Thermodynamics of Metabolism

Metabolism is the process by which cells use energy from the environment to synthesize necessary molecules. One important metabolic pathway is glycolysis, in which the combustion of glucose, $C_6H_{12}O_6$, produces water and carbon dioxide:

$$C_6H_{12}O_6(s) + 6O_2(g) \rightarrow 6CO_2(g) + 6H_2O(l)$$

Characterize the themodynamic favorability of this reaction with respect to temperature. The standard state free energy of formation, standard state enthalpy of formation and the absolute entropy for glucose are shown here; other necessary thermodynamic values may be found in your textboook:

$$\Delta G_f^o = -910.52 \text{ kJ/mol}_{rxn} \quad \Delta H_f^o = -1274.4 \text{ kJ/mol}_{rxn} \quad S^o = 212.1 \text{ J/mol}_{rxn}\cdot\text{K}$$

Imagine that a 60 kg man eats a candy bar containing 60 g of glucose and that his body is a perfect calorimeter. Assuming that the specific heat of the body is the same as that for water, calculate the change in the man's body temperature? In your experience as a consumer of candy bars, is your answer reasonable? Explain. If your answer isn't reasonable, provide at least one plausible explanation for why the calculated ΔT is larger or smaller than expected.

The first step in the glycolytic pathway is the transfer of a phosphate from adenosine-triphosphate (ATP) to glucose:

Reaction I: glucose + ATP $\rightarrow$ glucose-6-phosphate + ADP

Under standard state conditions and in the absence of ATP, glucose-6-phosphate is unstable and reacts with water to produce glucose and a free phosphate:

Reaction II: glucose-6-phosphate + $H_2O \rightarrow$ glucose + phosphate

Additionally, for the hydrolysis of ATP under standard state conditions

Reaction III: ATP + $H_2O \rightarrow$ ADP + phosphate

the free energy change is favorable.

$$\Delta G^o_{III} = -32.48 \text{ kJ/mol}_{rxn}$$

What prediction can you make concerning the sign of ΔG^o for Reaction II under standard state conditions? Explain.

The sign of ΔG^o for Reaction I under standard state conditions is unclear from the information provided above. Using Hess's law, what can you say about the value of ΔG^o_I? State your answer as ΔG^o_I must be greater than…, or ΔG^o_I must be less than…, or ΔG^o_I is equal to… Hint: note that Reaction III is the sum of Reactions I and II.

Another step in the glycolytic pathway is

fructose-1,6-diphosphate $\rightarrow$ dihydroxyacetone phosphate + glyceraldehyde-3-phosphate

for which ΔG^o is +23.8 kJ/mol_{rxn} at a temperature of 298 K. Although this reaction is unfavorable under standard state conditions, we know that it does routinely occur in cells; thus, the concentrations of reactants and products in the cells must not be at their standard states values. What is the largest reaction quotient, Q, that will produce a favorable free energy change? Recall that Q is a measure of the relative amounts of products to reactants.

The value of Q is approximately 10^{-4} in the cells of rats. What is the value of ΔG for this reaction under these conditions and what does this tell you about the favorability of this glycolytic pathway in rats? If you believe that the reaction is unfavorable, why might it still occur?