MCB 102 – SPRING 2008 – METABOLISM FINAL EXAM **NAME:** KEY

UNIVERSITY OF CALIFORNIA, BERKELEY
FINAL EXAM – MCB 102 – METABOLISM – HAAS PAVIL – MAY 17, 2008
INSTRUCTOR: BRYAN KRANTZ
THE TIME LIMIT FOR THIS EXAMINATION IS 2 HOURS AND 50 MINUTES

SIGNATURE: KEY

SIGN your name **in indelible ink** on the line above.

YOUR NAME:

PRINT your name **in indelible ink** on the line above and on the top right hand corner of each page.

WRITE all of your answers as **LEGIBLY** as possible. You may want to use pencil on certain sections; however, please **INK OVER** your final responses.

CONSICE and **STRAIGHTFORWARD** short answers are best.

GOOD LUCK!

CIRCLE THE NAME OF YOUR GSI:

Mary Couvillion	**Jack Dunkle**
Jeung Hyoun Kim	**Shirali Pandya**
Andrea Pezda	**Hiroki Satooka**
Lane Weaver	**Rachel Zunder**

SCORING: Eleven questions total to100 possible points. The breakdown is given below.

QUESTION	POINTS	(POSS.)
1.		(14)
2.		(7)
3.		(7)
4.		(5)
5.		(8)
6.		(5)
7.		(5)
8.		(7)
9.		(7)
10.		(5)
11.		(10)
12.		(8)
13.		(12)
TOTAL		(100)

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QUESTION 1: TRUE/FALSE (14 pts.) Circle the correct response. If the answer is false, then provide the corrected statement, using the smallest possible change in the wording of the phrase given (1 pt. ea.)

(i) Aldolase catalyzes an irreversible "splitting" of the hexose, fructose 1,6-bisphosphate, to form two triose sugars. **["False" are worth 0.5 pt. if correct; other 0.5 pt. received for corrected statement.]**

TRUE **FALSE**

False, Aldolase catalyzes a reversible "splitting" of the hexose, fructose 1,6-bisphosphate, [and thus the "joining" of the two triose sugars can also be catalyzed.] ←The bracketed part is optional.

(ii) Glycogen contains both sugars and amino acids.

TRUE **FALSE**

True.

(iii) Debranching enzyme catalyzes a transfer reaction, moving an α(1→6) linkage to the reducing end of the chain.

TRUE **FALSE**

False, debranching enzyme catalyzes a transfer reaction, moving an α(1→6) linkage to the non-reducing end of the chain.

(iv) A positive ΔG°' implies the products are favored over reactants under standard conditions.

TRUE **FALSE**

False, a negative ΔG°' implies the products are favored over reactants under standard conditions. [also could keep "positive" and change to "reactants favored over products".]

(v) A positive Δ*E*°' implies the products are favored over reactants under standard conditions.

TRUE **FALSE**

True.

(vi) 6-Phosphogluconate is a more reduced form of glucose 6-phosphate.

TRUE **FALSE**

False, 6-Phosphogluconate is a more oxidized form of glucose 6-phosphate.

(vii) The pyruvate kinase catalyzed step is a reversible reaction in glycolysis, allowing gluconeogenesis to procede via the same enzyme.

TRUE **FALSE**

False, the pyruvate kinase catalyzed step is an irreversible reaction in glycolysis, and therefore, gluconeogenesis requires separate enzymes to convert pyruvate to phosphoenolpyruvate.

(viii) Triose phosphate isomerase converts dihydroxyacetone phosphate to glyceraldehyde 3-phosphate through an intermediate with a carbon-carbon double bond.

TRUE **FALSE**

True.

(ix) Carbon dioxide is added to pyruvate to make oxaloacetate via activated carbamoyl phosphate, using the cofactor, biotin.

TRUE **FALSE**

False, CO2 is added to pyruvate via the activation of bicarbonate, using the cofactor, biotin.

(x) The urea cycle is limited to the tissues of the kidney, where urea is removed from the blood.

TRUE **FALSE**

False, The urea cycle is limited to the tissues of the liver; urea then enters the bloodstream, where it is removed by the kidney.

(xi) Arginine, ornithine, and citrulline are all amino acids used as intermediates in the Urea Cycle.

TRUE **FALSE**

True.

(xii) Ubiquinone, cytochrome *c*, NAD+, FAD, iron-sulfur clusters, and O_2 accept electrons during electron transfer reactions along the respiratory chain.

TRUE **FALSE**

False, Ubiquinone, cytochrome *c*, FAD, iron-sulfur centers, and O_2 accept electrons during electron transfer reactions along the respiratory chain. [NAD+ can be struck out or left out of the above statement.]

(xiii) The proton motive force is only comprised of the electrical potential energy imparted when protons build up charge on one side of the membrane.

TRUE **FALSE**

False, The proton motive force is comprised of the electrical potential energy imparted when protons build up on one side of the membrane and the chemical potential energy due to the difference in concentration of protons on either side of the membrane.

(xiv) The adenine nucleotide translocase exchanges an ATP in the matrix for an ADP in the intermembrane space, requiring the expenditure of some energy, i.e., one ATP per every four exchanges.

TRUE **FALSE**

False, adenine nucleotide translocase exchanges an ATP in the matrix for an ADP in the intermembrane space, requiring the expenditure of some energy; i.e., the electrochemical gradient is utilized to power transport.

QUESTION 2: CALCULATIONS (7 pts.) The last page of this exam has a log table and a list of equations.

(i) Consider the reaction, **A ←→ B + B**, where **ΔG^o** is zero **(2 pts.)**

(a) Explain, in general, how entropy may change during the catabolic reaction depicted above **(1 pt.)**

As two molecules of B are made from one molecule of A, the entropy of the products, B, would be greater than the reactants. The reactant, A, in a sense, is more ordered than two product Bs.

(b) Determine what the sign of the free energy change will be if the concentrations of all the species are raised above the standard conditions by 2-fold. Circle your answer from the three listed, and show your assumptions and equations used to justify your response **(1 pt.)**

(A) NEGATIVE **(B) NO SIGN / ZERO** **(C) POSITIVE**

$\Delta G = \Delta G^o + RT \ln Q$. ΔG^o is given as 0 kJ/mol.

$Q = [B]^2/[A] = 2*2/2 = 2$.

$\Delta G = 0 + RT \ln 2$. Since R, T and ln 2 are positive numbers, then the product, ΔG, is *positive*.

[Reasoning 0.5 pt. and circling answer (C) 0.5 pt.]

(ii) Calculate the ΔG for the creation of an electrochemical gradient of protons in a mitochondrion, when the membrane potential is 150 mV and the pHs are 7 and 8 on the P side (Intermembrane Space) the N side (Matrix Space) of the membrane, respectively. R = 8.315 J/mol/K; T = 298 K. F = 96,485 C **(2 pts.)**

$$\Delta G = 2.3\,RT\,(\text{pH\_P\_side} - \text{pH\_N\_side}) + nF\Delta\Psi$$
$$= 8.315\ \text{J/mol/K} \times 298\ \text{K} \times 2.3 \times 1 + 1 \times 96{,}485\ \text{J/V/mol} \times 0.15\ \text{V}$$
$$= \underline{20.2\ \text{kJ/mol}}$$

[Setup 1.5 pt. and answer 0.5 pt.]

(iii) If 0.1 M glucose 1-phosphate is incubated with phosphoglucomutase, the glucose 1-phosphate is transformed to glucose 6-phosphate. At equilibrium, the concentration of glucose 1-phosphate is 4.5×10^{-3} M and that of glucose 6-phosphate is 8.6×10^{-2} M. Calculate K_{eq}' and $\Delta G°'$ for this reaction (*i.e.*, in the direction of glucose 6-phosphate formation). T = 298 K. Show your work **(3 pts.)**

$$K_{eq}' = \frac{[\text{Glucose 6-phosphate}]}{[\text{Glucose 1-phosphate}]} = \frac{0.086\ \text{M}}{0.0045\ \text{M}} = \underline{19}$$ **[for 1.5 pts.]**

$$\Delta G°' = -RT \ln K_{eq}' = -8.315\ \text{J/mol/K} \times 298\ \text{K} \times \ln(19) = \underline{-7.3\ \text{kJ/mol}}$$ **[for 1.5 pts.]**

[Setup for each 1 pt. and answer 0.5 pt.]

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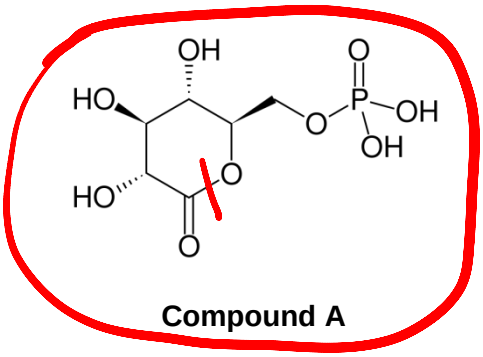
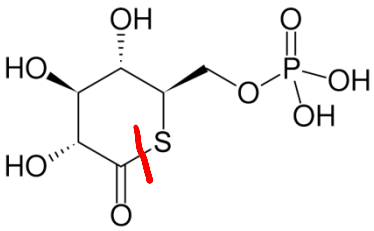
QUESTION 3: COMPOUND A OR B (7 pts.)



Compound A



Compound B

(i) Circle the compound encountered in typical sugar metabolism.

(ii) What is the actual name of the natural substrate?

6-Phosphogluconolactone [or 6-Phospho-glucono-δ-lactone even better]

(iii) What is the name of the enzyme that hydrolyzes the natural substrate, opening the sugar ring?

Lactonase

(iv) Draw a slash across the bond in the sugar rings of Compounds A & B that is cleaved by hydrolysis.

(v) What is the name of the pathway in which the natural sugar metabolite appears?

Pentose Phosphate Pathway

(vi) What types of functional groups are produced when the sugar rings in the compounds (A & B) are hydrolyzed?

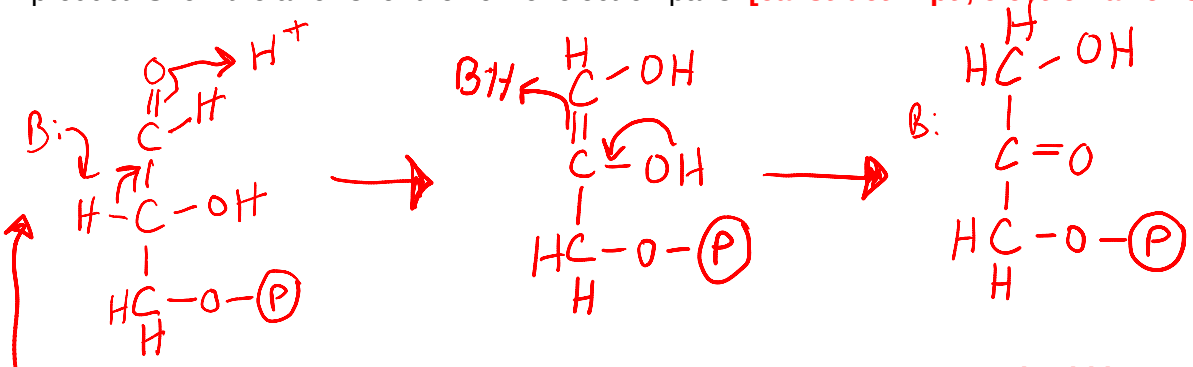
A carboxylic acid (in A & B), an alcohol group (in A), and a thiol group (in B).

(vii) Explain whether compound A or B should have a move negative $\Delta G^{o'}$ upon hydrolysis of the sugar ring.

Resonance stabilization lowers the free energy difference between the reactants and products of the oxygen-based ester; the thiolester, however, cannot obtain such resonance stabilization. Thus the thioester (in B) has a more negative free energy of hydrolysis than Compound A.

QUESTION 4: REACTION MECHANISM (5 pts.)

(i) Draw a reaction mechanism converting glyceraldehyde 3-phosphate to dihydroxyacetone phosphate, such that an enzyme-catalyzed intermediate is formed. Show each structure: reactant, intermediate, and product. Show the arrows for the flow of electron pairs. **[ea. struct. 1 pt., electron arrows 0.5 pt. ea.]**



General acid base

(ii) What type of enzyme catalyzed reaction is this called? **(1 pt.)** _____

[Can be –Ⓟ or drawn out phosphate. Not critical]

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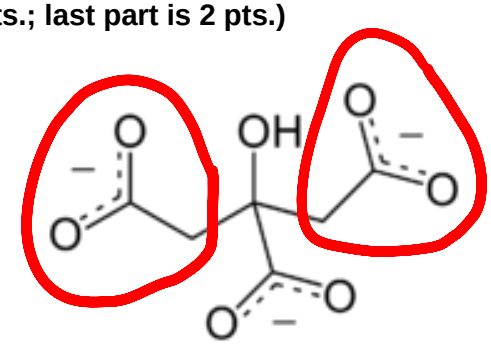
QUESTION 5: COMPOUND X (8 pts.; last part is 2 pts.)



[Circles must include all of $-CH_2COO^-$ groups]

Compound X

(i) What is the name of Compound X?
Citrate

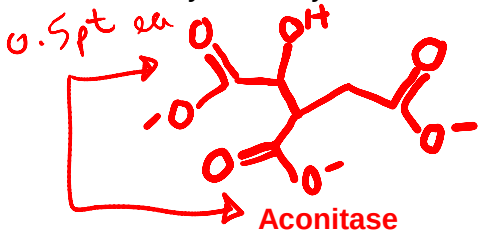
(ii) What are the substrates used to produce Compound X?
[1] Acetyl-CoA and [2] Oxaloacetate

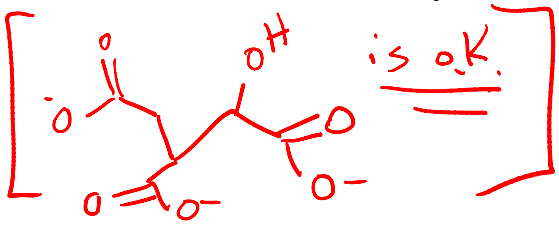
(iii) What metabolic pathway(s) does Compound X participate in?
Citrate Acid Cycle or Krebs Cycle or TCA Cycle [Optional: fatty acid biosynthesis is ok in addition to Citric Acid Cycle though]

(iv) Which enzyme produces Compound X?
Citrate Synthase

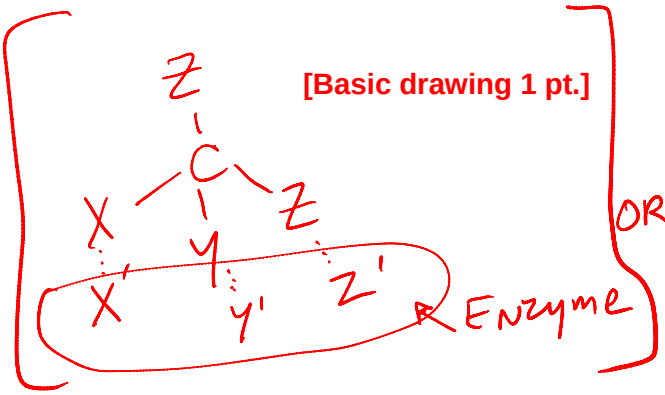
(v) Circle equivalent positions in Compound X that are symmetric.

(vi) What enzyme distinguishes between the symmetrical positions in Compound X? Draw the structure of the asymmetrical product made by this enzyme. Under the structure write the name of this enzyme.

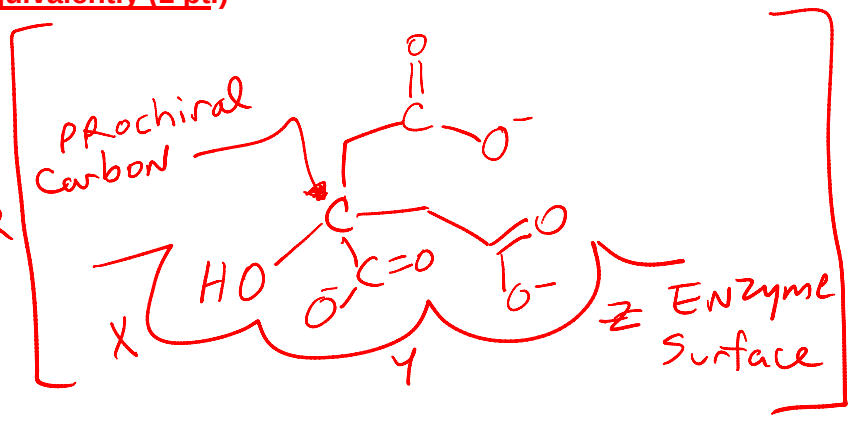




(vii) Explain how an enzyme could distinguish between the equivalent positions in Compound X. Provide an illustration showing your argument **(2 pts.)**
Citrate has the potential to be treated as chiral, since it is prochiral. Thus an asymmetric enzyme surface found on aconitase can act on citrate as through it were chiral. As a consequence the left and right acetyl groups are not treated equivalently (1 pt.)



OR



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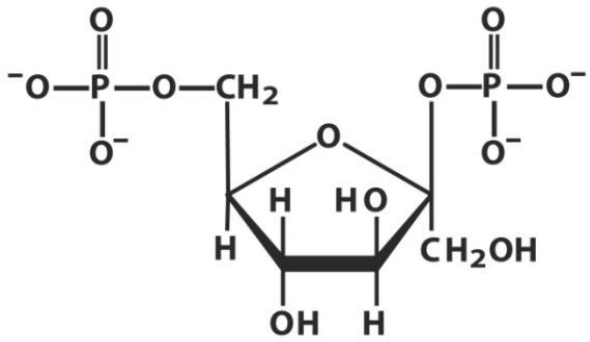
QUESTION 6: MOLECULE X (5 pts.; last part is 3 pts.)



Molecule X

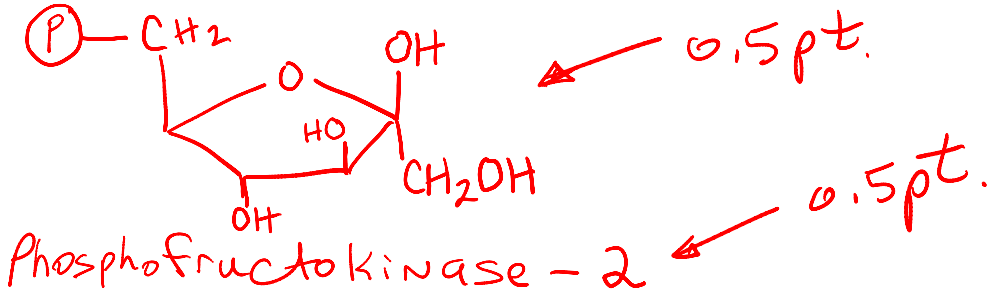
(i) Molecule X's specific name is:

Fructose 2,6-bisphosphate [(F26BP) abbr. is worth 0.5 pt but need the full name here.]

(ii) Draw the structure(s) of the sugar precursor molecule(s) that immediately lead to the formation of Molecule X. Under the structure(s) write the name(s) of the enzyme(s) that act on each to produce Molecule X.

[perfect stereochem. not req.]

[Hydrogens not required]



(iii) How will the hormone glucagon ultimately affect the concentration of Molecule X in the liver? In your answer discuss the pathway leading to the regulation of the enzyme(s) that alter the levels of Molecule X directly. State how the enzyme activities that produce Molecule X are affected and by what mechanism. Write out a 5 to 6 sentence response, addressing these mechanisms **(3 pts.)**

Glucagon will cause the level of Molecule X (F26BP) to decrease in the liver. The extracellular hormone will bind to the glucagon receptor and trigger a signaling cascade: first hormone binding will trigger a G protein to hydrolyze its GTP to GDP, the G protein in the GDP state will bind to adenylate cyclase and activate it to convert ATP→cAMP, cAMP will activate a protein kinase, the kinase will phosphorylate the enzyme phosphofructokinase-2 (PFK-2). When PFK-2 is phosphorylated, the enzyme's two different activities will become reciprocally regulated: the fructobisphosphatase-2 (FPK-2) activity increases and the phosphofructokinase-2 activity decreases. The reciprocal regulation causes the amount of F26BP (Molecule X) to go down, since the upregulation of the fructobisphosphatase-2 activity and simultaneous downregulation of the FPK-2 activity will favor fructose 6-phosphate or F26BP. [Give 0.5 pt. for each of the major underlined details.]

[*PARTIAL CREDIT: What if they think it is Fructose 1,6-bisphosphate (F16BP)? Well, they can get credit for the cascade, and they can get credit if they say how F26BP levels go down and F16BP levels go down. So even if parts i and ii are wrong they can get all the pts in iii*****]**

QUESTION 7: FILL IN THE BLANKS (5 pts.; 0.5 pt. each blank)

(i) The synthesis of fatty acids and their breakdown by occur by separate pathways. Compare the two paths by filling in the blanks with all species that apply.

	Synthesis	Breakdown
Activating group	Acyl carrier protein (ACP)	CoA
Electron carrier coenzyme(s)	NADPH	FAD & NAD^+
Basic units added or removed	Malonyl- & Acetyl-	Acetyl-
Cellular location of process	Cytosol	Mitochondrial matrix

(ii) Sterol synthesis is committed at the HMG-CoA Reductase catalyzed step.

(iii) 4-Phosphopantetheine is the long flexible arm covalently linked via a phosphate ester to a serine on the acyl carrier protein domain of the Fatty Acid Synthase complex.

[Phosphopantetheine or pantetheine OK]

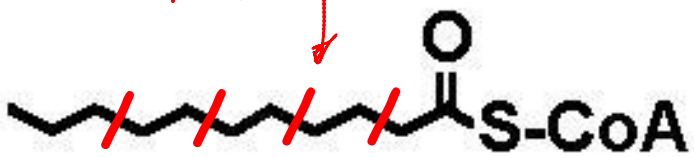
[$FADH_2$ & NADH O.K.]

[β-hydroxy Bmethyl glutaryl-CoA Reductase O.K.]

[Can give 0.25 pt. for ½ CORRECT blanks]

QUESTION 8: COMPOUND X (7pts.; last part is 2 pts.)

[Wrong slash -0.25 pts.] Each CORRECT slash 0.25 pts.



(i) The general name of this molecule is: **Fatty acid or acyl-CoA** [or Fatty acyl-CoA O.K.]

(ii) The type of metabolic process used to produce the smallest Coenzyme A (CoA) derivatives is:

β oxidation [fatty acid breakdown 0.5 pt. really need beta oxidation for full credit]

(iii) On the drawing indicate with a thick slash were the C-C bonds must be cleaved to produce the smallest final CoA intermediates.

(iv) What pathway in the cell catalyzes parallel enzymatic reactions to those required to break down the molecule drawn above. **Citric Acid Cycle [or "TCA Cycle" or "Krebs Cycle" are ok]**

(v) One residual acyl-CoA product *must* be converted to an intermediate found in the Citric Acid Cycle for proper metabolism. What is the name of **(a)** the residual acyl-CoA product and **(b)** the Citric Acid Cycle intermediate product?

(a) Residual acyl-CoA product: **Propionyl-CoA** [PROPIONYL- PROPIONATE O.K.]

(b) Citric Acid Cycle intermediate product: **Succinyl-CoA** [SUCCINATE 0.25pt]

(vi) In a short answer response, describe the enzyme mechanisms, intermediate species, and cofactors involved in converting the residual Acyl-CoA species to the Citric Acid Cycle intermediate **(2 pts.)**

Biotin is required to convert propionyl-CoA to D-methyl-malonyl-CoA via a carboxylation mechanism using bicarbonate. An epimerase enzyme is required to invert the stereochemistry, converting D-methyl-malonyl-CoA to L-methyl-malonyl-CoA. Finally, L-methyl-malonyl-CoA is converted to succinyl-CoA using a mutase enzyme through a radical mechanism that requires the coenzyme derived from vitamin B_{12}.

QUESTION 9: MULTIPLE CHOICE (7 pts.) Clearly circle your selection (0.5 pt. ea.)

(i) Which of the following cofactors *do not* form covalent adducts with enzymes' lysine residues?
(A) Lipoic acid
(B) Biotin
(C) NADH **(CHOICE C)**
(D) Pyridoxyl phosphate
(E) All of the above
(F) None of the above

(ii) Which of the following residues *are not* phosphorylated in the catalytic mechanism or regulation of an enzyme?
(A) H
(B) K **(CHOICE B)**
(C) S
(D) T
(E) Y

(iii) In normal mitochondria, the rate of NADH consumption (oxidation) will:
(A) be increased in active muscle, decreased in inactive muscle.
(B) be very low if the ATP synthase is inhibited, but increase when an uncoupler is added.
(C) decrease if mitochondrial ADP is depleted.
(D) decrease when cyanide is used to prevent electron transfer through the electron transport chain.
(E) All of the above are correct. **(CHOICE E)**

(iv) Which of the following statements about the chemiosmotic theory is *correct*?
(A) Electron transfer in mitochondria is accompanied by an asymmetric release of protons on *one* side of the inner mitochondrial membrane. **(CHOICE A)**
(B) It predicts that oxidative phosphorylation can occur even in the absence of an intact inner mitochondrial membrance.
(C) The effect of uncoupling reagents is a consequence of their ability to carry electrons through membranes.
(D) The membrane ATP synthase has no significant role in the chemiosmotic theory.
(E) All of the above are correct.

(v) Almost all of the oxygen (O_2) one consumes in breathing is converted to:
(A) Acetyl-CoA
(B) Carbon dioxide
(C) Carbon monoxide and then to carbon dioxide
(D) Superoxide
(E) Water **(CHOICE E)**

(vi) During oxidative phosphorylation, proton motive force that is generated by electron transport:
(A) creates a pore in the inner mitochondrial membrane.
(B) generates the substrates (ADP and P_i) for the ATP synthase.
(C) induces a conformational change in the ATP synthase. **(CHOICE C)**
(D) oxidizes NADH to NAD^+.
(E) reduces O_2 to H_2O.

(vii) Cholesterol is synthesized from:
(A) Acetyl-CoA **(CHOICE A)**
(B) Oleic acid
(C) Methyl-malonyl-CoA
(D) Malate
(E) Oxaloacetic acid

(viii) The anaerobic conversion of 1 mol of glucose to 2 mol of lactate by fermentation is accompanied by a net gain of:

(A) 1 mol of ATP
(B) 1 mol of NADH
(C) 2 mol of ATP **(CHOICE C)**
(D) 2 mol of NADH
(E) None of the above

(ix) Which of the following is a cofactor in the reaction catalyzed by glyceraldehyde 3-phosphate dehydrogenase?

(A) ATP
(B) Cu^{2+}
(C) heme
(D) NAD^{+} **(CHOICE D)**
(E) $NADP^{+}$

(x) Which of the following compounds *cannot* serve as the starting material for the synthesis of glucose via gluconeogenesis?

(A) Acetate **(CHOICE A)**
(B) Glycerol
(C) Propionate
(D) Oxaloacetate
(E) α-ketoglutarate

(xi) Glucose metabolism via the pentose phosphate pathway fates the C-1 carbon to become:

(A) Carbon dioxide **(CHOICE A)**
(B) Glycogen
(C) Sedheptulose
(D) Pyruvate
(E) Ribose 5-phosphate
(F) None of the above

(xii) Which of the following is *not* required in the synthesis of fatty acids?

(A) Acetyl-CoA
(B) NADH **(CHOICE B)**
(C) Biotin
(D) HCO_3^-
(E) Malonyl-CoA

(xiii) All of the following to lead to activation of the pyruvate dehydrogenase complex *except*

(A) A decrease in the concentration of NADH
(B) A decrease in the concentration of Acetyl CoA
(C) An increase in ADP
(D) A decrease in the activity of NADH dehydrogenase **(CHOICE D)**
(E) An increase in the activity of the Citric Acid Cycle
(F) None of the above

(xiv) Which of following urea cycles are *correct*? Stoichiometries are not precisely given. By-products are {bracketed}. AMP, ADP, PPi, and Pi by-products are not shown for brevity.

(A) CO2 + NH3 + ATP → Carbamoyl phosphate + Ornithine → Arginine + Succinate + CoA + ATP → Argininosuccinyl-CoA + Water → Citrulline + {Aspartate} → Ornithine + {Urea}

(B) CO2 + NH3 + ATP → Carbamoyl phosphate + Ornithine → Citrulline + Aspartate + ATP → Argininosuccinate → Arginine + {Fumarate} + Water → Ornithine + {Urea} **(CHOICE B)**

(C) CO2 + NH3 + ATP → Carbamoyl phosphate + Ornithine → Citrulline + Fumarate + ATP → Argininosuccinate → Arginine + {Aspartate} + Water → Ornithine + {Urea}

(D) CO2 + NH3 + ATP → Carbamoyl phosphate + Ornithine → Citrulline + Succinate + ATP → Argininosuccinate → Arginine + {Succinate} + Water → Ornithine + {Urea}

(E) CO2 + NH3 + ATP → Carbamoyl phosphate + Ornithine → Citrulline + Aspartate + ATP → Argininosuccinate → Arginine + {Succinate} + Water → Ornithine + {Urea}

QUESTION 10: PATHWAY ANALOGIES (5 pts.) These analogies highlight the parallels in metabolic pathways. Fill in the blanks to best demonstrate these parallels.

(i) Consider transaminase enzyme substrates and products.

Glutamate : α-ketoglutarate :: Alanine : Pyruvate

Glutamate : α-ketoglutarate :: Aspartate : Oxaloacetate

(ii) Consider fatty acid oxidation and the Citric Acid Cycle.

Succinate : Acyl-CoA :: Oxaloacetate : β-ketoacyl-CoA [keto acyl-CoA o.k.]

Succinate : Acyl-CoA :: Fumarate : Enoyl-CoA

(iii) Consider how the Cori Cycle parallels the Glucose/Alanine Cycle.

Lactate : Lactate Dehydrogenase :: Alanine : Alanine Transaminase

(iv) Consider electron transport chain reactions.

Ubiquinone : NADH :: Ubiquinol : NAD^+ [QH_2 is O.K.]

QH_2 : Complex III :: Cytochrome *c* (*red*) [ok if (*red*) is not there] : Complex IV

(v) Consider the Urea Cycle and Citric Acid Cycle.

Oxaloacetate : Ornithine :: Citrate : Citrulline [Can be reversed. O.K. full credit.]

Acetyl-CoA : Carbamoyl Phosphate :: CO_2 : Urea

QUESTION 11: SHORT ANSWER (10 pts.) Provide only a short, two-to-three-sentence response.

(i) What could the reagent sodium borohydride tell you about an enzyme mechanism?

Sodium borohydride can be used to test if an enzyme catalyzed reaction occurs via a protonated Schiff base, which is a covalent substrate-enzyme complex. The Schiff base will be reduced by borohydride to create a more permanent secondary-amine adduct between the enzyme and substrate. [This adduct can be isolated to determine the active site location by proteolysis.] ← optional additional statement in brackets.

(ii) Describe why the standard free energy of hydrolysis of ATP→ADP+Pi is exergonic and favorable. Based on your description explain whether GTP and ATP hydrolysis should differ significantly.

The basic features leading to the large free energy of hydrolysis for ATP are preserved in GTP, namely (1) relief of charge repulsion, (2) resonance stabilization in Pi leaving group, and (3) ionization due to deprotonation. Since the chemical differences in the bases do not affect reasons 1, 2, and 3 above then the std. hydrolysis free energies should be identical or nearly so.

(iii) Why isn't the hexokinase step (STEP 1) the committed step in glycolysis, since it is irreversible and occurs prior to the phosphofructokinase step (STEP 3)?

Because glucose 6-phosphate made in STEP 1 can also go down the pentose phosphate pathway, it is not committed solely to glycolysis, blocking at this upstream point would prevent the generation of ribose or NADPH at times when the cell has sufficient ATP levels. [One could also mention G-6-P could be used to make glycogen; thus blocking glycolysis at STEP 1 would prevent glycogen synthesis.] ← Either pentose phos or glycogen reasoning is sufficient for full credit here.

(iv) List the intermediates made when converting fructose 1,6-bisphosphate (F16BP) to the substrate for the enzyme that makes glycogen. Number the list in order, where F16BP is listed first and the substrate for glycogen synthesis is listed last.

[If they have glycogen at end, then this is O.K.]

1. **Fructose 1,6-bisphosphate**
2. **Fructose 6-phosphate**
3. **Glucose 6-phosphate [A chunk of 2 correct species in a row gets 0.5 pt of credit]**
4. **Glucose 1-phosphate [A chunk of 3 correct species in a row gets 1 pt of credit]**
5. **UDP-glucose [A chunk of 4 correct species in a row gets 1.5 pts of credit]**

(v) What is the pH inside the matrix of the mitochondrion relative to the intermembrane space? Explain in your answer how the pH is affected during respiration.

The pH inside the mitochondrial matrix is greater than the intermembrane space. The differential in pH occurs, because electron transfer along the electron transport chain causes protons to be transferred across the inner mitochondrial membrane from the matrix into the intermembrane space.

QUESTION 12: ATP 123… (8 pts.)

Which produces more ATP ultimately, twenty glucose or eight C_{12}-length saturated fatty acyl-CoA?

(i) Circle your answer from the three listed **(1 pt.)**

TWENTY GLUCOSES **THEY ARE THE SAME** **EIGHT C_{12} FATTY ACYL-COAS**

(ii) Show the basis of your answer reached in **(Part i)** by filling out the table below **(7 pts.)**

- State the major energy producing **pathways** by using these pathways and abbreviations: glycolysis **(GLY)**, citric acid cycle **(CAC)**, pyruvate dehydrogenase complex **(PDHC)**, or β oxidation **(βOX)**.
- State the **net carbon reaction** by writing the **chemical names and stoichiometries** of the carbon skeletons **including CO_2** *but not* the O_2, water molecules, cofactors, NAD+, FAD, Pi, ADP, etc.
- State the **net ATP** yielded, which includes the oxidation of reducing equivalents that may have been produced in these steps.
- Use the "**TOTAL**" row to make a total net carbon reaction and a total ATP tally.
- Assume that **NADH = 2.5 ATP** and **$FADH_2$ = 1.5 ATP**.

PATHWAY	NET CARBON REACTION	NET ATP
GLY	20 Glucose → 40 Pyruvate	140
PDHC	40 Pyruvate → 40 Acetyl-CoA + 40 CO_2	100
CAC	40 Acetyl-CoA → 80 CO_2	400
	[Either acetate or acetyl-CoA will be OK.]	
TOTAL	20 Glucose → 120 CO_2	640
βOX	8 C_{12} Fatty acids → 48 Acetyl-CoA	160
CAC	48 Acetyl-CoA → 96 CO_2	480
TOTAL	8 C_{12} Fatty acids → 96 CO_2	640

[Ea. line is 1 pt. Partial credit 0.5 pt. only if the pathway & either net carbon or ATP are correct.]

QUESTION 13: MOLECULAR MATCHING (11 pts.)

(i) Match these cofactors on the left with all the possible groups the bind with that cofactor. Enter your letter answers (one each) in the blanks preceding each of the groups on the right **(0.5 pt. ea.)**

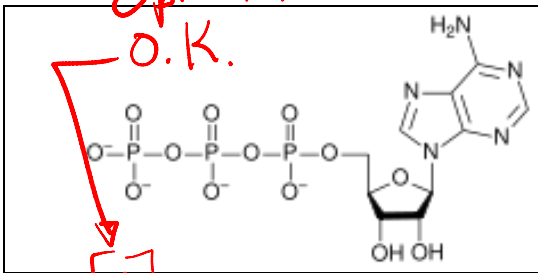
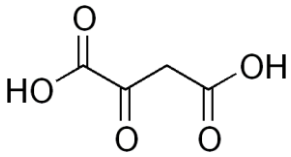
(A) NAD+
(B) Pyridoxyl phosphate (PLP)
(C) Biotin
(D) Thiamine pyrophosphate (TPP)
(E) B_{12}
(F) Coenzyme A (CoA)
(G) Mg^{2+}

F ____ **Succinyl**
E ____ **Deoxyadenosine**
D ____ **Dihydroxyethyl**
F ____ **Acetyl**
B ____ **Ammonium**

F ____ **Acyl**
F ____ **Enoyl**
C ____ **Carboxy**
A ____ **Hydride**
G ____ **ATP**

(ii) Match these structures with the functions and pathways provided. **Indicate all possible matches** in the box beneath each **(0.5 pt. ea.)** **[0.25 pt. increments are received if at least half of the answer given is correct.]**

(A) Coenzyme/cofactor
(B) Energy currency
(C) Urea cycle
(D) Citric acid cycle
(E) Oxidative phosphorylation
(F) Allosteric effector
(G) Glycolysis
(H) Hormone
(I) Uncoupler
(J) Fatty acid synthesis
(K) Gluconeogenesis
(L) Pentose Phosphate Pathway

	 optional O.K. [A]	
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	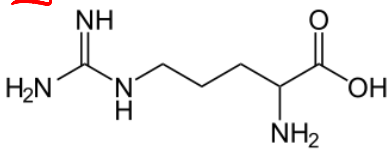	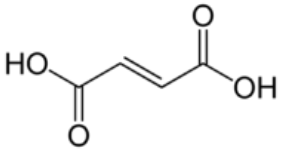
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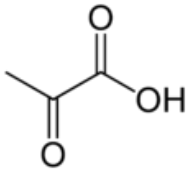
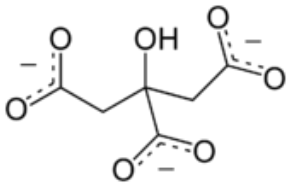
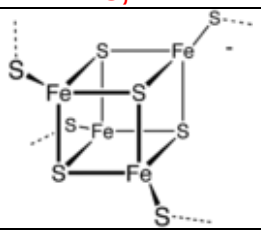
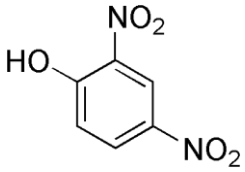
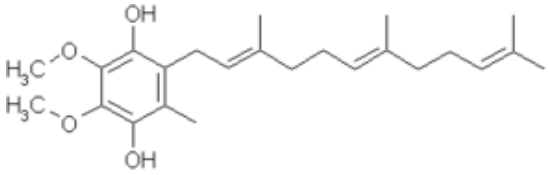
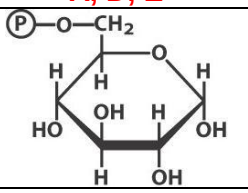
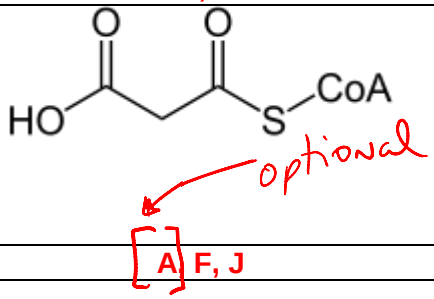
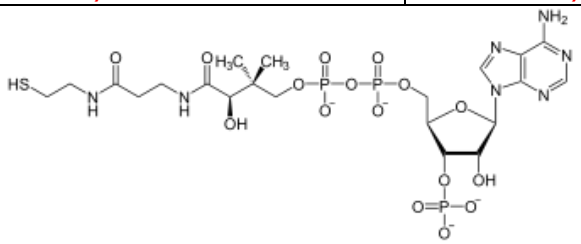
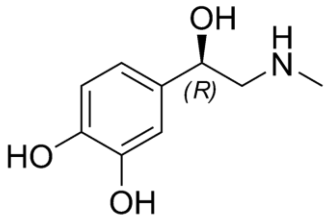
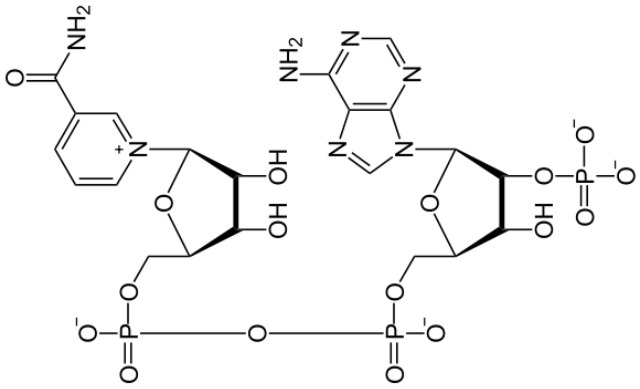
		
G, K	D, F [, J optional]	A, D, E
		
E, I	A, E	G, K, L
 optional [A]		
A, F, J	A, D, J	
		
H	A, F, J, L	

LOG TABLE

The table below lists the common logarithms (with base 10) for numbers between 1 and 10.
The logarithm is denoted in **bold face**. *E.g.*, the first entry in the third column means that the common log of 2.00 is **0.30.**
Use scientific notation to get values not present in the table, i.e., Log(850) = 2 + Log(8.5).
To calculate a natural log using this Log10 table, Ln(x) = Log(x) / Log (2.72), or you can multiply the Log(x) by 2.3.

x	Log(x)	x	Log(x)
1.00	**0.00**	5.00	**0.70**
1.10	**0.04**	5.10	**0.71**
1.20	**0.08**	5.20	**0.72**
1.30	**0.11**	5.30	**0.72**
1.40	**0.15**	5.40	**0.73**
1.50	**0.18**	5.50	**0.74**
1.60	**0.20**	5.60	**0.75**
1.70	**0.23**	5.70	**0.76**
1.80	**0.26**	5.80	**0.76**
1.90	**0.28**	5.90	**0.77**
2.00	**0.30**	6.00	**0.78**
2.10	**0.32**	6.10	**0.79**
2.20	**0.34**	6.20	**0.79**
2.30	**0.36**	6.30	**0.80**
2.40	**0.38**	6.40	**0.81**
2.50	**0.40**	6.50	**0.81**
2.60	**0.41**	6.60	**0.82**
2.70	**0.43**	6.70	**0.83**
2.80	**0.45**	6.80	**0.83**
2.90	**0.46**	6.90	**0.84**
3.00	**0.48**	7.00	**0.85**
3.10	**0.49**	7.10	**0.85**
3.20	**0.51**	7.20	**0.86**
3.30	**0.52**	7.30	**0.86**
3.40	**0.53**	7.40	**0.87**
3.50	**0.54**	7.50	**0.88**
3.60	**0.56**	7.60	**0.88**
3.70	**0.57**	7.70	**0.89**
3.80	**0.58**	7.80	**0.89**
3.90	**0.59**	7.90	**0.90**
4.00	**0.60**	8.00	**0.90**
4.10	**0.61**	8.10	**0.91**
4.20	**0.62**	8.20	**0.91**
4.30	**0.63**	8.30	**0.92**
4.40	**0.64**	8.40	**0.92**
4.50	**0.65**	8.50	**0.93**
4.60	**0.66**	8.60	**0.93**
4.70	**0.67**	8.70	**0.94**
4.80	**0.68**	8.80	**0.94**
4.90	**0.69**	8.90	**0.95**
		9.00	**0.95**
		9.10	**0.96**
		9.20	**0.96**
		9.30	**0.97**
		9.40	**0.97**
		9.50	**0.98**
		9.60	**0.98**
		9.70	**0.99**
		9.80	**0.99**
		9.90	**1.00**

EQUATION BOX

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

$aA + bB \leftrightarrow cC + dD$

$K_{eq}' = ([C]^c [D]^d) / ([B]^b [A]^a)$

$\Delta G^{o\prime} = -RT \ln K_{eq}'$

$\Delta G = \Delta G^{o\prime} + RT \ln Q$

$Q = ([C]^c [D]^d) / ([B]^b [A]^a)$

$E = E^{o\prime} + nF/(RT) \ln [e^-\text{ acceptor}] / [e^-\text{ donor}]$

$\Delta G^{o\prime} = -nF \times \Delta E^{o\prime}$

$PMF = \Delta\Psi + 2.3(RT/F)\,\Delta pH$

$\Delta G_{PMF} = 2.3RT\Delta pH + F\,\Delta\Psi$