MCAT Chemistry and Physics 3 Homework

Passage 1 (Questions 1-6)

Passage Outline

Paragraph 1: Intro to Penicillin

Paragraph 2: Lactam and beta-lactam reactions

Figure 1: Lactam formation reaction

Figure 2: Beta-lactam acylation reaction

Paragraph 3: Effect of Penicillin = ring-opening acylation

Q1.

Assess: This is a ranking problem, so we should consider what the extremes would be in order to first narrow down the answer choices.

Plan: Ask the class, what factors affect boiling point. Then ask, how would addition of the amine group affect boiling point?

Execute: Boiling point depends on intermolecular forces and size. Addition of the amine group provides strong hydrogen bonding capability, raising the boiling point. This means 4-amino butanoic acid will have a higher boiling point than butanoic acid. For the lactam, however, it is nearly impossible to tell. And the actual boiling points of this lactam and this 4-aminobutanoic acid are about the same. So a process of elimination must be used. We can eliminate all but the correct answer by looking for an answer that simply has butanoic acid listed as the one with the lowest boiling point.

Answer: B

Q2.

Assess: For a matching problem like this, we can identify an answer based on one or two bonds, rather than spending the time to this on all four.

Plan: Consider the mechanism of lactam synthesis based on info from the passage and consider which bonds must break and form, then rule out answer choices that do not reflect this and identify which one(s) does.

Execute: During the lactam synthesis, the NH_2 acts as a nucleophile, attacking the C=O carbon to make a new N-C bond. In doing so, the nitrogen loses an N-H bond and the C-O bond of the OH is broken as water must be protonated by bonding with the H from NH_2 and acting as a leaving group.

Answer: D

Q3.

Assess: For this problem we have to combine information from the passage with outside knowledge.

Plan: Briefly review once more the mechanism of lactam synthesis based on what the passage indicates. Consider which answer choice does not fit with how this mechanism should proceed.

Execute: During the lactam synthesis, nucleophilic attack on the carbonyl carbon by NH_2 occurs with an H_2O byproduct. However, the H^+ is an electrophile added to the hydroxyl, not a nucleophilic addition, so Choice A is immediately the false statement for which we are looking.

Answer: A

Q4.

Assess:

Plan: Elicit- What type of reaction is the beta-lactam synthesis? What is a necessary intermediate that must form in this type of reaction?

Execute: The passage points to this synthesis being a nucleophilic acyl substitution reaction. During nucleophilic acyl substitution, the intermediate oxygen anion reforms the C=O by kicking off a leaving group. This was previously discussed as a contrast to protonation in ketones/aldehydes.

Answer: C

Q5.

Assess: This is a straightforward question checking for ability to identify functional groups.

Plan: Ask the class how we can observe the structure of Penicillin without it being provided explicitly in the passage. Then ask which one of the listed functional groups is not observed.

Execute: We can use the lactam in Figure 1 to get an idea of the structure of Penicillin. The group listed in the answer choices not actually present is the amine group (amine: NR_3, amide: R-CO-NR_2).

Answer: D

Q6.

Assess: This question requires us to draw a conclusion using the information provided and our reasoning skills.

Plan: The question stem indicates the conversion of an amide to an ester is the opposite of what is expected. Examine the answer choices, keeping in mind the acylating reaction described, and consider which logically explains this reversal.

Execute: Normally, the ‘rule of reactivity’ does allow esters to form amides. Here, because ring breakage is favored through energy release, it is possible for penicillin to make its lactam into an ester by undergoing nucleophilic acyl substitution with the hydroxyl from the serine residue.

Answer: D

Passage 2 (Questions 1-5)

Passage Outline

Paragraph 1: Chemical fixation = preservation from decay

Paragraph 2: Cross-linking = fusion of proteins; increase strength and rigidity

Paragraph 3: Description of cross-linking reaction

Figure 1: Reaction step one- oxocarbenium and imine intermediates

Figure 2: Reaction step two- final cross-link between glutamine and lysine

Q1.

Assess: This problem requires a knowledge reaction types.

Plan: Elicit- What is happening in this reaction? What type of reaction must it then be?

Execute: Here we have a nucleophile attacking an electrophile and then a new hydroxyl group is formed. Textbook nucleophilic addition! The symmetry of the molecule can hide the simplicity of the reaction, and that's the intended difficulty of this question.

Answer: A

Q2.

Assess: This problem checks for memorization of certain structures; formaldehyde in particular.

Plan: Elicit- What type of organic molecule is formaldehyde? How does this type of molecule react with water?

Execute: Formaldehyde is an aldehyde and in water it will undergo a hydration reaction.

Answer: B

Q3.

Assess:

Plan: Ask the class what is happening in the first step of the reaction according to the passage and Figure 1. Elicit- Which of the answer choices describes this type of reaction?

Execute: Paragraph 3 and Figure 1 show "a hydroxyl group is eliminated from methanediol to form an oxocarbenium intermediate, which is attacked by the amino group on lysine." An amine is only a weak nucleophile. Therefore, it makes sense that the methanediol intermediate will first be protonated, and will eliminate, leaving behind the oxocarbenium intermediate, which the amine then attacks. This looks a lot like ammonia derivative condensation—water is lost and there is an imine product.

Answer: D

Q4.

Assess: This is a straightforward question about molarity.

Plan: Point out that Paragraph 3 says, "formaldehyde spontaneously reacts with water to form methanediol (Keq = 2000)." Elicit- What does this tell us about the reaction? How would we calculate molarity here?

Execute: With such a high equilibrium constant, we know this reaction will definitely proceed forward to the point where practically all of the formaldehyde becomes methanediol. 100 mg formaldehyde in 100 mL water = 100 mg methanediol in water = 100 mg / 100 mL = 1 g/L.

Answer: C

Q5.

Assess:

Plan: Briefly review the first step again, if necessary. Elicit- How would making the solution acidic affect what happens in this step? Which answer choice accurately describes this? (Paragraph 3) In this [first] step, a hydroxyl group is eliminated from methanediol to form an oxocarbenium intermediate… In acidic conditions, R–OH à $R–OH_2^+$,which is an excellent leaving group.

Execute: Paragraph 3 and Figure 1 show "a hydroxyl group is eliminated from methanediol to form an oxocarbenium intermediate, which is attacked by the amino group on lysine." The mechanism for this reaction involves the elimination of two hydroxyl groups from methandiol. The abundance of H^+ in an acidic environment stimulates the protonation of these hydroxyl groups, helping this elimination and making the imine formation more likely.

Wrong answer Choice A- While it is true that acidic conditions may cause the amino group to become protonated, this actually decreases the nucleophilicity of the group, because the protonated amino group is now charged. So this effect actually drops the rate of the reaction, however it is made up for by the other effects of acid catalysis.

Wrong answer Choice B- To convert formaldehyde to methanediol, an oxocarbenium intermediate is used, and the formation of the oxocarbenium intermediate is helped by acidic conditions.

Wrong answer Choice C- Imine formation requires that the hydroxyl group formed in the middle line of the mechanism be eliminated. This is helped by acidic conditions, which protonate the hydroxyl group.

Answer: D

Passage 3 (Questions 1-5)

Passage Outline

Paragraph 1: Sick boy might have ricin poisoning

Paragraph 2: Ricin protein description

Paragraph 3: Ricine indicates ricin poisoning; no cure

Figure 1: Ricinine structure

Q1.

Assess: The problem requires an understanding of separation techniques.

Plan: Elicit- What do we know about differences between the subunits? What lab technique could take advantage of this difference to separate them?

Execute: Paragraph 2 mentioned a difference in size between the two subunits. SDS -polyacrylamide gel electrophoresis (SDS-PAGE), using the proper gel conditions, would separate the two subunits of the polypeptide. PAGE can be used to separate via charge or size.

Wrong answer Choice B- Distillation is not often used to separate two solids, especially proteins.

Wrong answer Choice C- Gas chromatography is impractical for separating peptides. They are large, so they have high boiling points. The high heats would also denature the proteins, leaving a sticky mess in the instrument.

Wrong answer Choice D- Extraction with ethanol and water is impractical because these two solvents are miscible. Extraction requires using two solvents that will not mix and can be easily separated.

Answer: A

Q2.

Assess: This problem requires a knowledge of key IR peaks.

Plan: Elicit- What key IR peaks are present in this spectrum? Do these same features appear in the provided structure of ricinine?

Execute: This spectrum lacks a carbonyl (no sharp peak from 1700-1750) and has an –OH group (broad peak at 3300). The structure for ricinine is given in Figure 1. It features a carbonyl, but does not have an alcohol group. The absence of the carbonyl IR peak reveals that this cannot be ricinine. (In case anyone asks, this is actually the IR spectrum for ethanol.)

Answer: C

Q3.

Assess: Here we must draw a conclusion based on an understanding of protein reactivity.

Plan: Ask the class, which of the listed choices is something that would react with a protein?

Execute: As a protein, ricin can have antibodies raised against it. Antibodies have tremendous specificity, and an anti-ricin antibody conjugated to a bead could be used in column chromatography (or beyond the scope of the MCAT, ELISA could be used).

Wrong answer Choice B- While chocolate cures many ills, it cannot be used to detect ricin. Even if you do not know what theobromine is, the specificity of an antibody should be a cue to the correct answer. Don't pick an answer just because you do not know what it means.

Answer: D

Q4.

Assess: For this question, we must use provided information to draw a logical conclusion.

Plan: Elicit- What does the passage indicate about the function of ricin? What process does this affect?

Execute: According to the passage, ricin blocks ribosome function, which would impair production of new proteins during translation. We have no reason from the passage to suspect that it blocks the function of already existent proteins. As proteins turn over normally, they will not be replaced by new copies.

Wrong answer Choice A- Extreme. There are many water-soluble proteins that travel in the blood, such as antibodies, peptide hormones, albumin, etc

Wrong answer Choice B- Out of scope. Ricin does not exert its affect in the nucleus or by binding to DNA.

Wrong answer Choice D- Out of scope. Proteins are not filtered in healthy kidneys and would not show up in the urine.

Answer: C

Q5.

Assess: The answer choices all deal with extraction with acids or bases, so that should be the focus.

Plan: Elicit- What is extraction? How will addition of an acid and base affect benzoic acid? Which would be better for the extraction? How would the extraction differ if this solution were weak or strong?

Execute: The key to extractions is to separate the desired compound into one layer and the other compound into the other. If a base is added to the carboxylic acid, it will deprotonate and have a negative charge. This will then migrate into the aqueous phase of the extraction. Adding acid will protonate benzoic acid, leaving it uncharged and more likely to move into the organic phase. So, the better choice is using a base and we can eliminate Choices A and B. A strong base would be able to deprotonate both the alcohol and the benzoic acid, moving both species into the aqueous phase. A weak base would be able to deprotonate benzoic acid, but the alcohol would be largely untouched. Thus, using a weak base, the benzoic acid would partition into the aqueous phase, while the alcohol (remaining uncharged) would partition into the organic phase.

Answer: D

Passage 4 (Questions 1-5)

Passage Outline

Paragraph 1: Background info on esters

Paragraph 2: Esterification reaction is slow (equilibrium) but not with excess of reactant

Reaction 1: Esterification

Paragraph 3: Alternative method for ester synthesis

Reaction 2: Synthesis of ethanoyl chloride

Reaction 3: Synthesis of ethyl acetate

Q1.

Assess: This question tests an understanding of the esterification process.

Plan: Elicit- What type of reaction is esterification? What is the first step in all carbonyl reactions? Carbonyl is protonated first, then the nucleophile attacks

Execute: Esterification is nucleophilic addition, a type of carbonyl reaction. All such reactions begin with protonation of the carbonyl to make it more electrophilic. The alcohol attacks this cation and the result is the correct answer, choice (C). Alternatively, look at the structures in the answer choices and see that many of them violate Lewis structure rules, meaning they can be eliminated automatically.

Answer: C

Q2.

Assess: Answer choices here are all sentences, so the problem requires logical reasoning.

Plan: First ask the class, which compound is pyridine? Then ask, what is pyridine's function in the mechanism shown? Consider what effect this has based on the role of the acid.

Execute: Pyridine is the nitrogen-containing ring compound and it neutralizes the HCl by acting as a base and capturing its proton. This inorganic acid would have acted as a catalyst for the esterification reaction.

Answer: A

Q3.

Assess: This is another problem focusing on carbonyl reactions.

Plan: Briefly review once again what type of reaction esterification is and what the first step for such a reaction would be. Afterwards, ask the class what effect having an abundance of water would have for this type of reaction and its potential products.

Execute: Esterification is nucleophilic addition, a type of carbonyl reaction. All such reactions begin with protonation of the carbonyl to make it more electrophilic. An abundance of water would result in a hydrolyzation reaction that would convert products back to reactants.

Answer: D

Q4.

Assess: Because this is a ranking problem, we can employ some analytical reasoning to simplify it.

Plan: Point out that this is ranking problem and we should consider the extremes first (i.e. which is the strongest/weakest acid and is it on the appropriate end of the order) to eliminate answer choices. From there, evaluate the remaining choices to determine which fits the order asked for by the question (i.e. weakest to strongest or strongest to weakest).

Execute: Carboxylic acids are the most acidic of organic functional groups, so Choices A and C can be eliminated. The only task left is to determine if aldehydes or ethers are more acidic. Because the alpha hydrogens of carbonyl compounds are more acidic than the alkyl hydrogens of dimethyl ether, choose Choice B.

Answer: B

Q5.

Assess: This problem requires an understanding of synthesis reactions.

Plan: Elicit- What does hydrolysis of an acid anhydride yield? What does reaction of COOH with $SOCl_2$ yield?

Execute: Hydrolysis of an acid anhydride yields 2 moles of COOH. COOH with $SOCl_2$ yields acyl halide. Look for an answer choice showing 2 moles of acid and 2 moles of acyl halide.

Answer: D

Passage 5 (Questions 1-4)

Passage Outline

Paragraph 1: Intro to cyclohexanol

Figure 1: Dehydration of cyclohexanol

Paragraph 2: Mechanism of elimination

Paragraph 3: Dehydration of 2-methylcyclohexanol

Figure 2: Four elimination products

Paragraph 4: Experimental details

Table 1: Experimental results

Q1.

Assess: Our answer choices are sentences, therefore we must need to utilize logical reasoning.

Plan: Elicit- What is the mechanism of formation of 1-methylcyclohexene from 2-methylcyclohexanol? Which choices can then be eliminated? Which of the leftover choices makes the most sense?

Execute: Paragraph 2 states the reaction proceeds via a secondary carbocation. Between Choices A and C, the tertiary carbocation is more stable.

Answer: C

Q2.

Assess: This problem requires a combination of outside knowledge with critical reasoning skills.

Plan: Elicit- Do cis/trans isomers have different chemical properties? What is the structure of the reaction intermediate in which the 2-methylcyclohexanol is used?

Execute: : Cis/trans isomers have the same chemical properties. Regardless of which one is used, the same planar carbocation intermediate is formed, so there is no difference in the product composition.

Answer: C

Q3.

Assess: The answer choices are basically one, both, or cannot tell.

Plan: Ask the class, what does the question stem say about Zaitsev's rule? Then ask, which product shown is the more highly substituted?

Execute: Zaitsev's rule leads to the more highly substituted product. For this reaction, Product 1 is more highly substituted.

Answer: A

Q4.

Assess:

Plan: Elicit- What kind of reaction is the bromination of 3-methylcyclohexene with bromine? What is the stereochemistry of the reaction?

Execute: This reaction is addition of bromine to neighboring carbons. The stereochemistry is anti because the cyclic bromonium intermediate is rigid and can only be attacked from the side opposite the

first bromide. Look for the answer choice where bromine adds to two different carbons and are anti to each other.

Answer: C

Passage 6 (Questions 1-5)

Passage Outline

Paragraph 1: Background about reaction and use of UV-Vis

Equation 1: Oxidation of 1-propanol to propanal in presence of chromic acid

Paragraph 2: Student A experimental procedure

Paragraph 3: Student B experimental procedure

Table 1: IR analysis of distillate (portion boiled off)

Q1.

Assess: This problem requires use of reasoning to identify a compound.

Plan: Elicit- Where can we find information on the molecular structure of Student A's distillate? What characteristic peak is found in the IR data for Student A's distillate?

Execute: Information about Student A's distillate can be found in Table 1. The presence of a peak at 3600 cm^{-1} indicates alcohol.

Answer: D

Q2.

Assess: This problem also requires use of reasoning to identify a compound.

Plan: Elicit- Where can we find information on the molecular structure of Student B's distillate? What characteristic peak is found in the IR data for Student B's distillate?

Execute: Information about Student B's distillate can be found in Table 1. The presence of a peak at 1700 cm^{-1} indicates aldehyde or ketone. This leaves us with Choices A and B. We can eliminate B, however, because water has a significantly higher boiling point than propanal and would not be part of the distillate.

Answer: A

Q3.

Assess: This is a roman numeral question for which strategy can be applied.

Plan: Since this is a roman numeral problem, encourage the class to start with the numeral that appears in the most answer choices and work from there. Consider whether each statement is true.

Execute: Start with I^- when oxidation states of metals change, color changes. Color change is detected by UV-Vis; eliminate Choice C.

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II- 1-propanol used in excess, thus II true.
III- No need to look at it because we canceled out Choice C.
IV- Water & H2SO4 do not absorb visible light .
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Answer: D

Q4.

Assess: This is a straightforward question testing understanding of NMR signals.

Plan: Elicit- Where does the NMR signal for an aldehyde appear?

Execute: The signal for an aldehyde appears between 9 and 10 ppm.

Answer: B

Q5.

Assess: This problem requires an understanding of IR spectra.

Plan: Elicit- How does 2-propanol differ from 1-propanol? What does oxidation of a secondary alcohol yield? What does the absorption peak at 1750 cm^{-1} indicate?

Execute: 2-propanol is a secondary alcohol while 1-propanol is a primary alcohol. Oxidation of a secondary alcohol yields a ketone. Presence of an IR peak at 1750 cm^{-1} indicates a carbonyl, confirming the product is a ketone.

Answer: C

Discrete Question Practice (Questions 1-4)

Q1.

Assess: The answer choices have different functional groups.

Plan: Elicit- How many unique protons are shown? Is there a particularly characteristic peak?

Execute: Since there are four peaks, we know there are four unique protons. The most characteristic peak is the one at 10 ppm, which indicates an aldehyde.

Answer: B

Q2.

Assess: The answer choices have different functional groups.

Plan: Elicit- How many unique protons are shown? Is this a particularly characteristic peak?

Execute: Only one peak means only one type of proton. This peak at 7.2 ppm corresponds to an aromatic hydrogen.

Answer: A

Q3.

Assess: This reaction checks for knowledge of key reagents.

Plan: Elicit- What type of reagent is methylmagnesium chloride? What type of reaction do we expect to occur and what final product would be formed after protonation by an acid?

Execute: Methylmagnesium chloride is a Grignard reagent that will lead to the addition of the methyl to acetone. The last protonation step results in the formation of 2-Methyl-2-propanol.

Answer: C

Q4.

Assess: Here we have to compare various molecular structures.

Plan: Elicit- What affects ester reactivity? Which of the molecules shown contains such features? Which molecule contains the more effective group?

Execute: Presence of electron withdrawing groups makes the carbonyl carbon more electrophilic and therefore more reactive. Between Choices A and D, NO_2 is more electron withdrawing.

Answer: D