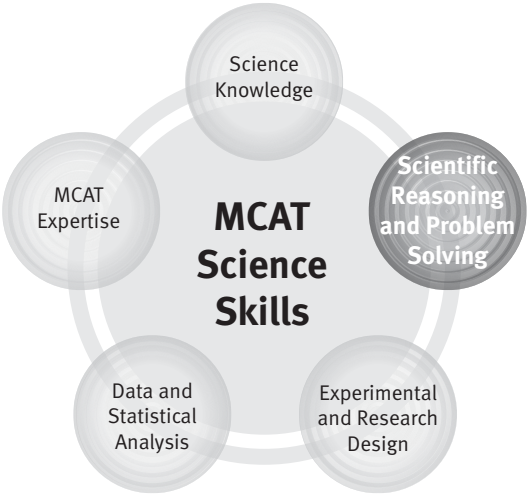
- Is imperative for making an effective plan to attack the question
- Makes a multistep problem more manageable
- Helps identify where to source information when answering a question:
  - Your baseline knowledge base
  - The passage/question
  - Both of the above

LESSON 2.2

MCAT Scientific Reasoning

In this lesson, you'll learn to:

- Determine the likelihood of a scientific phenomenon or a given explanation for a phenomenon
- Determine the likely cause or effect of a phenomenon
- Determine how observations influence scientific theories or models
- Gather information from various sources to draw conclusions



Science Topics:

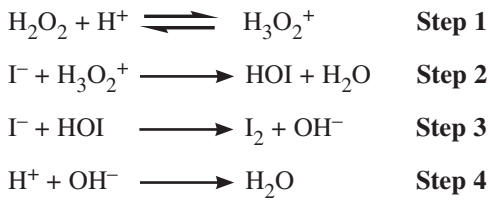
- Chemical Kinetics and Equilibrium
- Solubility
- Acids and Bases and Titrations

LESSON 2.2, LEARNING GOAL 1:

- Determine the likelihood of a scientific phenomenon or a given explanation for a phenomenon

Example Questions

1. In the following chemical mechanism, is acid acting as a catalyst?



A. Yes, because it lowers the activation energy of the reaction.
B. Yes, because it makes the reaction proceed faster.
C. No, because in the absence of nitric acid, the same reaction would occur at the same rate.
D. No, because the H^+ is not regenerated.

What is the phenomenon in this question?

2. If 1.0 mL of a 1.0×10^{-5} M NaSCN solution is added to 3.0 mL of a 1.0×10^{-5} M $AgNO_3$ solution, will there be any precipitate? (The K_{sp} of AgSCN is 1×10^{-12}.)

A. No, both NaSCN and $AgNO_3$ are completely soluble.
B. No, all ion concentrations are at or below saturation levels.
C. Yes, both AgSCN and $NaNO_3$ are completely insoluble.
D. Yes, Ag^+ and SCN^- concentrations are above saturation levels.

What is the phenomenon in this question?

KAPLAN TIP
You'll read a lot of research as a physician, so developing the skill of understanding questions about experiments on the MCAT is useful for your test as well as your future career.

LESSON 2.2, LEARNING GOAL 2:

- Determine the likely cause or effect of a phenomenon

Example Questions

3. In a reaction at equilibrium, it is concluded that helium gas behaves more ideally than carbon dioxide. Which of the following accurately explains why this is so?

I. CO_2 exerts a greater pressure because its molecules have lesser volume.
II. The intermolecular forces between CO_2 molecules are stronger than those in He.
III. Helium molecules have greater kinetic energy, and therefore behave more ideally.

A. I only
B. II only
C. II and III only
D. I, II, and III

What is the phenomenon in this question?

4. To make a standard solution of acid, a researcher dissolves 385.43 mg of the acid solid in water. Then he titrated the acid using base of unknown concentration. Despite not knowing how much water the acid was dissolved in, the calculated concentration of NaOH is unaffected. Why?

A. The volume of acid determines the volume of base added, not the concentration of that base.
B. The concentration of the base is determined solely by how many liters of acid are required to neutralize the base.
C. The concentration of the base is determined solely by how many moles of acid are required to neutralize the base.
D. The concentration of NaOH could not have actually been calculated due to the volume of the acid being unknown.

What is the phenomenon in this question?

KAPLAN TIP
Thinking through the scientific phenomena at hand and using your critical reasoning skills helps to answer Skill 2 questions on Test Day!

LESSON 2.2, LEARNING GOAL 3:

- Determine how observations influence scientific theories or models

Passage Excerpt (Questions 5–6)

Scientist 1

Water, a polar solvent, is better at solvating species with higher, rather than lower, polarity. The difference in the electronegativities of the ions that compose an ionic compound gives a measure of the polarity of the compound. See Table 1 for some common electronegativity values.

What does Scientist 1 think is the main reason some salts are more soluble than others?

Element	Electronegativity
Zn	1.6
Pb	1.9
I	2.5
Br	2.8
F	4.0

Table 1. Selected electronegativities.

Scientist 2

Upon dissolution, sparingly soluble salts are partially converted to ions. These ions vary in their ionic radii. Water forms hydrogen bonds with other water molecules. When ions with a smaller ionic radius are solvated, they do not significantly disrupt the hydrogen-bonding network of water. Larger ions, though, disrupt the intermolecular forces of water, and thus are less soluble. The relative sizes of the ions of some sparingly soluble salt ions are: $I^- > Br^- > F^- > Pb^{2+} > Zn^{2+}$.

What does Scientist 2 think is the main reason some salts are more soluble than others?

Passage Excerpt Questions

5. If ZnI_2 were more soluble than $PbBr_2$, how would this affect the hypotheses?

A. Only Scientist 1's hypothesis would be affected.
B. Only Scientist 2's hypothesis would be affected.
C. Scientists 1 and 2 would both be affected.
D. Neither Scientist 1 nor 2 would be affected.

What is the new observation in this question?

6. Upon adding a small amount of ZnF_2 to a saturated solution of PbF_2, a small amount of ZnF_2 dissolves and a small amount of PbF_2 precipitates. Which scientist's hypothesis would be supported by this phenomenon?

A. Only Scientist 1's hypothesis would be supported.
B. Only Scientist 2's hypothesis would be supported.
C. Scientists 1 and 2 would both be supported.
D. Neither Scientist 1 nor 2 would be supported.

What is the new observation in this question?

KAPLAN TIP
Skill 2 questions take the science to a deeper level of understanding. Practice these types of questions to get a competitive MCAT score!

LESSON 2.2, LEARNING GOAL 4:

- Gather information from various sources to draw conclusions

Practice Passage (Questions 7–10)

Lactic acidosis is a form of metabolic acidosis characterized by a blood pH lower than 7.35 and heightened lactate levels in the blood. This condition may arise either through excess lactate production by the tissues, limited hepatic metabolism, or a combination of these factors. In healthy individuals, the liver acts as a blood pH regulator. Two mechanisms by which the liver can regulate pH are as follows:

Mechanism 1: Increasing or decreasing metabolism of acid anions, such as lactate, citrate, gluconate, and acetate, will increase or decrease blood pH, respectively. In the case of lactate, two pathways by which lactate is metabolized are illustrated below:

Reaction 1: Lactate + $3O_2 \rightarrow HCO_3^- + 2CO_2 + 2H_2O$

Reaction 2: 2 Lactate + $2CO_2 + 2H_2O \rightarrow 2HCO_3^-$ + glucose

Mechanism 2: Production of plasma proteins, such as albumin, that can buffer H^+.

An anesthesiologist conducted an experiment to investigate the effects of Hartmann's solution on lactic acidosis. Hartmann's solution is isotonic with blood and consists of NaCl, $NaC_3H_5O_3$ (sodium lactate), $CaCl_2$, and KCl. In the experiment, patients suffering from lactic acidosis received intravenous Hartmann's solution. In order to determine the outcome of the treatment, each patient had his or her anion gap measured before and after treatment. After the experiment, the anesthesiologist concluded that Hartmann's solution failed to treat the lactic acidosis in all cases.

Anion gap is calculated as follows: anion gap = $[Na^+] - ([Cl^-] + [HCO_3^-])$. Table 1 illustrates the significance of anion gap measurements. Typically, a low anion gap occurs due to hypoalbuminemia (low blood albumin levels) and a high anion gap is the result of lactic acidosis.

Physiological Condition	Anion Gap (mEq/L)
Abnormally low	Less than 6
Normal	6 – 12
Abnormally high	Greater than 12

Table 1. Anion gap measurements comparison.

Passage Outline

P1.

M1.

R1.

R2.

M2.

P2.

P3.

T1.

7. Why is the anion gap generally greater in patients suffering from lactic acidosis?

A. Hepatic function is limited, so endogenous bicarbonate production is reduced.
B. Serum albumin levels are too high, displacing the anions used to calculate anion gap.
C. Urine volume increases to remove bicarbonate from the body and Na^+ follows.
D. Citrate and gluconate cannot be properly metabolized, so H^+ is abundant.

8. Typically, serum lactate level is measured to determine the severity of lactic acidosis. Why is this not the ideal approach in the experiment with Hartmann's solution from the passage?

A. Acid anions other than lactate are also relevant in causing lactic acidosis.
B. Hypoalbuminemia may be masking the effects of a heightened lactate concentration.
C. Hartmann's solution will confound the measurement of serum lactate.
D. It is not clear whether each patient's lactic acidosis is caused by Hartmann's solution or exercise.

9. A 20 mL blood sample is taken from a patient with lactic acidosis. The pH is measured and found to be below physiological pH. What must be true of the $[OH^-]$ of the sample?

A. It is less than the $[H^+]$ in the sample.
B. It has a minimum value of approximately 4.5×10^{-8} mmol/mL.
C. It has maximum value of approximately 6.0×10^{-7} mmol/mL.
D. It is impossible to make any judgments on $[OH^-]$ with this information.

10. The conversion of pyruvate to lactate by lactate dehydrogenase is depicted below:

$$\text{Pyruvate} + \text{NADH} + H^+ \leftrightarrow \text{Lactate} + NAD^+$$

The ratio of lactate to pyruvate is 10:1 in cells of a healthy individual. If the cells of patients in the study have an average ratio of 20:1, which of the following is most likely to also be true?

A. Their ratio of NAD^+ to NADH must be greater than the ratio in a healthy individual.
B. Their ratio of NAD^+ to lactate must be greater than the ratio in a healthy individual.
C. Their ratio of lactate to H^+ must be less than the ratio in a healthy individual.
D. Their ratio of NAD^+ to pyruvate must be less than the ratio in a healthy individual.

KAPLAN TIP
Don't forget to use the whole passage to answer questions, especially Skill 2 questions.

LESSON 2.2 REVIEW

MCAT Skill 2 Questions

Scientific Reasoning and Problem Solving

- Reasoning about scientific principles, theories, and models
- Analyzing and evaluating scientific explanations and predictions

To answer these types of questions:

- Determine the likely cause or effect of a phenomenon and determine how observations influence scientific theories or models.
- Determine the validity of an explanation of a phenomenon.

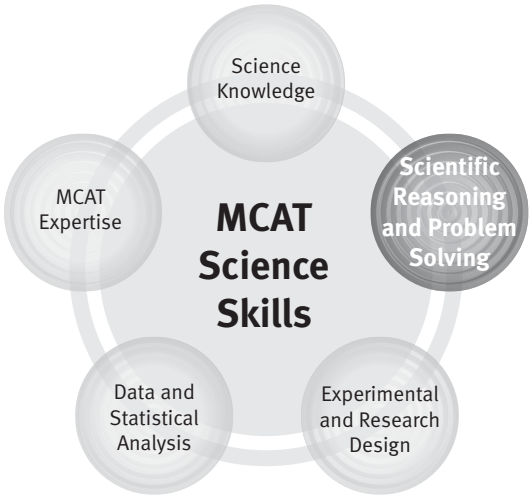
Formulas on the MCAT

In this lesson, you'll learn to:

- Select the right formula to use in solving a quantitative question

Science Topics:

- Sound
- Thermochemistry and Thermodynamics
- Acids and Bases and Titrations
- Circuit Elements
- Electrostatics



LESSON 2.3, LEARNING GOAL 1:

- Select the right formula to use in solving a quantitative question

Equation Recall

1. The human circulatory system can be thought of as an electric circuit with the heart as the voltage source and the flow of blood as the current. Given this, what is the flow rate if the heart is supplying a potential difference of 5 units and the resistance is at 61 units?

A. 4.1×10^{-3} units
B. 8.2×10^{-2} units
C. 4.1×10^{-1} units
D. 8.2×10^{1} units

Which variables are given?

Which variable needs to be solved for?

Which equation should you use?

2. Given the following data, at what temperature is the system at equilibrium?

$x(l) \rightarrow x(g)$

$\Delta H = 44$ kJ

$\Delta S = 118$ J/K

A. 53°C
B. 86°C
C. 102°C
D. 119°C

Which variables are given?

Which variable needs to be solved for?

Which equation should you use?

3. A train is moving at 80 mph. A car in front of it is moving in the same direction at 50 mph. If the frequency of a whistle on the train is f, what is the frequency heard by a passenger riding in the car? (v = speed of sound in air in mph)

A. $f\dfrac{(v+50)}{(v+80)}$
B. $f\dfrac{(v-50)}{(v+80)}$
C. $f\dfrac{(v+50)}{(v-80)}$
D. $f\dfrac{(v-50)}{(v-80)}$

Which variables are given?

Which variable needs to be solved for?

Which equation should you use?

Connecting Equations

4. The K_a of methyl red is 8.1×10^{-6}. At 25°C, the concentration of the conjugate base is 10 times that of the acid form of methyl red. What is the pH of the solution?

A. 4.2
B. 5.2
C. 6.2
D. 7.2

Which variables are given?

Which variable needs to be solved for?

Which variable connects the given variables to the variables in the answer choices?

Which equations should you use?

5. The two plates of an automated external defibrillator are held 0.45 m apart and experience an instantaneous electrostatic force of 11 N. If the instantaneous charge on one of these plates is 0.005 C, what is the potential difference between the plates?

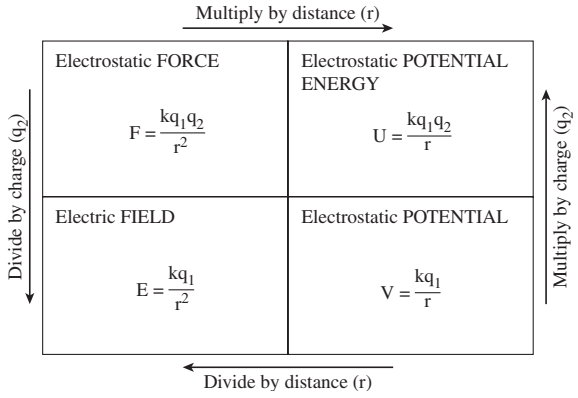
A. 990 V
B. 1,595 V
C. 2,080 V
D. 10,045 V

Which variables are given?

Which variable needs to be solved for?

Which variable connects the given variables to the variables in the answer choices?

Which equations should you use?



KAPLAN TIP

Flashcards are a great way to keep track of all the equations you'll need for Test Day!

LESSON 2.3 REVIEW

Study Skills

Make use of equation flashcards

Solving MCAT Problems Using Equations

Determine which variables are given
Determine which variable needs to be solved for
Think of any potential equations to connect given variables to unknown variables
Recall the correct equations

Chemistry and Physics 2: Scientific Reasoning on the MCAT

PASSAGE I (QUESTIONS 1–4)

The adult male human is comprised of approximately 60% water. The blood (which is largely water) is packed with various solutes that can move freely through the body. Of these solutes, salt makes up a significant portion. Sparingly soluble salts are similar to the salt in the blood in that they are ionic compounds, but they only somewhat dissociate in water. Two scientists developed hypotheses to determine if one sparingly soluble salt was more or less soluble than the other.

Scientist 1

Water, a polar solvent, is better at solvating species with higher, rather than lower, polarity. The difference in the electronegativities of the ions that compose an ionic compound gives a measure of the polarity of the compound. Comparing ZnF_2 and $PbBr_2$, fluoride is more electronegative than bromide, and the lead(II) ion is more electronegative than the zinc(II) ion. The polarity of ZnF_2 is greater than the polarity of $PbBr_2$; therefore, ZnF_2 is more soluble than $PbBr_2$.

Table of Selected Electronegativities

Element	Electronegativity
Zn	1.6
Pb	1.9
I	2.5
Br	2.8
F	4.0

Scientist 2

Upon dissolution, sparingly soluble salts are partially converted to ions. These ions vary in their ionic radii. Water forms hydrogen bonds with other water molecules. When ions with a smaller ionic radius are solvated, they do not significantly disrupt the hydrogen-bonding network of water. Larger ions, though, disrupt the intermolecular forces of water, and thus are less soluble. The relative sizes of the ions of the sparingly soluble salts ZnF_2 and $PbBr_2$ are: $Br^- > F^- > Pb^{2+} > Zn^{2+}$. The ions of ZnF_2 are smaller than those of $PbBr_2$; therefore, ZnF_2 is more soluble than $PbBr_2$.

1. What would Scientist 2 predict about the relative solubilities of PbF_2 and ZnF_2?

A. PbF_2 is more soluble than ZnF_2 because the electronegativity difference of the ions that compose PbF_2 is smaller.
B. PbF_2 is more soluble than ZnF_2 because the ions that compose PbF_2 are larger.
C. PbF_2 is less soluble than ZnF_2 because the electronegativity difference of the ions that compose PbF_2 is smaller.
D. PbF_2 is less soluble than ZnF_2 because the ions that compose PbF_2 are larger.

2. The solubility of ZnF_2 is 2.03 g/100 mL at 25°C. What is the K_{sp} value for ZnF_2?

A. 8.32×10^{-3}
B. 3.04×10^{-2}
C. 4.11×10^{-2}
D. 8.21×10^{-2}

3. Which of the following is the correct order for the boiling points of the listed solutions and water? (The K_b of water is 0.51 °C·kg/mol.)

I. Saturated solution of ZnF_2 in water
II. Saturated solution of $PbBr_2$ in water
III. Pure water

A. III < II < I
B. III < I < II
C. I < II < III
D. II < I < III

4. What would Scientist 1 predict about the solubilities of PbF_2 and PbI_2 in benzene?

A. PbF_2 is more soluble than PbI_2.
B. PbI_2 is more soluble than PbF_2.
C. The solubilities would be roughly the same.
D. Scientist 1 only refers to the solubilities of compounds in water.

PASSAGE II (QUESTIONS 1–5)

Hydrogen peroxide decomposes into oxygen and water according to Equation 1:

$$2H_2O_2(aq) \longrightarrow O_2(g) + 2H_2O(l)$$

Equation 1

Hydrogen peroxide is an antiseptic usually used to treat minor abrasions and scrapes. When it is applied to an open wound, the enzyme catalase in the blood converts hydrogen peroxide to water and oxygen gas. However, hydrogen peroxide will also decompose on its own when exposed to air, according to Equation 1.

Iodide catalyzes the decomposition of hydrogen peroxide by Mechanism 1:

$$H_2O_2(aq) + I^-(aq) \longrightarrow IO^-(aq) + H_2O(l)$$

$$H_2O_2(aq) + IO^-(aq) \longrightarrow I^-(aq) + H_2O(l) + O_2(g)$$

Mechanism 1

A student decided to investigate the shelf life of hydrogen peroxide by studying the kinetics of hydrogen peroxide decomposition.

Experiment 1
The student prepares two stock solutions of 0.060 M and 0.090 M KI in water, as well as stock solutions of 0.040 M and 0.080 M H_2O_2 in water. The student stores the hydrogen peroxide solutions in the freezer until beginning the experiment. He adds 100 mL of each hydrogen peroxide solution to 100 mL of each KI solution. The student measures the rate of oxygen formation for each trial. The results are summarized in Table 1.

Trial No.	KI stock concentration (M)	H_2O_2 stock concentration (M)	Initial rate of O_2 formation ($mol \cdot L^{-1} \cdot sec^{-1}$)
1	0.060	0.040	3.61×10^{-8}
2	0.060	0.080	7.25×10^{-8}
3	0.090	0.040	5.39×10^{-8}
4	0.090	0.080	1.08×10^{-7}

Table 1

Experiment 2
The student repeats Experiment 1, but uses flasks that were not properly cleaned. He observes the formation of molecular iodine, but no oxygen formation.

The student suspects that acid was present in the reaction vessel. In order to test his hypothesis, the student performs a third experiment.

Experiment 3

The student repeats Experiment 1, except he adds 100 mL of nitric acid to each reaction vessel before he adds the hydrogen peroxide solutions. He measures the initial rate of I_2 formation for the various concentrations of reactants. The results are summarized in Table 2.

Trial No.	Initial KI concentration (M)	Initial H_2O_2 concentration (M)	Initial HNO_3 concentration (M)	Initial rate of I_2 formation ($mol \cdot L^{-1} \cdot sec^{-1}$)
1	0.060	0.040	0.250	4.09×10^{-6}
2	0.060	0.080	0.250	8.23×10^{-6}
3	0.090	0.040	0.250	6.17×10^{-6}
4	0.060	0.040	0.500	8.21×10^{-6}

Table 2

After analyzing the experimental results, the student determines that $k_{obs}[H^+][I^-][H_2O_2]$ is the rate expression that governs the reactions of Experiments 2 and 3. The student proposes a mechanism consistent with this rate law, as shown in Mechanism 2.

$H_2O_2 + H^+ \rightleftharpoons H_3O_2^+$ **Step 1**

$I^- + H_3O_2^+ \longrightarrow HOI + H_2O$ **Step 2**

$I^- + HOI \longrightarrow I_2 + OH^-$ **Step 3**

$H^+ + OH^- \longrightarrow H_2O$ **Step 4**

Mechanism 2

1. What is the rate expression for the reaction in Experiment 1?

A. Rate = $k[I^-][H_2O_2]$
B. Rate = $k[H^+][I^-][H_2O_2]$
C. Rate = $k[I^-]^2[H_2O_2]$
D. Rate = $k[I^-][H_2O_2]^2$

2. What is the slowest step in the mechanism proposed for Experiments 2 and 3?

A. Step 1
B. Step 2
C. Step 3
D. Step 4

3. What type of reaction is Step 4 of Mechanism 2?

A. Precipitation
B. Reduction-oxidation
C. Neutralization
D. Displacement

4. What is the maximum mass of $I_2(s)$ that the student can obtain from Trial 2 of Experiment 3?

A. 0.20 g
B. 0.76 g
C. 2.03 g
D. 3.18 g

5. Which of the following would increase the rate of I_2 formation in Experiments 2 and 3?

A. Adding additional H^+ to further catalyze the reaction
B. Adding additional OH^- to drive the reaction toward the products
C. Increasing the temperature of the reaction vessels
D. Removing HOI to drive the reaction toward the products

PASSAGE III (QUESTIONS 1–6)

Magnetic therapy is a form of alternative medicine in which magnetic fields are applied to specific parts of the body. Practitioners believe this treatment has various health benefits, although there is little scientific support. It is thought that magnetic field strength must exceed 0.04 T to be effective. To determine the magnetic field strength of a magnetic therapy bracelet, a student created a device, which is illustrated in Figure 1. The device accomplishes this task by balancing the magnetic force against a known force generated by the spring with spring constant k. The circuit consists of a DC battery supplying 100 V connected through a 2.5 Ω resistor and a metal rod. The metal rod is 30 cm long, has a mass of 0.7 kg, and slides with negligible friction along the arms of the circuit. The circuit is fixed in the plane of the page, and a permanent magnetic field B points out of the page (the generator is not shown). A spring is connected to the metal rod on one end and to an immobile piece of nonconducting material on the other.

In the configuration shown below, the metal rod experiences a force generated by the spring and a magnetic force $F = iLB$, where i is the current through the rod, L is the length of the rod, and B is the magnitude of the external magnetic field. The spring's equilibrium length x_{eq} is defined as the spring length for which the rod experiences no net force. In Figure 1, the switch is open, the spring is at its relaxed length x_0, and the metal rod is at rest.

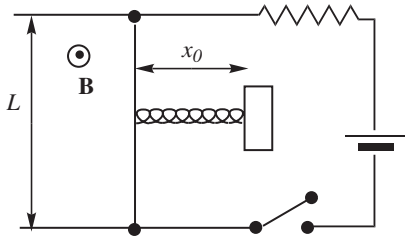


Figure 1

1. After the switch has been closed, which of the following best describes what happens to the spring?

A. The spring compresses.
B. The spring stretches.
C. The length of the spring doesn't change.
D. The spring will either stretch or compress depending on the strength of the magnetic field.

2. If another 2.5 Ω resistor is added in series with the resistor and the battery in the circuit, how will the magnetic force on the rod change?

A. It will decrease by a factor of 2.
B. It will not change.
C. It will increase by a factor of 2.
D. It will increase by a factor of 4.

3. If the 2.5 Ω resistor were replaced with a 2.5 F capacitor, which of the following describes the motion of the rod when the switch is closed?

A. It remains motionless at first.
B. It accelerates.
C. It moves with a constant velocity.
D. It accelerates until it reaches a constant velocity.

4. If the metal rod were lengthened to 45 cm, how would the current through the circuit change?

A. It would remain the same.
B. It would increase.
C. It would decrease.
D. It would first increase, then decrease.

5. If the switch were closed, how long would it take for 16 kJ of heat to be dissipated by the 2.5 Ω resistor?

A. 1.0 s
B. 2.0 s
C. 4.0 s
D. 8.0 s

6. If a capacitor were inserted after the 2.5 Ω resistor, what is the maximum potential difference that could exist across its plates?

A. 40 V
B. 80 V
C. 100 V
D. 120 V

PASSAGE IV (QUESTIONS 1–4)

Oxidative phosphorylation, when viewed holistically, is a combustion reaction. However, each of its constituent steps is not. It is necessarily broken up into smaller steps to prevent a rapid release of energy. The explanation for this is twofold. One, if the energy were released all at once, it would undoubtedly kill the cell. Two, it is far more efficient and manageable to harness energy that is released in smaller amounts over time. The overall energy released from NADH as a result of oxidative phosphorylation is the enthalpy of the cellular redox reaction.

All reactions result in enthalpy changes that represent the heat absorbed or lost by a system at constant pressure. The standard enthalpy of formation (ΔH_f°) is a specific case of enthalpy describing the heat lost or gained when a substance in its standard state is formed from the appropriate elements in their standard states. Enthalpy values are commonly in kJ/mol.

The enthalpy change of a reaction is often found by adding the enthalpy changes of simpler reactions that comprise the net reaction. For example, since Reaction 3 = Reaction 1 + Reaction 2 (below), $\Delta H_3 = \Delta H_1 + \Delta H_2$.

$$2H_2(g) \rightarrow 4H(g)$$

Reaction 1

$$C(g) + 4H(g) \rightarrow CH_4(g)$$

Reaction 2

$$C(g) + 2H_2(g) \rightarrow CH_4(g)$$

Reaction 3

Enthalpy is important in finding the free energy of a system, which can help determine the spontaneity of the reaction. Free energy is defined by the following formula:

$$\Delta G = \Delta H - T\Delta S$$

where ΔG = the free energy change of the reaction

ΔH = the enthalpy change of the reaction

T = the absolute temperature of the reaction

ΔS = the entropy change of the reaction

The following enthalpy values were gathered to study the energies of different hydrocarbons.

Fuel	Formula	ΔH_{comb} (kJ/mol)
Hydrogen	H_2	–241.8
Ethanol	CH_3CH_2OH	–1235.4
Acetylene	C_2H_2	–1255.5
Ethane	C_2H_6	–1427.7
Propanol	$C_6H_{12}O_6$	–2021

1. If the ΔH_f° of $CO_2(g)$ is –393.5 kJ/mol, and the ΔH_f° of $H_2O(g)$ is –241.8 kJ/mol, what is the ΔH_f° of acetylene?

A. –620.1 kJ/mol
B. –226.6 kJ/mol
C. 226.6 kJ/mol
D. 620.1 kJ/mol

2. Which of the following reactions would produce the greatest increase in entropy?

A. Combustion of hydrogen
B. Combustion of acetylene
C. Combustion of ethanol
D. Combustion of propanol (–2021 kJ/mol)

3. Given that ΔS for the combustion of ethanol is 0.217 kJ/mol·K at 25°C, what is the value of the change in the Gibbs free energy for this reaction?

A. –64.7 kJ/mol of ethanol
B. –1170 kJ/mol of ethanol
C. –1235 kJ/mol of ethanol
D. –1300 kJ/mol of ethanol

4. Which of the following pairs of characteristics defines a reaction that is temperature dependent?

I. Positive ΔH, positive ΔS
II. Positive ΔH, negative ΔS
III. Negative ΔH, positive ΔS
IV. Negative ΔH, negative ΔS

A. I and II only
B. I and III only
C. I and IV only
D. II and III only

PASSAGE V (QUESTIONS 1–5)

Chronic usage of loop diuretics can induce contraction alkalosis. Contraction alkalosis is characterized by a loss of fluid in the extracellular space. Without this fluid, the concentration of bicarbonate in the blood is relatively high. The bicarbonate snatches up the H^+ in solution and increases the pH of the blood. Contraction alkalosis is identified by measuring urine [Cl^-]. If urine [Cl^-] falls below 25 mEq/L, contraction alkalosis is indicated. [Cl^-] can be determined by titrating with $AgNO_3$. It is important not to overestimate the amount of [Cl^-] in order to ensure an accurate diagnosis. The Volhard method is one way to determine the exact endpoint of the titration.

The exact concentration of silver ion in solution can be determined experimentally by titrating with the thiocyanate ion, SCN^-. This method for silver determination is called the *Volhard method* and uses iron (III) as an indicator because it gives a deep red color at the first excess of thiocyanate ion in solution. The solution must be kept fairly acidic to prevent $Fe(OH)_3$ formation. The most useful application of the Volhard method is in the determination of halide ion concentration. After a halide solution has been titrated with silver ion to precipitate out insoluble silver halide salts, the solution can be back-titrated with thiocyanate to determine the amount of excess silver ion. This gives a more accurate reading of the halide endpoint. Relevant solubility products for the precipitates involved are given below.

A student planned to determine the concentration of chloride ion in an unknown solution. In order to obtain the best possible endpoint of silver, he filtered out the silver chloride precipitate and titrated the solution with 0.001M sodium thiocyanate. The sodium thiocyanate was contaminated with NaOH and the red $FeSCN^{2+}$ indicator never formed.

Compound	K_{sp}
AgSCN	1.0×10^{-12}
AgCl	1.8×10^{-10}
$Fe(OH)_3$	2.6×10^{-39}

Table 1

1. In a Volhard titration, why does AgSCN precipitate before any $FeSCN^{2+}$ forms?

A. The anion to cation bond in silver thiocyanate has more ionic character.
B. Silver thiocyanate is the less stable of the two compounds.
C. Silver thiocyanate reaches equilibrium in solution at lower concentrations.
D. Silver thiocyanate is the heavier of the two compounds.

2. Which of the following has the highest molar solubility?

A. $BaCrO_4$ ($K_{sp} = 2.1 \times 10^{-10}$)
B. AgCl ($K_{sp} = 1.6 \times 10^{-10}$)
C. $Al(OH)_3$ ($K_{sp} = 3.7 \times 10^{-15}$)
D. $PbCO_3$ ($K_{sp} = 3.3 \times 10^{-14}$)

3. Why was the endpoint never indicated in the student's Volhard titration?

A. The presence of NaOH prevented NaSCN dissociation.
B. A hydrated AgOH complex formed which is almost completely soluble.
C. A hydrated $Fe(OH)_3$ complex formed which is almost completely insoluble.
D. The NaOH neutralized the cations in the solution.

4. When measuring $[Cl^-]$ using the Volhard method, it was determined that 0.1 moles of thiocyanate reacted. If it took 0.5 moles of Ag^+ to reach the equivalence point, how many moles of Cl^- were present in solution?

A. 0.3 moles
B. 0.4 moles
C. 0.5 moles
D. 0.6 moles

5. What is the minimum $[OH^-]$ necessary for $Fe(OH)_3$ to form in the Volhard titration?

A. 1×10^{-11} M
B. 1×10^{-10} M
C. 3×10^{-10} M
D. 3×10^{-9} M

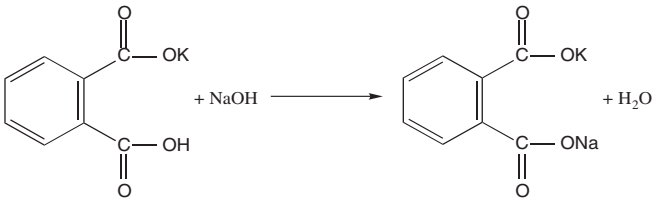
PASSAGE VI (QUESTIONS 1–7)

In order for a titration to yield concentration data with an acceptable level of accuracy, standardized solutions with precisely known normalities must be prepared. This is no small accomplishment, as most commonly used titrants are difficult to handle in the pure state. Sodium hydroxide, for example, is a common basic standard; it is hygroscopic as a solid and thus absorbs water from the atmosphere. Hydrogen chloride, a common acidic standard, is a gas at ambient temperatures and pressures; saturated aqueous solutions can be prepared simply by bubbling the gas through deionized water, but temperature effects on solubility and volatility generally limit the significance of concentration calculations to the nearest 0.1 M.

To overcome the difficulties inherent in the preparation of standard solutions, one usually resorts to the use of a primary standard such as sodium carbonate, Na_2CO_3, or potassium hydrogen phthalate (KHP). The primary standard is used to determine the concentration of a newly prepared solution, whose concentration can then be adjusted via dilution. The fundamental criteria for the selection of a primary standard are listed below:

1. It must be stable in light, in air, and in the solution to be titrated.
2. It must be free of any significant quantity of impurities.
3. It must be sufficiently soluble in the solution to be titrated.
4. It must react with the substance to be titrated by a single, known pathway.
5. Its reaction with the titrated substance must be rapid.
6. It should be nontoxic, and present few disposal problems.
7. It should be readily available and relatively inexpensive.

A student preparing to perform a series of titrations on a group of vitamin samples produced a secondary standard of 0.01000 N NaOH(*aq*) by first making a more concentrated solution. She dissolved approximately 2.5 mg of NaOH(*s*) in enough water to make 250.0 mL of solution. This solution was then standardized against KHP according to the reaction:



KHP
(204.2 g/mol)

The student placed 385.43 mg of KHP into a clean flask, added 50 mL of deionized water and two drops of phenolphthalein solution, and then titrated with the freshly prepared NaOH solution. The endpoint was reached upon addition of 25.10 mL of the basic solution. From this titration data the student calculated the concentration of the NaOH solution as 0.07520 N then, using a pipette and a volumetric flask, diluted the NaOH solution, as needed, to a final concentration of 0.01000 N.

1. The student decides to study venous [Cl^-], but must first prepare a $AgNO_3$ secondary standard. Which of the following compounds would be an acceptable primary standard for the titration of a $AgNO_3$ solution?

A. NaCl
B. HCl
C. KOH
D. Hg_2Cl_2

2. $Ca(OH)_2$ is commonly used to treat tooth infections. If a solution of $Ca(OH)_2$ were prepared, the addition of 0.5 mol/L of which of the following compounds would result in the greatest change in [Ca^{2+}] in a 0.01 N $Ca(OH)_2$ solution?

A. $Co(OH)_2$
B. CsOH
C. $Fe(OH)_3$
D. $Al(OH)_3$

3. In addition to being an indicator, phenolphthalein can be used to detect the presence of blood, as it turns pink upon binding to hemoglobin. When used in the titration of NaOH, phenolphthalein has a pK_a closest to which of the following?

A. 3.8
B. 5.5
C. 7
D. 9.3

4. A student is preparing a NaOH solution to titrate a folic acid (vitamin B9) solution. She adds 5 grams of NaOH(*s*) to 1 L of water. Which of the following is likely to be the molarity of the resulting solution?

A. 0.120 M
B. 0.125 M
C. 0.130 M
D. 0.135 M

5. While analyzing samples for vitamin B content, a student found it necessary to titrate for niacin. If a 5.00 mL sample containing no other acidic compounds required the addition of 3.75 mL of 0.01000 N NaOH solution to reach the equivalence point, how many moles of niacin would be found in one liter of the sample solution?

A. 18.75
B. 0.75
C. 1.3×10^{-2}
D. 7.5×10^{-3}

6. Commercially available KHP must be prepared in a "dry box," usually under an argon atmosphere. One likely reason for this necessity is that:

A. freshly prepared KHP is hygroscopic, and thus must be kept in an inert atmosphere.
B. the phthalic acid from which it is made is extremely volatile, and thus must be used in the absence of oxygen.
C. the KOH used in the preparation is hygroscopic, and thus must be weighed in an anhydrous environment.
D. very pure KHP is extremely toxic, and thus requires careful handling.

7. According to the information contained in the passage, which of the following reactions would be the best choice for the standardization of an aqueous nitric acid solution?

A. $Al_2O_3(s) + 6HNO_3(aq) \rightarrow 2Al(NO_3)_3(aq) + 3H_2O(l)$
B. $ZnCl_2(aq) + 2HNO_3(aq) \rightarrow Zn(NO_3)_2\,(aq) + 2\,HCl(aq)$
C. $2Cu(s) + 6HNO_3(aq) \rightarrow 2Cu(NO_3)_2(aq) + NO(g) + NO_2(g) + 3H_2O(l)$
D. $NaOH(s) + HNO_3(aq) \rightarrow NaNO_3(aq) + H_2O(l)$

PASSAGE VII (QUESTIONS 1–6)

The biological cell membrane is a complex structure known for its function as a tightly managed gatekeeper for the cell. The cell membrane can be modeled as an electrical circuit consisting of a capacitor in parallel with four pathways, each consisting of a variable conductor in series with a battery. Figure 1 shows this equivalent circuit model for the cell membrane.

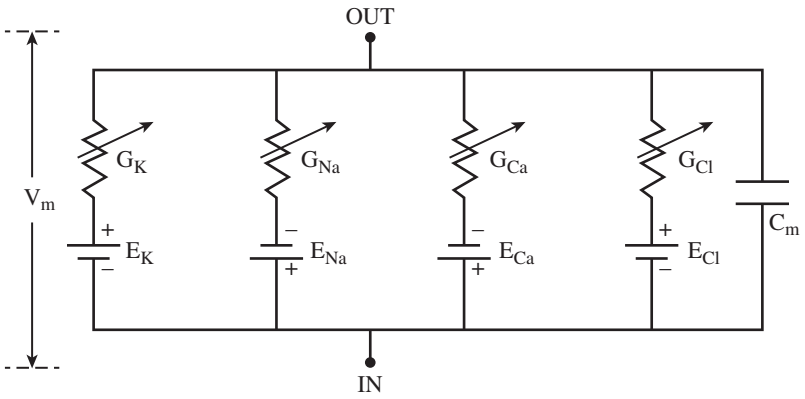


Figure 1. Equivalent circuit model for the cell membrane.

Cytoplasm and extracellular fluid are two electrically conducting regions separated by a thin dielectric, the lipid bilayer, which, at about 8 nm thickness, is thin enough so that the accumulation of charges on one side of the bilayer creates a coulombic force strong enough to attract opposite charges on the other side. The cell membrane thus acts as a capacitor, C_m, with a constant value estimated to be about 2 $\mu F/cm^2$.

A concentration gradient corresponding to each of the four principal biological ions—potassium, sodium, calcium, and chloride—exists across the plasma membrane. This creates an electromotive force that drives the ion through its ion-specific channel at a constant rate. The Nernst potential for that ion is the electrical potential difference across the channel, which can be represented in the equivalent circuit of the cell membrane as a battery.

The hydrophobic portion of the lipid bilayer impedes the movement of charges across it, which gives rise to the electrical resistance of the cell membrane. The conductance of a pure lipid bilayer is so low that the movement of ions across the membrane is almost entirely through alternative pathways provided by embedded molecules like leakage channels, ligand-gated channels, and voltage-gated ion channels. Thus, the conductances corresponding to each of the principal ions vary with the number and type of ion channels present in that patch of the cell membrane.

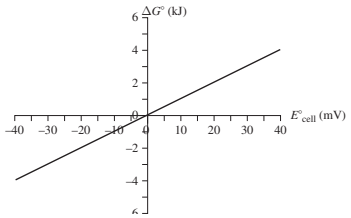
1. If $[K^+]$cytoplasm = 400 mM and $[K^+]$extracellular fluid = 20 mM for the neuron of a giant squid, what is the value of $|E_k|$ in the equivalent circuit for this neuron?

Assume standard conditions. (RT/F = 0.025 V/mol, ln 0.05 = –3)

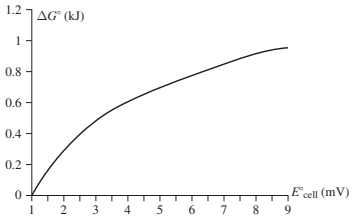
A. 0 mV
B. 25 mV
C. 50 mV
D. 75 mV

2. **W**hich of the following graphs accurately represents the relationship between standard Gibbs free energy (ΔG°) and standard cell potential (E°cell)?

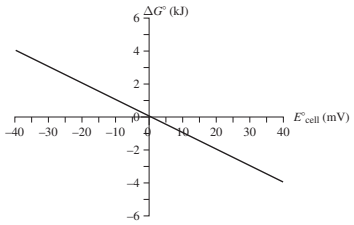
A.



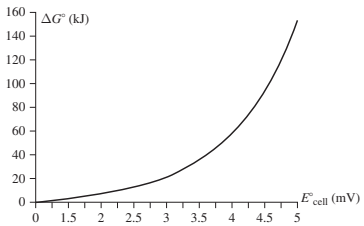
B.



C.



D.



3. What is the value of G_{Cl} if the current flowing through the pathway corresponding to the chloride ion is 0.5 μA, V_m = 10 mV and E_{Cl} = 5 mV?

A. $5 \times 10^{-5}\ \Omega^{-1}$
B. $1 \times 10^{-4}\ \Omega^{-1}$
C. $5 \times 10^{-2}\ \Omega^{-1}$
D. $1 \times 10^{-1}\ \Omega^{-1}$

4. Which of the following statements about the movement of ions across the plasma membrane is TRUE?

A. Ions with high permeability move through a low-resistance pathway and ions with low permeability move through a high-resistance pathway.
B. Ions with high permeability move through a high-resistance pathway and ions with low permeability move through a low-resistance pathway.
C. Ions with high permeability move through a high-resistance pathway and ions with low permeability move through a high-resistance pathway.
D. Ions with high permeability move through a low-resistance pathway and ions with low permeability move through a low-resistance pathway.

5. Which of the following statements about the equivalent circuit model for the plasma membrane is TRUE?

A. The capacitance of the membrane is relatively unaffected by the molecules that are embedded in it.
B. The capacitance of the membrane is inversely proportional to the area of the membrane.
C. The resistance of the membrane is relatively unaffected by the molecules that are embedded in it.
D. The resistance of the membrane is directly proportional to the area of the membrane.

6. Which of the following statements about the electromotive force created by the concentration gradient of an ion across a membrane is TRUE?

A. Its unit of measurement is Newtons or $kg \cdot m/s^2$.
B. It is the work done to move a unit charge around a complete circuit.
C. Its positive terminal is closer to the side with the higher ion concentration.
D. It is analogous to the voltage generated by a concentration cell, which is a special type of electrolytic cell.

DISCRETE PRACTICE QUESTIONS (QUESTIONS 1–7)

1. A man standing at the top of a hill hears a loud explosion followed by a tremor of the ground beneath his feet. What is likely true based on this situation?

A. The sound waves produced from the explosion traveled faster through the air than they did through the ground.
B. The temperature of the air is greater than the temperature of the ground.
C. The bulk modulus of the ground is less than the bulk modulus of the air.
D. The explosion and the tremor did not originate from the same source.

2. If a grandfather perceives sound as 100 times less intense than his grandchild, with what decibel level will the grandchild perceive a sound that his grandfather hears as 90 decibels?

A. 70 dB
B. 90 dB
C. 100 dB
D. 110 dB

3. A tone from a tuning fork travels down the ear canal of a listening musician. Given that the musician's ear canal can be thought of as a pipe with one closed end with a length of 2.5 cm, what is the wavelength of this tone's third harmonic in the ear canal?

A. 0.033 cm
B. 0.67 cm
C. 3.3 cm
D. 6.7 cm

4. A sound wave of 103 decibels is incident upon an eardrum with a surface area of 5.5×10^{-2} m^2. Assuming no loss of energy, what is the power transmitted on that eardrum?

A. 1.4 J
B. 5.5 J
C. 27 J
D. 55 J

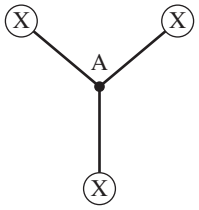
5. An electron (-1.6×10^{-19} C) orbiting He^+ is about 2×10^{-10} m from the nucleus. Approximately what is the force exerted on the electron by the nucleus?

A. (6.5×10^{-29})*k
B. (1.3×10^{-28})*k
C. (1.3×10^{-18})*k
D. (3.9×10^{-28})*k

6. If the bond between two phosphate groups in ATP is 9×10^{-11} m, by how much would the electrical potential energy change if the bond length were three times shorter?

A. It would decrease by three times.
B. It would decrease by nine times.
C. It would increase by three times.
D. It would increase by nine times.

7. The net charge of a particular amino acid is 'x'. If three copies of this amino acid are equidistant from point A, what is the electric potential at A?



A. 0
B. kx/r
C. kx/r^2
D. 3kx/r