

MCAT Chemistry and Physics 2 Homework

Passage I (Questions 1-7)

This passage discusses some of the challenges of using common acidic and basic standards in titrations. It lists criteria for primary standards, which overcome some of these challenges. It then goes on to describe a titration performed with KHP and NaOH.

Passage Outline

Paragraph 1: Difficulties of preparing a standard solution for titration

Paragraph 2: Resolve difficulty through use of Na_2CO_3 or KHP. Criteria for primary standard.

Paragraph 3: Preparation of NaOH solution using KHP standard

Figure: Reaction of NaOH with KHP

Paragraph 4: Preparation of NaOH solution using KHP cont.

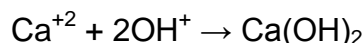
Question 1: A

The first question asks us to select a primary standard for the titration of a new compound. How do we know what makes a good primary standard. Luckily, the passage provides us with a list of criteria that make a good primary standard. Any of the answers that violate these rules will NOT make good primary standards. Let's look at the answer choices.

Answer (A) suggests NaCl and is correct. We can't assess its compliance with all the criteria, but we certainly know that it is stable, nontoxic, and inexpensive. Answer (B) suggests HCl. We already know that HCl is a poor primary standard from the passage which cites temperature effects on solubility and volatility as reasons that limit the calculations made when using it in titrations. Answer (C) suggests KOH. KOH is very similar to NaOH, which was cited in the passage as a poor primary standard. Additionally, the AgOH product from AgNO_3 and KOH is not sufficiently insoluble to make for a good titration, violating criteria 3. Answer (D) suggests Hg_2Cl_2 which is insoluble in water and thus violates criteria 3. Mercury is also a toxic substance, which violates criteria 6, and makes it a poor primary standard.

Question 2: B

This question gives us a solution of .01 N $\text{Ca}(\text{OH})_2$ and asks which compound would produce the smallest change in $[\text{Ca}^{+2}]$ if .5 M were added. To answer this question we need to employ Le Chatelier's Principle, which basically states that a system at equilibrium will shift to counteract any changes placed on the system. What is the equilibrium equation in this case?



Do we see any similarities in the answer choices? All the answers contain OH^- ions. Which way will adding OH^- ions shift the system? To the right to counteract the addition on the left. As the system shifts to the right, it will consume Ca^{+2} , thus reducing the $[\text{Ca}^{+2}]$. Thus, we can predict that the compound that will **change** $[\text{Ca}^{+2}]$ the least will have the lowest number of moles of OH^- . We are told we are given .5 mol/L of each compound so first we will need to calculate the number of moles of OH^- for each compound.

$$\frac{.5 \text{ mol Co(OH)}_2}{\text{liter}} \times \frac{2 \text{ mol OH}^-}{1 \text{ mol Co(OH)}_2} = 1 \text{ mol OH}^-$$

$$\frac{.5 \text{ mol CsOH}}{\text{liter}} \times \frac{1 \text{ mol OH}^-}{1 \text{ mol CsOH}} = .5 \text{ mol OH}^-$$

$$\frac{.5 \text{ mol Fe(OH)}_3}{\text{liter}} \times \frac{3 \text{ mol OH}^-}{1 \text{ mol Fe(OH)}_3} = 1.5 \text{ mol OH}^-$$

$$\frac{.5 \text{ mol Al(OH)}_3}{\text{liter}} \times \frac{3 \text{ mol OH}^-}{1 \text{ mol Al(OH)}_3} = 1.5 \text{ mol OH}^-$$

We see from the above calculations that CsOH will introduce only .5 mol of OH^- while the others will yield 1 or 1.5 moles. Because of this, it will **push** the equation to the right the least amount, and produce the smallest reduction in $[\text{Ca}^{+}]$.

Question 3: D

Question 3 asks us what the likely pKa of phenolphthalein is. To answer this, we need to have some knowledge of indicators, titration, and the henderson hasselbalch equation. Indicators are typically weak acids or bases that will change color near the equivalence point of the titration. What is the equivalence point? The equivalence point is where we have an equal number of acid and base equivalents. (This is in contrast to the end point, which is the point where the indicator changes color.) The henderson hasselbalch equation gives us an expression to calculate the pH of a buffer solution. An important relationship is that at the equivalence point, the $\text{pH}=\text{pKa}$. (At the equivalence point, the concentration of acid and base will be equal, and the log of 1 is 0 (see equation)).

$$\text{pH} = \text{pK}_a + \log \frac{[\text{conjugate base}]}{[\text{weak acid}]}$$

Let's put this all together. In the titration in the question, NaOH was titrated with KHP, a weak acid. (Looking at its structure in the passage, we see a carboxylic acid group). We know that NaOH is a strong base. Titrations of strong base and a weak acid should have basic (greater than 8) equivalence points. Thus, we know that the equivalence point in this titration was basic. Because phenolphthalein was used as the indicator, we know it must have a pKa similar to that of KHP. Because $\text{pH}=\text{pKa}$ at the equivalence

point, and we know we must have a basic pH at the equivalence point, we can reason that pKa of KHP (and phenolphthalein) is greater than 8. The only answer choice greater than 8 is answer (D).

Question 4: A

This question asks us to calculate the molarity of a solution made from 5 grams of NaOH and 1 L of water. Molarity is simply moles per liter. We are given the value for L so all we need to do is calculate moles from grams.

$$5 \text{ g NaOH} \times 1 \text{ mol}/40 \text{ gNaOH} = 5/40 \text{ mols NaOH} = .125 \text{ mols NaOH}$$

$$0.125 \text{ mol NaOH}/1 \text{ L H}_2\text{O} = 0.125 \text{ M NaOH}$$

This would be the concentration of NaOH if our 5 gram sample was 100% NaOH. However, the passage tells us that NaOH is hygroscopic and will absorb water. Thus, a percentage of that 5 grams was water, so the actual concentration of NaOH will be less than .125 M. Answer (A) is the only one that fits the bill.

Question 5: D

This question asks us to calculate the number of moles of niacin in one liter of the sample solution. In this question, a sample containing niacin was titrated with NaOH. It gives us the volume and normality of the NaOH at the equivalence point, as well as the volume of the sample at the equivalence point. We can use this information to calculate the normality of the sample with the following equation:

$$V_a N_a = V_b N_b$$

$$N_a(5 \text{ ml}) = (.01 \text{ N})(3.75 \text{ ml}) \quad N_a = .0075 \text{ N}$$

Recall that normality is simply molar equivalents of acid per liter. Thus, 1 L of a .0075 N solution would contain .0075, or 7.5×10^{-3} moles of niacin.

Question 6: C

This question asks us why KHP must be kept in a dry box. We aren't told much about KHP in the passage so it's probably best to jump right into the answer choices.

Answer (A) suggests KHP is hygroscopic and thus should be kept in an inert atmosphere. We know from the passage that a hygroscopic compound will absorb water from the atmosphere. We can't be sure if KHP is indeed hygroscopic, but an inert environment doesn't mean it won't contain water. Answer (B) suggests the phthalic acid component of KHP is volatile and should be kept in the absence of oxygen. While this may be true, it is not a reason for keeping KHP in an environment devoid of water. (Oxygen can still be present in a dry box) Answer (C) suggest KHP is hygroscopic and should be weighed in an anhydrous environment. If KHP absorbs water from the atmosphere, a dry box would indeed provide an anhydrous environment for weighing. Answer (D) suggest KHP is toxic and requires careful handling. Like (B), this may be true, but a dry box won't do anything to address the toxicity.

Question 7: A

Question 7 asks us which of the following reactions would be best to standardize aqueous nitric acid solution. Here it's tough to make a prediction, so it's best to tackle the answer choices one by one. Since the question is asking about standard selection we should be ready to refer back to the passage for the list of standard criteria.

Answer (A) is the best answer mostly because the other answers are flawed. We see it reacting on a single pathway, and is not in violation of any of any of the criteria listed in the passage. Answer (B) shows that all the reactants and products are aqueous, thus making this a mixture, rather than a double displacement reaction. Additionally, we see HCl listed as a product. Having two strong acids would make it impossible to determine an endpoint and make it useless in a titration. Answer (C) is wrong because it violates criteria 3 (solid copper is not soluble in water) and violates criteria 4 (we see multiple products forming). Answer (D) has NaOH being used as the primary standard. As mentioned at the beginning of the passage, NaOH has several limitations that make it a poor primary standard.

Passage II (Questions 1-5)

This is an experimental passage discussing the decomposition of H_2O_2 . It describes several experiments meant to determine the rate law for this reaction.

Passage Outline

Paragraph 1: Hydrogen peroxide decomposes to water and oxygen

Equation 1: Decomposition of H_2O_2

Mech 1:Decomposition of H_2O_2 with I^- catalyst

Experiment 1: Experiment measures rate of O_2 production in H_2O_2 decomposition

Experiment 2:Repeat of exp. 1 with acidic contaminant

Experiment 3:Experiment measures rate of I_2 formation with added nitric acid

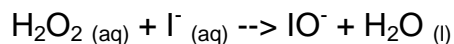
Table 1: Results of experiment 1

Table 2: Results of experiment 3

Mech 2:Proposed rate law and mechanism for exp. 3

Question 1: A

This question asks us to find the rate expression for the reaction in experiment 1. We should be able to make a strong prediction here. Recall that rate expressions must be determined experimentally. What is the reaction in question?



The general rate law expression is a constant multiplied by the concentration of the reactants raised to an exponent. In this case:

$$\text{rate} = k[\text{H}_2\text{O}_2]^x[\text{I}^-]^y$$

To determine the exponents we must refer to experimental data. Where is the data for experiment 1? We will find it in table 1. To determine the exponent for H_2O_2 we need to find a trial where the $[\text{KI}]$ is kept constant, and then compare the change in H_2O_2 to the change in rate. Trials 1 and 2 work in this case. We see that when H_2O_2 doubles, the rate also doubles. Thus we can say that the reaction is first order in terms of H_2O_2 , and $x=1$.

Trial No.	KI stock concentration (M)	H_2O_2 stock concentration	Initial rate of O_2 formation ($\text{mol}\cdot\text{L}^{-1}\cdot\text{sec}^{-1}$)
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}

Both double

same

Table 1

To determine the exponent for I^- we need to find a trial where the $[\text{H}_2\text{O}_2]$ is kept constant, and then compare the change in I^- to the change in rate. Trials 1 and 3 work in this case. We see that when KI increases by 50%, the rate also increases by 50%. Thus we can say that the reaction is first order in terms of KI , and $y=1$.

Trial No.	KI stock concentration (M)	H_2O_2 stock concentration (M)	Initial rate of O_2 formation ($\text{mol}\cdot\text{L}^{-1}\cdot\text{sec}^{-1}$)
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}

increase by 50%

increase by 50%

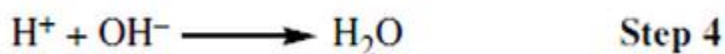
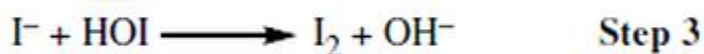
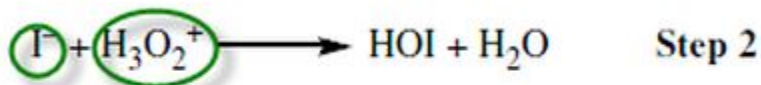
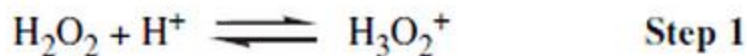
same

Table 1

Putting this all together we get $\text{rate} = k[\text{H}_2\text{O}_2]^1[\text{I}^-]^1$ which matches perfectly with choice (A).

Question 2: B

This question asks us to determine which step of the mechanism proposed for experiments 2 and 3 is the slow step. Recall that the slowest step determines the rate law. The passage tells us that the rate law for experiments 2 and 3 is $\text{rate} = k[\text{H}^+][\text{I}^-][\text{H}_2\text{O}_2]$. The slowest step will be the one that contains all the species present in the rate law. Looking at the mechanism, Step 2 fits the bill. (H_3O_2^+ is H_2O_2 plus a H^+)



Mechanism 2

Answer (B) is the best choice.

Question 3: C

This question asks us to identify the reaction type of step 4 in mechanism 2. Step 4 is $\text{H}^+ + \text{OH}^- \rightarrow \text{H}_2\text{O}$. Here we see an acid and a base combining to form water. What kind of reactions form water from an acid and a base? Neutralization reactions typically form a salt and water from an acid and a base. Thus choice (C) is the best answer here.

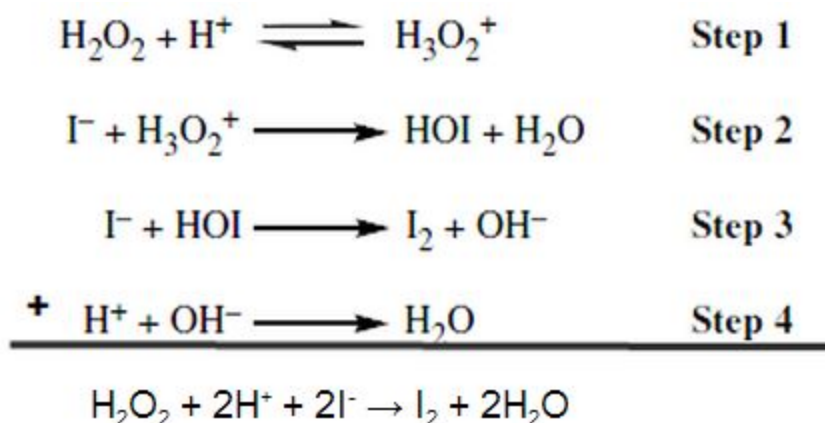
Answer (A) precipitation reactions will form a solid from an aqueous species. Answer (B) Redox reactions involve one atom losing electrons and another atom gaining them. Answer (D) Displacement reactions involve one atom or group being shuffled from one molecule to another.

Question 4: B

This question asks us to determine the maximum mass of I_2 that can be obtained from trial 2 of experiment 3. To calculate the maximum mass that can be obtained for a reaction we need to go through several steps. 1) Create a balanced equation 2) Identify the limiting reagent 3) Calculate the mass of the product obtained using the limiting reagent.

Step 1: Create a balanced equation.

To do this we need to add up the four steps of mechanism 2.



Step 2: Identify limiting reagent. Identifying the limiting reagent means looking at the starting amounts of each of the reactants and determining which one will **run out first**. To do this, we must take the concentrations of the reactants in trial 2 and convert them to moles, then divide by its coefficient to determine the moles of product (I_2) that will be formed. The reactant that will result in the least number of moles will be the limiting reagent.

$$1 \times 10^{-1} \text{ L} \times \frac{.06 \text{ mol KI}}{\text{L}} \times \frac{1 \text{ mol I}^-}{1 \text{ mol KI}} \times \frac{1 \text{ mol I}_2}{2 \text{ mol I}^-} = .003 \text{ mol I}_2$$

$$1 \times 10^{-1} \text{ L} \times \frac{.08 \text{ mol H}_2\text{O}_2}{\text{L}} \times \frac{1 \text{ mol I}_2}{1 \text{ mol H}_2\text{O}_2} = .008 \text{ mol I}_2$$

$$1 \times 10^{-1} \text{ L} \times \frac{.250 \text{ mol HNO}_3}{\text{L}} \times \frac{1 \text{ mol H}^+}{1 \text{ mol HNO}_3} \times \frac{1 \text{ mol I}_2}{2 \text{ mol H}^+} = .0125 \text{ mol I}_2$$

We see that KI will be the limiting reagent. To calculate the maximum mass of I_2 produced we convert moles of I_2 produced by the limiting reagent to grams of I_2 .

$$.003 \text{ mol I}_2 \times 250 \text{ g I}_2 / 1 \text{ mol I}_2 = .75 \text{ g I}_2$$

This matches best with answer (B).

Question 5: C

This question asks which of the answer choices will increase the rate of the I_2 production. Let's look at each answer separately.

Answer (A) suggests adding H^+ to further catalyze the reaction. Adding H^+ to the reaction would increase the rate of reaction, but H^+ is not a catalyst, so this answer can't be correct. Answer (B) suggests adding OH^- to drive the reaction to the products. Looking at mechanism 2, we see that OH^- is an intermediate, thus changing its concentration will not change the rate. Answer (C) suggests increasing the temperature of the reaction vessel. In general, increasing the temperature will increase the reaction rate by increasing the rate of collisions between molecules. Answer (D) suggests removing HOI. Like OH^- , HOI is an intermediate and will not affect the reaction rate.

Passage III (Questions 1-6)

This is an experimental passage that describes using a spring to determine the magnetic field.

Passage Outline

Paragraph 1: Magnetic field $>.04\text{ T}$ to be effective for treatment

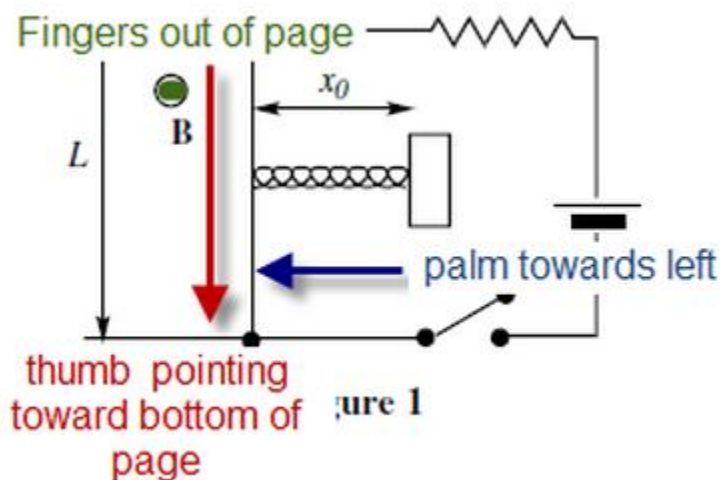
Paragraph 2: Experiment, magnetic $F = \text{spring } F$. I is in plane of page. B is pointing out of page

Paragraph 3: Description of Figure 1

Figure: Spring, magnetic field apparatus

Question 1: B

This question asks us what will happen when the switch is closed. Previewing the answer choices we see that they all require us to determine the direction of the magnetic force. To find the direction of the magnetic force, we use the right hand rule. The fingers point in the direction of the magnetic field (out of the page), the thumb points in the direction of the current (down), which results in the right palm facing in the direction of the magnetic force (to the left). Thus, the rod will move to the left and cause the spring to stretch, choice (B).



Question 2: A

This question asks what will happen to the magnetic force if we add another resistor in series with existing resistor in the circuit. What equation gives us the magnetic force?

$$F = ILB$$

Will any of the terms in this equation be changed by a changed resistance? We know that current is related to resistance by

$$V = IR$$

which can be rearranged to

$$I=VR$$

Combining these two equations gives us

$$F=(V/R)LB$$

We know that for resistors in a series, the total resistance is given by the sum of the resistances of the resistors. Thus, adding a resistor will increase the total resistance. We see in the above equation that increasing the resistance (R) will result in a decrease in magnetic force. Answer choice (A) is the only choice that mentions a decrease and is the best answer.

Question 3: B

This question asks us what will happen the rod if we remove the resistor and replace it with a capacitor. Just as in question 2, we know that the magnetic force, is given by

$$F=ILB$$

Combining this with ohms law, we see that

$$F=(V/R)LB$$

Removing the resistor will decrease the resistance, and thus increase the magnetic force. The second paragraph tells us that the magnetic force is usually balanced by the spring force. If we increase the magnetic force, the forces will no longer be balanced and the rod will experience a net force. If it experiences a net force, it will experience acceleration, choice (B). Answer (A) If it experiences a net force, it will be moving and thus won't be motionless. Answer (B) is correct. Answer (C) The rod will experience a net force, and thus will accelerate. If it is accelerating it can't be moving at a constant velocity. Answer (D) The rod will accelerate until it stops. For a body to have velocity it must be in motion.

Question 4: C

This question asks what effect lengthening the rod would have on the current through the circuit? What would lengthening the wire change? We know that resistance can be represented mathematically by

$$R = \frac{\rho L}{A}$$

where R is resistance, ρ is resistivity, L is length of the wire, and A is cross sectional area of the wire. We see that increasing length (L) would result in an increase in resistance (R). Applying this to Ohm's law, $I=V/R$ we see that increasing resistance (R) would decrease current (I). This matches perfectly with answer (C).

Question 5: C

This question asks us to calculate the number of seconds it would take a quantity of energy to be dissipated by a resistor. What relates time and energy? Power. Watts are the units for power, which can be broken down into energy/time, or J/s. The formula for power is $P=IV$. The voltage (V) is given in the passage as 100. We can calculate current (I) by substituting the values provided in the passage for resistance (2.5) and voltage (100 V) into Ohm's law.

$$I = V/R = 100/2.5 = 40 \text{ A}$$

Using the given voltage of 100 V, and the calculated current of 40 A, we can calculate the power dissipated by the resistor.

$$P=IV$$

$$P=(40)(100)$$

$$P=4000 \text{ W}$$

We know that watts=J/s, so solving for s, we get

$$s=J/W$$

$$s=(16 \times 10^3) \text{ J} / (4 \times 10^3) \text{ W}$$

$$s=4$$

This matches with choice (C).

Question 6: C

This question asks us what the maximum potential difference would be on a capacitor inserted after the resistor in the circuit. The capacitor will charge up until it achieves a voltage equal to that of the battery. Because the battery is 100 V, the maximum potential difference across the capacitor is 100 V, making choice (C) the best answer.

Passage IV (Questions 1-4)

This passage begins explaining how oxidative phosphorylation is a combustion reaction. It goes on to discuss enthalpy and free energy.

Passage Outline

Paragraph 1: Ox phos is a combustion rxn

Paragraph 2: Describes the enthalpy of formation

Paragraph 3: Adding enthalpy changes for simpler reactions gives net enthalpy change for rxn

Reactions: Shows the breakdown of hydrogen, and production of methane

Paragraph 4: Describes the free energy equation

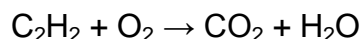
Table: Enthalpies of combustion

Question 1: C

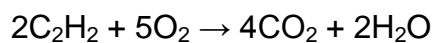
This question gives us the heats of formation for water and CO₂ and asks us what the heat of formation of acetylene is. Based on the information provided and the topic of the passage you should be thinking about using Hess's Law, which says that enthalpy changes for reactions are additive and can be expressed as

$$H_{\text{rxn}} = H_f (\text{products}) - H_f (\text{reactants})$$

Before we apply Hess's Law, we first must find the equation in question and balance it. What kind of reactions involve H₂O and O₂? Combustion reactions! Because the question asks about the H_f of acetylene, we need to write the equation for the combustion of acetylene.



Our next step is balance the equation.



Applying this equation to Hess's Law, we get

$$H_{\text{combustion}}(\text{acetylene}) = H_f (\text{CO}_2 + \text{H}_2\text{O}) - H_f (\text{C}_2\text{H}_2 + \text{O}_2)$$

Substituting H_f's given in the question, the H_{combustion} for acetylene given in the passage, and making sure to multiple the H_f's by their coefficients from the balanced equation we get

$$2(-1300) = [4(-400) + 2(-250)] - [2(H_f \text{ acetylene}) + 0]$$

Note that H_f for O₂ is 0 because it is in its standard state.

$$-2600 = -2100 - 2(H_f \text{ acetylene})$$

$$-500 = -2(H_f \text{ acetylene})$$

$$250 = (H_f \text{ acetylene})$$

This is closest to answer choice (C). Note that we rounded in our calculations so our answer will not be exact.

Question 2: D

This question asks us which of the reactions will produce the largest increase in entropy. Recall that entropy is a general measure of the disorder of a system. Gases will have greater entropy than solids as the molecules are more spread out, moving faster, and thus are more 'disordered. **Looking at the answer choices, we see that they are all combustion reactions. The product of combustion reactions are H₂O and CO₂. We can predict the reaction that will produce the greatest amount of entropy will be the one that produces the greatest amount of CO₂. Therefore, the more carbons a molecule has, the more CO₂ it will be able to produce. The answer with the compound containing the most carbons will produce the most moles of CO₂ and will thus create the greatest increase in entropy. Propanol has three carbons, making answer (D) the best answer.**

Question 3: D

This question asks us to calculate the Gibbs free energy change for the combustion of ethanol. This is a simple **plug and chug** question. We use the free energy formula from the passage $G=H-TS$. Substituting the change in entropy from the question, the heat of combustion of ethanol from the table, and the temperature in Kelvin, we get $G=(-1235)-(25+273)*(.217)$. Without carrying out the calculation, we see that our answer must be less than (more negative) than -1235. Answer (D) is the only answer choice that fits the bill.

Question 4: C

This roman numeral question asks which of the following reaction conditions are temperature dependent. Consider the free energy formula from the passage $G=H-TS$. We see that when H is negative and S is positive, the G will always be negative. Likewise, when H is positive and S is negative, the G will always be positive. All other conditions will produce (when the signs of H and S are the same) will result in a positive or negative G depending on the temperature, and thus can be called **temperature dependent**. This is summarized in the table below.

Statement	ΔG	ΔH	ΔS	Reaction
I	Negative if T is high	Positive	Positive	Spontaneous at high temperatures
II	Always positive	Positive	Negative	Never spontaneous
III	Always negative	Negative	Positive	Always spontaneous
IV	Negative if T is low	Negative	Negative	Spontaneous at low temperatures

Roman numerals I and IV are temperature dependent making answer (C) the best choice.

Passage V (Questions 1-5)

This passage describes the Volhard method for determine the silver ion concentration in a solution via titration.

Passage Outline

Paragraph 1: Contraction alkalosis results in \uparrow pH. Can measure it by measuring $[Cl^-]$.

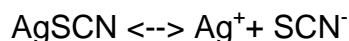
Paragraph 2: Volhard method determines concentration of silver ion via titration

Paragraph 3: Experiment to determine $[Cl^-]$; base contamination failed experiment

Table 1:Ksp Values

Question 1: C

This question asks us why AgSCN would precipitate before any FeSCN⁺² forms. Recall that a salt exists in equilibrium in a solution with its ions. The solution has a **capacity** for the dissolved ions which is represented by the Ksp. For example,



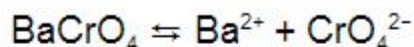
$$K_{sp} = [\text{Ag}^+][\text{SCN}^-]$$

When the concentration of ions exceeds the Ksp, a precipitate will form. This point at which this occurs is called the equilibrium point. A compound with a low Ksp will precipitate before a compound with a higher Ksp. Our answer should reflect this idea.

Answer (A) suggest that AgSCN bond has greater ionic character than FeSCN⁺². Ionic character wouldn't change the Ksp or concentrations of the ions. Answer (B) We have no reason to think AgSCN is any more stable. Furthermore, stability does not influence solubility. Answer (C) correctly suggests that AgSCN reaches equilibrium in solution at lower concentrations. If AgSCN reaches the Ksp at lower concentrations, and thus the equilibrium point, it would indeed precipitate sooner. Answer (D) Weight does not influence solubility.

Question 2: C

Like most questions that begin with the phrase, **Which of the following**, we cannot predict the answer based just on the stem and we will have to read the answer choices. Three of these choices—(A), (B), and (D)—all dissolve into two particles. Choice (C), however dissolves into four particles. This will have a profound effect on the relationship between molar solubility and Ksp. For the two-particle substances, the one with the highest Ksp, BaCrO₄, will have the highest molar solubility. Let's determine the molar solubility of BaCrO₄. For every particle of BaCrO₄ that dissolves, one particle of Ba²⁺ and one particle of CrO₄²⁻ will be produced. If the molar solubility (the concentration of BaCrO₄ that dissolves) is x, then the concentration of Ba²⁺ present at saturation is x, and the concentration of CrO₄²⁻ is also x. This means that the Ksp is x². Setting this as equal to the Ksp in the question stem allows us to calculate x, the molar solubility.

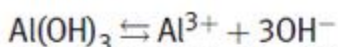


$$K_{sp} = [\text{Ba}^{2+}][\text{CrO}_4^{2-}] = x^2 = 2.1 \times 10^{-10}$$

$$\text{Molar solubility of BaCrO}_4 = x = 1.4 \times 10^{-5}$$

Now let's determine the molar solubility of Al(OH)₃. Aluminum hydroxide dissolves into four particles, one Al³⁺ and three OH⁻'s. Again, we refer to the molar solubility as x. The concentration of Al³⁺ present at saturation is x, but the concentration of OH⁻ present is 3x because three particles are produced for every one particle of aluminum hydroxide.

This means the $K_{sp} = (x)(3x)^3 = 27x^4$. Setting this equal to the K_{sp} given in the question stem and solving for x gives us something slightly greater than 10^{-4} .



$$K_{sp} = [\text{Al}^{3+}][\text{OH}^-]^3 = (x)(3x)^3 = 27x^4 = 3.7 \times 10^{-15}$$

Molar solubility of $\text{Al(OH)}_3 =$

$$x = \sqrt[4]{\frac{3.7 \times 10^{-15}}{27}} = \sqrt[4]{1.3 \times 10^{-16}} = 1.1 \times 10^{-4}$$

Thus, Al(OH)_3 has the highest molar solubility. The correct answer is choice (C). Note that this question is very calculation heavy, and answers (B) and (D) can be eliminated early. If you are pressed for time on Test Day, it may be best to take a 50/50 shot and come back to do the calculations later if you have time.

Question 3: C

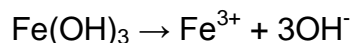
This question asks us why an endpoint was never indicated in the student's titration. Recall that the endpoint is where the indicator changes color. The passage tells us that **iron is used as an indicator**, but that the **sodium thiocyanate was contaminated with NaOH and the red FeSCN^{+2} indicator never formed**. The passage also tells us that **the solution must be kept acidic to prevent Fe(OH)_3 formation**. The problem the student had was that it was contaminated with NaOH. NaOH would have made the solution basic, thus failing to keep it at the acidic pH necessary to prevent Fe(OH)_3 formation. We see from the table that Fe(OH)_3 has a very low solubility. This would mean it would precipitate out at very low concentrations. The Fe^{+3} ions needed to form the FeSCN^{+2} indicator would be sucked up by the OH^- ions to make Fe(OH)_3 , thus preventing any color change. This matches best with answer (C).

Question 4: B

This question asks us to calculate the number of moles of Cl^- present in a solution using the Volhard method. As described in the passage, in the Volhard method Cl^- ions are added to an excess of Ag^+ ions. This solution is then titrated with SCN^- to determine the excess of Ag^+ . By taking the total number of moles of Ag^+ added and subtracting the number of moles of SCN^- that reacted, we can calculate the actual amount of Ag^+ required to reach the equivalence point. $0.5 \text{ moles of Ag}^+ - 0.1 \text{ moles SCN}^- = 0.4 \text{ moles of Ag}^+$ at equivalence point. The number of moles of Ag^+ will be equal to the number of moles of Cl^- at the equivalence point. Thus 0.4 moles of Cl^- will be present in solution, choice (B).

Question 5: C

This question asks us to calculate the $[\text{OH}^-]$ necessary for Fe(OH)_3 to form in the Volhard reaction. To determine this, we will need to write an equation for the formation of Fe(OH)_3 , followed by the solubility product constant equilibrium expression. The reaction for the dissociation of Fe(OH)_3 is



Next, we need to determine the solubility product constant equilibrium expression.

$$K_{sp} = [\text{Fe}^{3+}][3\text{OH}^-]^3$$

$$K_{sp} = [x][3x]^3$$

$$2.6 \times 10^{-39} = 27x^4$$

$$x = 1 \times 10^{-10}$$

We have calculated x, but recall that the equilibrium concentration of $[\text{OH}^-]$ is $3x$, so the minimum $[\text{OH}^-]$ required for precipitation is 3×10^{-10} . Answer (C) is the best answer choice.

Passage VI (Questions 1-4)

This passage discusses the various factors that influence solubility, specifically electronegativity and ionic radius.

Passage Outline

Paragraph 1: Blood contains salts. Sparingly soluble salts only slightly dissociate in H_2O

Scientist 1: Greater difference in electronegativity = greater solubility

Table 1: Table of electronegativities

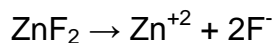
Scientist 2: Bigger ions are less soluble b/c they disrupt intermolecular forces of water

Question 1: D

This question asks us what scientist 2 would say about the relative solubilities of PbF_2 and ZnF_2 . What did scientist 2 hypothesize about solubilities? His/her theory was that bigger ions are less soluble. Therefore, we can eliminate answers (A) and (C) as their reasoning both discusses electronegativities, not ionic size. Which molecule would scientist 2 predict is more soluble between PbF_2 and ZnF_2 ? The passage tells us that ZnF_2 ions are smaller (you could also deduce this using periodic trends). This reasoning matches perfectly with answer (D).

Question 2: B

This question asks us to calculate the K_{sp} for ZnF_2 using the information given. To do this, we will need to write out the dissociation reaction for ZnF_2 and find the K_{sp} expression.



$$K_{sp} = [\text{Zn}^{+2}][\text{F}^-]^2$$

Next, we need to convert the g/ml of ZnF_2 we are given to molarity.

$$(2.03 \text{ g ZnF}_2 / 1 \times 10^{-10} \text{ L}) \times (1 \text{ mol ZnF}_2 / 100 \text{ g}) = 0.2 \text{ mol/L ZnF}_2$$

We can now plug this concentration into our solubility expression. The concentration for the fluoride ion will be double because two moles of fluoride are formed for each mole of ZnF_2 .

$$K_{sp} = [.2][.4]^2$$

$$K_{sp} = 3 \times 10^{-2}$$

This matches the most closely with answer choice (B).

Question 3: A

This question asks us to rank the boiling points of three different solutions. What effect does adding a solute to water have on its boiling point? Adding a solute to water raises its boiling point. Thus, roman numeral III (pure water) must have the lowest boiling point, so we can eliminate answers (C) and (D). Between the solutions of ZnF_2 or PbBr_2 , we would predict that the solution with more dissolved particles would have the higher boiling point. The passage tells us that ZnF_2 is more soluble than PbBr_2 , so we would expect to have the higher boiling point. Answer (A) shows ZnF_2 having the highest boiling point and is the best answer.

Question 4: B

Scientist 1 believes that solubility is determined by the difference in electronegativities of the ions that make up a compound. (Bigger electronegativity difference = more soluble) Using the table from the passage (or periodic trends!) we see that PbI_2 would have a larger electronegativity difference than PbF_2 , and thus would be more soluble. This matches with answer (B).

Passage VII (Questions 1-6)

This passage gives us an electrical circuit as a model for a biological cell membrane. The various ions present in a cell function as batteries, with each generating an emf. The questions in this section are more conceptual than calculation heavy and will help to reinforce important concepts in circuitry.

Passage Outline

Paragraph 1: Parallel capacitor circuit model for cell membrane

Figure 1: Diagram of cell membrane circuit

Paragraph 2: Lipid bilayer functions as lipid bilayer. Cell membrane is a capacitor

Paragraph 3: Concentration gradients for ions generate emf.

Paragraph 4: Lipid bilayer conductance is low. Most ions travel through channels.

Question 1: D

This question gives us the intra and extracellular concentrations of K^+ and asks us to calculate the absolute value of E_K in a neuron (cell) off a giant squid. The situation that is proposed in this question is akin to a concentration cell. The difference in

concentrations between the two cells (in this case, the two cells are a. the intracellular environment and b. the extracellular environment) will generate an electric potential, or EK. This electric potential is mainly determined by the concentrations of the two cells. To obtain a value, we use a derivation of the Nernst equation call the Nernst potential.

$$E = RT \ln([extracellular]/[intracellular])$$

E is electric potential we are calculating, T is temperature, and R and F are constants. Substituting our concentrations provided in the question gives us:

$$E = RT \ln([20 \text{ mM}]/[400 \text{ mM}]) = RT \ln([2 \cdot 10^1 \text{ mM}]/[4 \cdot 10^2 \text{ mM}]) = RT \ln[.05 \text{ mM}]$$

Our question conveniently provides us with the values for (RT/F) and for ln of .05:

$$=.025 \text{ V/mol} \cdot 3 = .075 \text{ V/mol} = 7.5 \cdot 10^{-3} \text{ mV/mol}$$

This matches nicely with answer (D). The other answer choices are various miscalculations.

Question 2: C

This question provides us with a number of graphs of Ecell versus Gibbs free energy. The questions asks us which one represents the relationship between the two. This question requires us to recall another equation. In this case, it is the equation relating Gibbs free energy to Ecell.

$$\Delta G^\circ = - n F E_{cell}^\circ$$

G is Gibbs free energy, n is the number of moles, F is Faraday's Constant, and Ecell is the standard cell potential. We see that the negative sign on the right side of equation means that when the sign of G will always be opposite of the sign of Ecell. Do any of the answer choices reflect this? Answer choice (C) matches perfectly. For any given point on the graph, if G is positive then Ecell is negative and vice versa.

Answer (A) is opposite of the relationship given by the equation. It shows G and Ecell having the same sign. Answer (B) again shows the opposite relationship given by the equation. Answer (C) is correct for the reasons stated above. Answer (D) show the opposite relationship given by the equation.

Question 3: B

This question asks us to calculate the value of Gcl. The question tells us that the current flowing through Gcl is .5A and the electric potential difference for Gcl is 5mV. From the passage we know that Gcl functions in this model as a resistor, so we can use Ohm's law to solve for R.

$$R = V/I$$

$$R = 5 \cdot 10^{-3} \text{ V} / 5 \cdot 10^{-7} \text{ A}$$

$$R = 1 \cdot 10^4$$

We have now calculated the resistance in Ohms. However, we see that our answer choices have the units of ohms^{-1} , thus we must take the inverse of 1×10^4 which gives us 1×10^{-4} , making choice (B) the best answer.

Question 4: A

This question asks us to evaluate which of the four answer choices are true regarding the movement of ions across the plasma membrane. Previewing the answer choices we see that the answers deal with ions of high and low permeability and, and permeability relationship with resistance. Where are these issues discussed? In the last paragraph, paragraph 4, we are told that **conductances vary with the number of ion channels present**. We also told that because of the low conductance of the lipid bilayer **movement of ions across the membrane is almost entirely through [various channels]**.

What are the two ways an ion can cross, or permeate, the lipid bilayer? They can either move directly across (high resistance), or move through a channel (low resistance). Because the passage tells us that the bilayer has very low conductance, we can reason that permeability is really a function of the number of channels available. If an ion has a lot of channels available, it will be highly permeable because it has a large number of low resistance pathways to move through. If there are few channels available, the ion will have low permeability, because its main/only route to cross the bilayer will be the high resistance route directly across. Answer choice (A) matches with this perfectly.

Answer (A) is correct as discussed above. Answer (B) is opposite. Ions with high permeability would have to through low resistance pathways, not high resistance pathways as this answer suggests. Answers (C) and (D) both suggests various incorrect combinations of permeability and resistance.

Question 5: A

This question presents us with various statements discussing capacitance and resistance and asks us to find which one is true. Before looking at the answers, let's discuss the factors that will affect resistance and capacitance. Let's start with resistance. The equation for resistance is

$$R = \frac{\rho L}{A}$$

where R is resistance, ρ is resistivity (intrinsic value reflecting the resistance of a material), and L is the length of the resistor, and A is the cross sectional area. Thus, resistance is directly proportional to resistivity and length, and inversely proportional to area.

Capacitance, on the other hand, is given by

$$C = \epsilon_0 \frac{A}{d}$$

where C is capacitance, ϵ_0 is the permeability of free space (a constant), A is the cross sectional area of the capacitor, d is the distance between the two

plates. Thus, capacitance is directly proportional to area, and inversely proportional to distance.

Let's look at the answers.

Answer (A) suggests the molecules that are embedded in the membrane don't affect the capacitance. From the above equation, we see that the main things influencing capacitance are area and distance. The makeup of the material is not mentioned, making (A) the best answer. Answer (B) incorrectly suggests capacitance is inversely proportional to area. As discussed above, capacitance is directly proportional to area. Answer (C) suggests the embedded molecules in a membrane don't affect the resistance. We know that the (resistivity) is value determined by the materia. Changing the molecules of a resistor would likely change the ρ , thus making this answer incorrect. Answer (D) incorrectly states that resistance is directly proportional to area. As discussed above, resistance is inversely proportional to area.

Question 6: B

This question asks to evaluate each answer and find the one that is true regarding the emf generated by a concentration gradient. Let's look at each of the answers. Answer (A) incorrectly states that the emf has units of newtons or $\text{kg}\cdot\text{m}/\text{s}^2$. These are the units for mechanical force. Despite the nomenclature, emf is not a force. Emf is measured in volts. Answer (B) correctly states that the emf is the work done to move a charge around a circuit. This is the textbook definition of emf. Answer (C) incorrectly states that the positive terminal is closer to the side with the higher concentration. Electrons flow down their concentration gradients which would put the positive terminal on the side with the lower concentration. Answer (D) correctly states that emf is analogous to the voltage generated by the concentration cell. However, it incorrectly states that a concentration cell is a type of electrolytic cell. Recall that electrolytic cells require a power source, whereas concentration cells generally supply power.

Discrete Questions (Questions 1-7)

Question 1: D

This question tells about a man who hears an explosion and then feels a tremor in the ground and asks which statement would explain this. First let's consider the factors that influence the speed of sound. Broadly speaking, the speed of sound is influenced by elastic factors and inertial factors. The main elastic factor is the phase (solid, liquid, gas) of the material. Sound will travel faster through more elastic (more rigid) materials. Thus sound travels fastest through solids, then liquids, then gases. Inertial properties are density and bulk modulus. Their relationship with the speed of sound can be expressed as

$$c = \sqrt{\frac{K}{\rho}}$$

Answer (A) suggests that sound waves moved faster through air than the ground. As mentioned above, the chief determinant of the speed of sound is the phase of matter.

Sound will always travel faster in solids. Answer (B) Increasing the temperature will decrease the density and thus increase the speed of sound in air. However, changes in inertial factors will not be able to overcome the significant effect of elastic factors (phase of matter). Sound will still move faster in the ground despite the warmer air temperature. Answer (C) Bulk modulus is an inertial factor. Even if the Bulk modulus of air is higher than the ground, it will not be great enough to overcome the significant increase in speed that the phase of matter has on the speed of sound. If the air and ground were both gases, (C) could be true. Answer (D) correctly suggests that the sources of the tremor and the explosion are different. If they were from the same source we would expect that you would feel the explosion before hearing it.

Question 2: D

This question tells us that a grandchild has hearing 100 times greater than his grandfather and asks us at what decibel level he would hear a sound that his grandfather hears at 90 dB. Decibels are a logarithmic scale that measures the intensity of sound and are related to intensity by the following equation.

$$B = 10 \cdot \log(I/I_0)$$

B is decibels, I is intensity of sound, and I_0 is the reference intensity. In this case, our reference intensity will be the grandfather's intensity and will be equal to one. Our I will be the grandchild and will be 100, because he hears things as 100 times more intense than the grandfather.

$$B = 10 \cdot \log(100/1)$$

$$B = 10 \cdot 2$$

$$B = 20$$

The reference level for decibels was 90, so the decibels perceived by the grandchild will be 20 dB plus 90, or 110 dB which matches perfectly with choice (D).

Question 3: C

This question gives us a closed pipe with a length of 2.4 cm and asks us to calculate the wavelength of the third harmonic. Wavelengths of harmonics for closed pipes are given by the formula

$$\text{wavelength} = 4L/n$$

L is the length of the pipe, and n is any odd integer. Plugging in our values we get

$$\text{wavelength} = 4(2.5)/3 = 3.3$$

Since our length was in cm, our wavelength will also be in cm making (C) the best choice.

Question 4: B

This question asks us what the power transmitted to an eardrum will be with a given surface area and intensity. The power delivered across a surface is given by the

equation $P=IA$ where P is power, I is intensity (in dB) and A is the surface area. Substituting values, we get $P=(10^3)(5.5*10^{-2})$. We can make the calculation a bit easier with some rounding and conversion to scientific notation. $P=(1*10^2)(6*10^{-2})$ and thus $P=6$. Taking into account the rounding we did, answer choice (B) is the closest to 6 and is the best answer.

Question 5: C

This question asks us what the power transmitted to an eardrum will be with a given surface area and intensity. The power delivered across a surface is given by the equation $P=IA$ where P is power, I is intensity (in dB) and A is the surface area. Substituting values, we get $P=(103)(5.5*10^{-2})$. We can make the calculation a bit easier with some rounding and conversion to scientific notation. $P=(1*10^2)(6*10^{-2})$ and thus $P=6$. Taking into account the rounding we did, answer choice (B) is the closest to 6 and is the best answer.

This question asks us to calculate the F exerted on an electron orbiting a helium atom. The force between two charges can be calculated using Coulomb's Law:

$$F = k*Q_1*Q_2 / r^2$$

where k is a constant, Q_1 and Q_2 are the two charges, and r is the distance between the two charges. What are the two charges in question? The electron and the nucleus. Q_1 will be the charge of the electron and Q_2 will be the charge of the nucleus. We are told that the charge of the electron is $-1.6*10^{-19}C$. The charge of the nucleus is a bit trickier. Because we are discussing helium, the nucleus will be made of two protons, each of which will have a charge of $-1.6*10^{-19}C$. (Although protons are much more massive than electrons, they have the same charge)

$$F = k \frac{(-1.6*10^{-19})(2(-1.6*10^{-19}))}{(2*10^{-10})^2}$$

$$F = k \frac{(-1.6*10^{-19})(2(-1.6*10^{-19}))}{(2*10^{-10})^2}$$

$$F = k \frac{(-1.6*10^{-19})(3.2*10^{-19})}{(2*10^{-10})^2}$$

$$F = k \frac{(-5.12*10^{-38})}{(4*10^{-20})}$$

$$F=k*(1.3*10^{-18})$$

Question 6: C

This question is asking us about the electric potential energy between two charges. The electric potential between two charges is given by $PE = kQ_1Q_2/r$ where k is a constant, Q_1 and Q_2 are the charges, and r is the distance between the charges. We see that if we decrease the r (in the denominator) by a factor of 3, it will result in an increase in the electric potential by a factor of 3. This matches best with choice (C). Note that the r in this equation is not squared (as it is in the equation for gravitational force and coulomb's law) and would not result in an increase by a factor of 9, choice (D).

Question 7: D

This question asks us to determine the electric potential at a point equidistant from three identical charges. The electric potential is given by $V=kQ/r$ where k is a constant, Q is the charge, and r is the distance between the point in question and the charge. Electric potential is a scalar quantity, and thus the electric potential at point A is the sum of the electric potential from each of the three charges. The charges are identical (each carrying a charge of x), so the electric potential can be expressed as $V=3k(x/r)$. This matches perfectly with choice (D).