This exam consists of 7 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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<tr>
<td>1</td>
<td>4</td>
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<td>20 (+2)</td>
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<td>TOTAL</td>
<td>100 (+2)</td>
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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

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

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 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).

Signature________________________________________  Date____________________________

Undergraduate Student
Completing Incomplete
Open Enrollment Student
Graduate Student
1. (4 pts) Warm-up question. Given below are pairs of reactants and products (note that the stoichiometry is not necessarily complete or balanced). Use your general understanding of thermodynamics, of chemical reactions and of metabolism to predict if the reactions as written are thermodynamically favorable (\(\Delta G^o\)) or unfavorable (\(\Delta G^o\)) 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^o))</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADP, Pi</td>
<td>ATP, H(_2)O</td>
<td>positive</td>
</tr>
<tr>
<td>H(_2), O(_2)</td>
<td>H(_2)O</td>
<td>positive</td>
</tr>
<tr>
<td>PPI, H(_2)O</td>
<td>Pi, Pi</td>
<td>positive</td>
</tr>
<tr>
<td>Acetate, Coenzyme A</td>
<td>Acetyl-CoA, H(_2)O</td>
<td>positive</td>
</tr>
</tbody>
</table>

2. (26 pts) Short questions on glycolysis.

a) Briefly define the term substrate-level phosphorylation. (2 pts)

The generation of ATP from ADP by transfer of a phosphate group from a phosphorylated substrate with a more negative free energy of hydrolysis than ATP.

b) Provide the name and chemical structure of the end product for both aerobic and anaerobic glycolysis in humans. (6 pts)

- **Aerobic glycolysis**
  - Name of end product: Pyruvate/Pyruvic Acid
  - Its chemical structure: CH$_3$-CO-COOH

- **Anaerobic glycolysis**
  - Name of end product: Lactate/Lactic Acid
  - Its chemical structure: CH$_3$-CHOH-COOH

c) Describe in one sentence the purpose of the last reaction in anaerobic glycolysis? (2 pts)

The last reaction in anaerobic glycolysis regenerates NAD$^+$ by the reduction of pyruvate to lactate.
d) The ten reactions of aerobic glycolysis are catalyzed by enzymes that belong to four of the six systematic enzyme classes. For each of the four enzyme classes (underlined below), correctly identify one of the ten steps in glycolysis by providing the balanced reaction (use common abbreviations for all reactants) and by giving the corresponding common enzyme name. (12 pts)

**Isomerase**

Reaction: see booklet (aerobic glycolysis)

Enzyme: **Phosphogluco isomerase or Triose-P isomerase or Phosphoglycerate mutase**

**Oxidoreductase**

Reaction: \( \text{GA3P} + \text{Pi} + \text{NAD}^+ \leftrightarrow \text{NADH} + 1,3\text{bisPGA} \)

Enzyme: **Glyceraldehyde-3-P dehydrogenase**

**Transferase**

Reaction: see booklet (aerobic glycolysis)

Enzyme: **Hexo/Glucokinase or Phosphofructokinase or Phosphoglycerate kinase or Pyruvate kinase**

**Lyase**

Reaction: see booklet (aerobic glycolysis)

Enzyme: **Aldolase or Enolase**

e) A yeast culture is grown in the presence of glucose and undergoes ethanolic fermentation. The glucose is radioactively labeled at certain positions with \([^{14}\text{C}]\)-carbon. All the \([^{14}\text{C}]\)-label is found in CO\(_2\). Which carbon atom(s) of the glucose are \([^{14}\text{C}]\)-labeled? To answer the question, draw the structure of glucose (Fisher projection) and circle the radioactively labeled atoms. (4 pts)

![Draw structure of glucose](image)
3. (12 pts) In glycolysis, fructose-1,6-bisphosphate (F1,6BP) is converted into glyceraldehyde-3-phosphate (GA3P) and dihydroxyacetone phosphate (DHAP).

a) The $\Delta G^o$ for this reaction is $+23.8 \text{ kJ mol}^{-1}$. Calculate the equilibrium constant ($K_{eq}$) at standard conditions ($25^\circ \text{C}$). For full credit, you must show your work and place your final answer on the line below. (6 pts)

At equilibrium: $\Delta G^o = -RT \ln K_{eq}$ or $\Delta G^o = -2.303RT \log K_{eq}$

$23.8 \text{ kJ mol}^{-1} = -8.315 \text{ J mol}^{-1} \text{ K}^{-1} \times 298 \text{ K} \times \ln K_{eq}$

$\ln K_{eq} = - \frac{(23,800 \text{ J mol}^{-1})}{(8.315 \text{ J mol}^{-1} \text{ K}^{-1} \times 298 \text{ K})}$

$\ln K_{eq} = -9.6$ or $\log K_{eq} = -4.17$

$K_{eq} = e^{-9.6}$ or $K_{eq} = 10^{-4.17}$

$K_{eq} = 0.000067$ or $6.7 \times 10^{-5}$

$K_{eq} = 0.000067$ or $6.7 \times 10^{-5}$

d) The following concentrations of reactants and products were measured in erythrocytes: F1,6BP ($31 \times 10^{-6} \text{ M}$); DHAP ($140 \times 10^{-6} \text{ M}$); GA3P ($19 \times 10^{-6} \text{ M}$). What is the $\Delta G$ in erythrocytes at body temperature ($37^\circ \text{C}$)? For full credit, you must show your work and place your final answer on the line below. (6 pts)

$\Delta G = \Delta G^o + RT \ln [\text{Prod.}]/[\text{React.}]$

$\Delta G = +23,800 \text{ J mol}^{-1} + (8.315 \text{ J mol}^{-1} \text{ K}^{-1} \times 310 \text{ K} \times \ln [19 \times 10^{-6} \times 140 \times 10^{-6}]/[31 \times 10^{-6}])$

$\Delta G = +23,800 \text{ J mol}^{-1} + (8.315 \text{ J mol}^{-1} \text{ K}^{-1} \times 310 \text{ K} \times \ln [85.8 \times 10^{-6}])$

$\Delta G = +23,800 \text{ J mol}^{-1} + (8.315 \text{ J mol}^{-1} \text{ K}^{-1} \times 310 \text{ K} \times -9.36)$

$\Delta G = +23,800 \text{ J mol}^{-1} + (-24,127 \text{ J mol}^{-1})$ (-24,136 J mol$^{-1}$, if not rounded)

$\Delta G = -327 \text{ J mol}^{-1}$ or $-0.33 \text{ kJ mol}^{-1}$ (-336 J mol$^{-1}$ or -0.34 kJ mol$^{-1}$)

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4. (16 pts) Answer the following questions about various metabolically important compound classes that are depicted in the box below.

![Chemical structures](image)

a) Match the chemical structures shown in the box above with the most appropriate compound class name given below. **Place the corresponding letter (only one!) above each line.** (6 pts)

- Ester: __C__
- Ether: __D__
- Phosphoester: __A__
- Thioester: __E__
- Phosphoanhydride: __F__
- Acylphosphate: __B__

b) Which of the molecules in the box are considered “high-energy” compounds because their hydrolytic cleavage (arrow) is thermodynamically highly favorable (i.e., $\Delta G^0$ at least -25 kJ mol$^{-1}$)? **Circle correct answer(s) below (for each additional incorrect circle 1 pt will be deducted!).** (6 pts)

- A  B  C  D  E  F

b) Which structure in the box is most closely related to Acetyl-CoA? **Circle correct answer below.** (2 pts)

- A  B  C  D  E  F

c) Which of the compounds listed below have the same type of linkage (indicated by the arrow) as molecule F? **Circle correct compound(s) below.** (2 pts)

- Glc-6-P  ATP  Phosphoenolpyruvate  UDP-Galactose
5. (8 pts) D-Altrose is a rare dietary monosaccharide that is converted into an intermediate of glycolysis by three reactions (see box below). Answer the following questions:

![Diagram of D-Altrose and glycolysis intermediate]

a) D-Altrose belongs to what class of compounds? (1 pt) **Circle only one compound class!**

Polyalcohol   **Aldohexose**   Ketohexose   Carboxylic Acid

b) What is the name of the glycolysis intermediate that is produced from D-Altrose? (1 pt)

Name: **Fructose-6-phosphate/Fru-6-P/F6P**

c) Each of the three reactions (see box above) is catalyzed by an enzyme. For each step, identify either the enzyme class (e.g., oxidoreductase) **or** derive a more specific name (e.g., dehydrogenase), as long as it makes sense for that particular reaction. Note, while the order of reactions #2 and #3 does not matter, it is important that you identify the correct enzyme class (or name) for reaction #1! (6 pts)

**Enzyme 1:** **Transferase/Phosphotransferase/Kinase/Hexokinase/Altrose kinase**

**Enzyme 2:** **Isomerase/Epimerase/Altrose-P epimerase**

Order of 2 and 3 may be switched

**Enzyme 3:** **Isomerase/ketol isomerase/Altrose-P isomerase**
6. (14 pts) Short questions on co-factors.

a) Describe in *one sentence* the general function of co-factors in enzyme catalysis? (1 pts)

Co-factors are metals or small organic molecules are required for catalytic activity and expand the repertoire of functional groups beyond that of protein amino acid side chains.

b) Describe in *one sentence* the difference between a co-substrate and a prosthetic group? (2 pts)

Co-substrates are soluble co-factors, whereas prosthetic groups are co-factors that are covalently coupled to or tightly bound by the enzyme.

c) Given below are the chemical structures of 5 co-factors discussed in class: TPP, Coenzyme A, NAD⁺, Lipoic acid, and FADH₂. Identify each co-factor by placing its name into the appropriate box. (5 pts)
Question 6 continued:

d) Which of the five co-factors function in oxidoreduction and carbon (C) transfer reactions? (6 pts)

**Oxidoreduction**  
FADH₂, NAD⁺, Lipoic Acid

**C-Transfer**  
TPP, Coenzyme A, Lipoic Acid

7. (20 + 2 pts) Multiple-choice questions. **Circle the best answer.** There is **only one best answer** per question. Each question is worth 2 pts.

a. The carbon of which one of the following groups is the most oxidized?

i  -CH₂OH  
ii -CH₂-  
iii -COOH  
iv -CHO  
v -CH₃

b. **Pyruvate Dehydrogenase** catalyzes the following overall reaction:

i The conversion of pyruvate to lactate  
ii The conversion of pyruvate to ethanol  
iii The conversion of pyruvate to acetate  
iv The conversion of phosphoenolpyruvate to pyruvate  
v The conversion of pyruvate to activated acetate

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d. The **phosphorolysis** of intracellular glycogen produces the following **primary product**:

i. UDP-Glucose  
ii. **Glucose-1-phosphate**  
iii. Glucose-1,6-bisphosphate  
iv. Glucose-6-phosphate  
v. Pyrophosphate

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

i. Pyruvate kinase  
ii. **Phosphofructokinase**  
iii. Hexokinase  
v. Phosphoglycerate kinase

f. If lactate is the end product of glycolysis from glucose produced by phosphorolysis from glycogen, how many moles of ATP and NADH are eventually produced per mole glucose?

i. 4 moles ATP and 2 moles NADH  
ii. 3 moles ATP and 2 moles NADH  
iii. 2 moles ATP and 1 mole NADH  
iv. **3 moles ATP and 0 moles NADH**  
v. 2 moles ATP and 2 moles NADH

g. Arsenite reacts with vicinal (neighboring) sulfhydryl groups of organic compounds and forms covalent adducts. Which one of the following enzymes discussed in class would be inhibited by arsenite?

i. Glyceraldehyde-3-P Dehydrogenase  
ii. Aldolase  
iii. **Pyruvate Dehydrogenase**  
iv. Pyruvate Decarboxylase  
v. Enolase
h. Which of the following compounds is not a carbohydrate:

i. Glucose
ii. Galactose
iii. Glycogen
iv. Glycin
v. Glyceraldehyde

i. In oxido-reduction reactions, the reductant (or reducing agent) becomes itself:

i. oxidized
ii. reduced
iii. protonated
iv. deprotonated
v. phosphorylated

j. The following compounds have a large negative $\Delta G^\circ$ of hydrolysis EXCEPT:

i. Pyrophosphate
ii. Fructose-1,6-bisphosphate
iii. Acetyl-CoA
iv. Phosphoenolpyruvate
v. ADP

k. **Bonus question (2 extra points)!** Which one of the following gases is the most oxidizing?

i. $\text{F}_2$
ii. $\text{H}_2$
iii. $\text{O}_2$
iv. $\text{N}_2$
v. $\text{CO}_2$
BIS103-002 (Spring 2009)  
Midterm #1 (April 21)  

Use as scratch paper if needed.