This exam consists of 6 questions. A maximum of 100 points can be earned. Partial credit will be given. There are a total of 11 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 2-10. 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.

<table>
<thead>
<tr>
<th>Question</th>
<th>Value</th>
<th>Score</th>
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<tbody>
<tr>
<td>1</td>
<td>4</td>
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<td>2</td>
<td>18</td>
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<td>5</td>
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<td>6</td>
<td>20 (+2)</td>
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<td><strong>TOTAL</strong></td>
<td><strong>100 (+2)</strong></td>
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</table>

T = 25 °C (298 K)  
T = 37 °C (310 K)  
R = 8.315 J mol⁻¹ K⁻¹  
F = 96.5 kJ mol⁻¹ V⁻¹  
n = moles of electrons  

\[ \Delta G = \Delta G^\circ' + RT \ln \frac{\text{Prod.}}{\text{React.}} \]  
\[ \Delta G^\circ' = -RT \ln K_{eq} \]  
\[ \Delta G^\circ = -nF \Delta E^\circ' \]  
\[ \Delta E^\circ = E^\circ_{\text{Oxidant}} - E^\circ_{\text{Reductant}} \]  

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 Conduct¹ may be reported to UC Davis Student Judicial Affairs.

¹Examples 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).
1. (4 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 are thermodynamically favorable (-ΔG°”) or unfavorable (+ΔG°”) 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 (ΔG°”)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADP, Pi</td>
<td>ATP, H₂O</td>
<td>positive</td>
</tr>
<tr>
<td>Succinyl-CoA, H₂O</td>
<td>Succinate, Coenzyme A</td>
<td>negative</td>
</tr>
<tr>
<td>Phosphoenolpyruvate, ADP</td>
<td>Pyruvate, ATP</td>
<td>positive</td>
</tr>
<tr>
<td>H₂O</td>
<td>H₂, O₂</td>
<td>positive</td>
</tr>
</tbody>
</table>

2. (18 pts) The first reaction of the TCA cycle is catalyzed by the enzyme citrate synthase (CS). The ΔG°” for this reaction is –32.2 kJ mol⁻¹.

a) Write the CS-catalyzed reaction (do not draw structures, use words or common abbreviations) (2 pts)

b) Calculate the equilibrium constant Kₑₒ for the citrate synthase reaction under standard conditions. For full credit you must show your work and encircle your final answer. (4 pts)

Kₑₒ = ______________________________
c) In heart mitochondria, the following metabolite concentrations were measured: citrate (220 x 10^{-6} M); oxaloacetate (1 x 10^{-6} M); acetyl-CoA (1 x 10^{-6} M); and coenzyme A (65 x 10^{-6} M). Calculate the ΔG of the citrate synthase reaction under cellular conditions. For full credit you must show your work and encircle your final answer. (8 pts)

\[ ΔG = \text{______________________________} \]

c) What is the direction of the citrate synthase reaction in heart mitochondria? (2 pts)

Answer: _____________________________________________

d) Hydrolysis of the intermediate citroyl thioester is part of (or coupled to) the citrate synthase reaction. The ΔG° for the hydrolysis of thioesters is about – 31.5 kJ mol^{-1}. If there would be no coupling of the citroyl thioester hydrolysis to the citrate synthase reaction, what would be the metabolic consequence in heart mitochondria? (2 pts)

Answer: _____________________________________________
3. (16 pts) Lactic acid is formed when the bacteria in tooth plaque degrade sugars and carbohydrates from the human diet under anaerobic conditions. Lactic acid exposure destroys the enamel of the teeth causing cavities. Many communities add fluoride (F\(^-\)) to their drinking water to promote dental health. Fluoride (F\(^-\)) is a known inhibitor of *enolase*, an enzyme of the glycolytic pathway, and thus inhibits bacterial growth.

a) Write the names of the products of the enolase-catalyzed reaction below the product boxes. (3 pts)

b) Draw the structures of the reactant (2-PGA) and the products into the respective boxes. (5 pts)

```
Reactant          Products

2-Phosphoglycerate (2-PGA) Name:_________________ Name:_________________
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c) Why does inhibition of the enolase reaction effectively inhibit bacterial growth under anaerobic conditions? Briefly discuss *two* metabolic consequences. (8 pts.)
4. (16 pts) Short questions on co-factors and enzymes.

a) What is the general function of co-factors in enzyme catalysis? (2 pts)

b) Briefly explain the difference between a “co-substrate” and a “prosthetic group”. (4 pts)

c) The table below lists enzymes and co-factors discussed in class (ATP can be considered a co-factor). For each enzyme, indicate all required co-factors by placing an “X” in the appropriate box. Note: Some enzymes may not require a co-factor. You will lose your point if you select additional co-factors that are not required by the enzyme. (1 pt for each enzyme and correct co-factor requirement; 10 pts total)

<table>
<thead>
<tr>
<th>Enzyme</th>
<th>ATP</th>
<th>NAD⁺/NADH</th>
<th>FAD/FADH₂</th>
<th>Lipoic Acid</th>
<th>TPP</th>
<th>CoA-SH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Succinate Dehydrogenase (SDH)</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Hexokinase</td>
<td></td>
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<tr>
<td>Pyruvate Dehydrogenase (PDH)</td>
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<tr>
<td>Glycogen Phosphorylase</td>
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<tr>
<td>Pyruvate Decarboxylase (PDC)</td>
<td></td>
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<tr>
<td>Malate Dehydrogenase (MDH)</td>
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<tr>
<td>α-Ketoglutarate Dehydrogenase (α-KGA-DH)</td>
<td></td>
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<tr>
<td>Glyceraldehyde-3-P Dehydrogenase</td>
<td></td>
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<tr>
<td>Aldolase</td>
<td></td>
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<tr>
<td>Isocitrate Dehydrogenase (IDH)</td>
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</table>
5. (26 pts) Short questions on glycolysis.

a) In glycolysis, 2 ATP per glucose are initially consumed, but 4 ATP are finally generated, which equals a net production of 2 ATP per glucose. Why is the initial investment of 2 ATP necessary? Give two reasons. (4 pts)

b) The two enzymes that utilize ATP during the initial or “investment” phase of glycolysis belong to what major class of enzymes? **Encircle one enzyme class only (no credit otherwise)** (2 pts)

```
Oxidoreductases  Transferases  Hydrolases  Lyases  Isomerases  Ligases
```

c) Calculate $\Delta G^{\circ}$ for the lactic fermentation (Pyruvate $\rightarrow$ Lactate). For full credit, you must show your work and place the final answer on the line below. (6 pts). Use the following information:

\[
\text{NAD}^+ + 2\text{H}^+ + 2\text{e}^- \rightarrow \text{NADH} + \text{H}^+ \quad (E^o = -0.32 \text{ V}) \\
\text{Pyruvate} + 2\text{H}^+ + 2\text{e}^- \rightarrow \text{Lactate} \quad (E^o = -0.18 \text{ V})
\]

$\Delta G^{\circ} = \text{______________________________}$
d) Why is it not possible to calculate the \( \Delta G^\circ \) value of the aldolase reaction from standard reduction potentials? (2 pts)

e) The enzyme “aldolase” belongs to what major class of enzymes? **Encircle one enzyme class only (no credit otherwise)** (2 pts)

Oxidoreductases Transferases Hydrolases Lyases Isomerases Ligases

f) The degradation of glycogen is an important process that supplies glycolysis with glucose. Briefly explain the major differences between **glycogen hydrolysis** and **glycogen phosphorolysis**. (4 pts)

g) Mannose is a wide-spread monosaccharide in fruits and vegetables, which is converted by two reactions into an intermediate of glycolysis. **Encircle the (three) correct statements.** (6 pts)

Mannose is a…

Triose Aldohexose Aldoketose

,which is converted to…

Glucose-6-P Fructose-1-P Fructose-6-P

by the following pairs of enzymes:

Kinase/ Oxidoreductase Kinase
Lyase Isomerase Isomerase
6. (20 pts) Multiple-choice questions. **Circle the best answer.** There is **only one best answer** per question. Each question is worth 2 pts.

a. Which one of the following compounds is **NOT** a carbohydrate?
   i. Glucose
   ii. Galactose
   iii. Glycogen
   iv. Glycerol
   v. Glyceraldehyde

b. The following compounds have a **large negative ΔG° of hydrolysis** EXCEPT:
   i. Adenosine triphosphate
   ii. Fructose-1,6-bisphosphate
   iii. Acetyl-CoA
   iv. Phosphoenolpyruvate
   v. 1,3-Bisphosphoglycerate

c. Which one of the following co-factors does **NOT** participate in oxidoreduction reactions?
   i. FAD
   ii. NAD
   iii. Coenzyme A
   iv. Lipoic acid
   v. all of the above

d. The essentially **irreversible** reactions of glycolysis include the one catalyzed by:
   i. phosphoglucoisomerase
   ii. phosphofructokinase
   iii. phosphoglycerate kinase
   iv. phosphoglycerate mutase
   v. aldolase
e. Which one of the following enzymes catalyzes *substrate-level phosphorylation* of ADP to ATP?

i. Succinyl-CoA synthetase  
ii. Triose kinase  
iii. Hexokinase  
iv. Pyruvate dehydrogenase  
v. Glyceraldehyde-3-P dehydrogenase

f. Which of the following statements is **NOT** true for enzymes:

i. enzymes facilitate a reaction by changing its rate  
ii. enzymes facilitate a reaction by decreasing its activation energy  
iii. enzymes facilitate a reaction by decreasing its free energy change  
iv. enzymes facilitate a reaction by binding to other metabolites  
v. enzymes facilitate a reaction by providing stereospecificity

g. The pyruvate dehydrogenase (PDH) complex is present and functions in the…?

i. Plasma membrane  
ii. Cytosol  
iii. Outer mitochondrial membrane  
iv. Inner mitochondrial membrane  
v. Mitochondrial matrix

h. Under aerobic conditions, the complete oxidation of 1 mole glucose via glycolysis and the TCA cycle yields how many moles of NADH + H⁺ and FADH₂?

i. 10 moles NADH + H⁺ and 4 moles FADH₂  
ii. 12 moles NADH + H⁺ and 4 moles FADH₂  
iii. 14 moles NADH + H⁺ and 2 moles FADH₂  
iv. 10 moles NADH + H⁺ and 2 moles FADH₂  
v. 16 moles NADH + H⁺ and 0 moles FADH₂
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. Which of the following is meant by the statement that glucose and galactose are epimers?
   i one is an aldose and the other is a ketose
   ii one is a pyranose and the other a furanose
   iii they are mirror images of each other
   iv they differ only at the configuration at one carbon atom
   v after cyclization, they differ only at the configuration at the carbon atom C-1

k. **Bonus question (2 extra points)!** The TCA cycle catalyzes the complete degradation of the acetyl unit (CH₃-CO⁻, provided as acetyl-CoA) into two molecules of CO₂. Thus, three additional oxygen atoms must be acquired for generating two CO₂ molecules from acetyl-CoA. What are the compounds that enter the TCA cycle and provide the extra three oxygen atoms?
   i  O₂ and H₂O
   ii  3 H₂O
   iii 2 H₂O and Pi
   iv H₂O and 2 Pi
   v  O₂ and Pi
Use blank sheet as scratch paper.