This exam consists of 7 questions. A maximum of 100 points can be earned. Partial credit will be given. There are a total of 12 pages, including the cover page and one blank sheet at the end for notes. However, do not use the blank sheet for your final answers. If you need more space, use the back of pages 2-8. Write your name on top of each page! Petitions for regarding will be considered only if you have used permanent ink, unless an addition error has occurred.

*IT IS YOUR RESPONSIBILITY TO WRITE LEGIBLE! No extra effort will be made to decipher your handwriting.

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<tr>
<th>Question</th>
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<td>TOTAL</td>
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\[
\Delta G = \Delta G^{o'} + RT \ln \frac{\text{Prod.}}{\text{React.}} \\
\Delta G^{o'} = -nF \Delta E^{o'} \\
\Delta E^{o'} = E^{o'} \text{Oxidant} - E^{o'} \text{Reductant}
\]

I, ________________________________________________, authorize the University to distribute publicly this graded exam (e.g., handed out in class or left in a bin for pick up).

I am aware of the fact that violations of the Academic Code of Conduct\(^1\) may be reported to UC Davis Student Judicial Affairs.

\(^1\)Examples of academic misconduct include: receiving or providing unauthorized assistance on examinations, using unauthorized materials during an examination, altering an exam and submitting it for re-grading, or using false excuses to obtain extensions of time (http://sja.ucdavis.edu/cac.htm).

Signature________________________________________  Date____________________________
1. (5 pts) Given below are pairs of reactants and products (the stoichiometry is not necessarily complete or balanced). Use your general understanding of thermodynamics, chemical reactions and metabolism to predict if the reactions as written (\( \rightarrow \)) are thermodynamically favorable (-\( \Delta G^{\circ} \)) or unfavorable (+\( \Delta G^{\circ} \)) under standard conditions. Circle the correct answer (1 pt for each reaction).

<table>
<thead>
<tr>
<th>Reactants</th>
<th>Products</th>
<th>Standard Free Energy Change (( \Delta G^{\circ} ))</th>
</tr>
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<tbody>
<tr>
<td>CO₂, H₂O</td>
<td>Glucose, O₂</td>
<td>positive positive negative</td>
</tr>
<tr>
<td>H₂, O₂</td>
<td>H₂O</td>
<td>positive positive negative</td>
</tr>
<tr>
<td>ADP</td>
<td>AMP, Pi</td>
<td>positive positive negative</td>
</tr>
<tr>
<td>Glucose</td>
<td>2x Pyruvate</td>
<td>positive positive negative</td>
</tr>
<tr>
<td>Glucose, Pi</td>
<td>Glucose-6-P</td>
<td>positive positive negative</td>
</tr>
</tbody>
</table>

2. (16 pts) The enzyme pyruvate kinase catalyzes the last step in glycolysis:

\[
\text{Phosphoenolpyruvate (PEP) + ADP} \rightarrow \text{Pyruvate (Pyr) + ATP}
\]

a) Draw the structures of PEP and Pyr in the boxes given below (6 pts).

![PEP Structure](image)

![Pyr Structure](image)

b) Pyruvate kinase belongs to what major class of enzymes? (2 pts) Encircle only one enzyme class!

- Oxidoreductases
- Transferases
- Hydrolases
- Lyases
- Isomerases
- Ligases
c) Calculate the $\Delta G^\circ$ and the corresponding equilibrium constant $K_{eq}$ of the pyruvate kinase reaction by using the following information (Pi = phosphate):

PEP + H$_2$O $\rightarrow$ Pyr + Pi \quad ($\Delta G^\circ = -62.2 \text{ kJ/mol}$)
ATP + H$_2$O $\rightarrow$ ADP + Pi \quad ($\Delta G^\circ = -30.5 \text{ kJ/mol}$)

For full credit, you must show your work! Place your final answer on the line below (8 pts).
3. (17 pts) The enzyme phosphoglycerate mutase catalyzes the following reaction in glycolysis:

$$3\text{-Phosphoglycerate (3-PGA)} \Leftrightarrow 2\text{-Phosphoglycerate (2-PGA)}$$

a) The $\Delta G^\circ$ of the phosphoglycerate mutase reaction is $+4.4$ kJ/mol in the direction of 2-PGA formation. The following metabolite concentrations were measured in skeletal muscle: 3-PGA = 220 µM and 2-PGA = 11 µM. What is the $\Delta G$ in muscle tissue at body temperature (37 °C)? For full credit, you must show your work! Place your final answer on the line below (8 pts).

$\Delta G = \text{___________________________}$
b) Why is it not possible to calculate $\Delta G^\circ$ of the phosphoglycerate mutase reaction from standard reduction potentials? (3 pts)

c) 3-PGA and 2-PGA belong to what class of compounds? (2 pts) **Encircle only one compound class!**

<table>
<thead>
<tr>
<th>Triose</th>
<th>Aldohexose</th>
<th>Ketohexose</th>
<th>Carboxylic Acid</th>
</tr>
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</table>

d) What is the purpose of the phosphoglycerate mutase reaction in glycolysis? Brief answer! (4 pts)
Arsenic compounds are powerful poisons that have multiple targets in metabolism. One example is briefly explained. Arsenate (\(\text{HAsO}_4^{2-}\)), which can be considered an analog of phosphate (\(\text{HPO}_4^{2-}\)), is readily used as a substrate by a glycolytic enzyme to produce an ‘acyl arsenate’. However, unlike acyl phosphates, acyl arsenates are kinetically extremely labile and decompose non-enzymatically by hydrolysis, releasing arsenate.

a) What glycolytic enzyme (common name) produces an acyl phosphate by incorporating free Pi? (2 pts)

Name: ____________________________________________________________

b) Write a balanced reaction of this step in glycolysis (do not draw structures but provide full names of the carbohydrate derived substrate and product; use common abbreviations for the other reactants and products). (6 pts)

c) Given that acyl arsenates readily hydrolyze non-enzymatically, how do you explain the poisoning effect of arsenate on glycolysis, particularly in anaerobic conditions? (6 pts)
5. (12 pts) Ethylene glycol (see below), also known as antifreeze, is a toxic diol (i.e., an alcohol with two hydroxyl groups). If accidentally ingested, ethylene glycol is converted to oxalic acid (a dicarboxylic acid) via glyoxal (a dialdehyde). Crystals of oxalic acid deposit in the kidneys, which eventually leads to renal failure. Ethylene glycol is converted to oxalic acid by types of enzymes discussed in class. Because these enzymes have a low substrate specificity, therapeutic doses of ethanol are used as antidotes to competitively inhibit reaction 1. This treatment alleviates the adverse effects of ethylene glycol poisoning. \(\textit{Note, the structures below do not show C-H bonds.}\)

![Chemical structures](image)

1. Ethylene glycol  
2. Glyoxal  
3. Oxalic acid

a) The two reactions converting ethylene glycol into oxalic acid are conceptually similar. The enzymes catalyzing both reactions are members of what enzyme class? (2 pts) **Encircle only one enzyme class!**

Oxidoreductases  
Transferases  
Hydrolases  
Lyases  
Isomerases  
Ligases

b) Both enzyme reactions require the same co-factor. Which of the five co-factors discussed in class participates in both reactions? (2 pts) **Encircle only one co-factor!**

Coenzyme A  
TPP  
NAD\(^+\)/NADH  
FAD/FADH\(_2\)  
Lipoic Acid

c) Briefly explain the function of this co-factor in both reactions. (2 pts)

Function: ____________________________________________

d) Briefly state one general function for three additional co-factors (out of the five listed in b., but different from the one discussed in c.). (6 pts)

1. ____________________________

2. ____________________________

3. ____________________________
6. (14 pts) Short answers.

a) Honey consists mainly of glucose and fructose. What enzyme (common name) can convert both monosaccharides into intermediates of glycolysis? (3 pts)

Enzyme:________________________________________________

b) Adults who engage in strenuous physical activity require a daily intake of about 160 grams of carbohydrates. However, per day they only need about 20 milligrams of niacin, the precursor of NAD⁺, which is required for carbohydrate degradation. How do you explain this discrepancy? (4 pts)

c) Why is the phosphorolytic cleavage of endogenous glycogen in muscle and liver by the enzyme glycogen phosphorylase more advantageous than glycogen cleavage by hydrolysis? (4 pts)

d) What enzyme (common name) converts the product of glycogen phosphorylase, glucose-1-P, into an intermediate of glycolysis? (3 pts)

Enzyme:________________________________________________
7. (22 pts)  Multiple-choice questions.  Circle the best answer.  There is only one best answer per question.  Each question is worth 2 pts.

a.  Which equation defines a system (a process or reaction) at equilibrium?

i   \( \Delta G > 0 \)

ii  \( \Delta G^\circ = \Delta G \)

iii  \( \Delta G = 0 \)

iv  \( \Delta G^\circ = 0 \)

v  \( \Delta G = RT \ln Q \)

b.  Virtually all life on earth ultimately depends on what source of energy?

i  geothermal energy

ii  \( \Delta G \) of phosphoanhydrides and thioesters

iii  energy stored in chemical bonds

iv  solar energy

v  mental energy

c.  “High-energy” compounds are characterized by a large negative \( \Delta G^\circ \) of their hydrolysis and include all EXCEPT:

i  phosphate esters

ii  phosphate anhydrides

iii  acyl phosphates

iv  enol phosphates

v  thioesters

d.  The metabolite with a lowest phosphoryl group transfer potential is:

i  ADP

ii  AMP

iii  PEP (phosphoenol pyruvate)

iv  PPi (pyrophosphate)

v  1,3-bisPGA (1,3-bisphosphoglycerate)
e. Coupling of a reaction to the hydrolysis of ATP *in vivo* can shift the equilibrium constant of that reaction by a factor of about:

i. $10$
ii. $10^3$
iii. $10^6$
iv. $10^8$
v. $10^{10}$

f. If carbon 2 (C-2) is the carbonyl of a ketohexose, which carbon determines if the sugar is a D- or L-stereoisomer?

i. C-1
ii. C-3
iii. C-4
iv. C-5
v. C-6

g. The step that commits glucose to glycolysis is catalyzed by:

i. pyruvate kinase
ii. phosphofructokinase
iii. hexokinase
iv. glucokinase
v. glycerol kinase

h. Addition of water across a double bond, or removal of water from a double bond, is catalyzed by a subclass of lyases. Which of the following enzymes is a lyase?

i. maltase
ii. lactase
iii. invertase
iv. amylase
v. enolase
i. Under anaerobic conditions, skeletal muscles generate lactate from pyruvate in order to:
   i. lower the pH for prolonged contraction
   ii. promote release of oxygen from hemoglobin
   iii. to generate additional ATP via PEP formation
   iv. to activate glycogen phosphorolysis
   v. to regenerate NAD$^+$ for further glycolysis

j. Glycerol enters glycolysis at what stage?
   i. dihydroxyacetone phosphate
   ii. 3-phosphoglycerate
   iii. 2-phosphoglycerate
   iv. phosphoenolpyruvate (PEP)
   v. pyruvate

k. Which of the following co-factors can form a thioester?
   i. NAD$^+$
   ii. FAD
   iii. Lipoic acid
   iv. TPP
   v. none of the above