MMG 301 Study Guide for Bioenergetics

The energies available from balanced **fermentation reactions** are based on the Gibb's free energy difference ($\Delta G^{o'}$) that is calculated as the free energies of formation for the products minus the free energies of formation of the substrates. In mathematical lingo this is:

$$\Delta G^{o'} = G^{o'}(\text{products}) - G^{o'}(\text{substrates})$$

$G^{o'}$ values for a large number of substances are shown in your book in Table A1.1.

The energies available from **respiration reactions** are based on the difference in reduction potentials of the electron donor minus the electron acceptor. In other words:

$$\Delta E_o' = E_o' \text{ (acceptor)} - E_o' \text{ (donor)}$$

E_o' values for a large number of compounds are shown in your book in Table A1.2.

The values of $\Delta G^{o'}$ and $\Delta E_o'$ are interconverted by a simple equation:

$$\Delta G^{o'} = -nF\Delta E_o'$$

(n is the number of electrons transferred in each reaction, often 2 in biology, and F = 96.48 kJ/mole). Thus, fermentation reactions can be used to produce an electrochemical gradient or respiratory reactions can be used to synthesize desired compounds.

Practice questions:

1. What value of $\Delta G^{o'}$ do you calculate for the energy available to yeast growing by alcoholic fermentation? (1 glucose converted to 2 ethanol plus 2 CO_2)

2. What value of $\Delta G^{o'}$ do you calculate for heterolactic fermentation? (1 glucose converted to 1 lactic acid, 1 ethanol, and 1 CO_2)

3. What value of $\Delta G^{o'}$ do you calculate for *Clostridium kluyveri* growing by the following fermentative process: ethanol + acetate + CO_2 converted to caproate + butyrate + H_2 gas?

4. What value of $\Delta E_o'$ do you calculate for a cell growing on H_2 + fumarate to form succinate? What is this in $\Delta G^{o'}$?

5. What value of $\Delta E_o'$ do you calculate for a cell growing on H_2 + oxygen to form water? What is this in $\Delta G^{o'}$?

6. What value of $\Delta E_o'$ do you calculate for a cell growing on H_2 + sulfate to form hydrogen sulfide (H_2S)? What is this in $\Delta G^{o'}$?

Answers:

1. Your calculation should be as follows (keeping track of the number of moles of each substance): [2(-181.75) + 2(-394.4)] – (-917.2) = -235.1 (all in units of kJ/mol). Note that this is an negative number; thus, energy is available for the cells to grow.

2. Your calculation should be as follows (the multiplication factors are all one in this case): [(-517.81) + (-369.41) + (-394.4)] – (-917.2) = -364.42 kJ/mol. Again, energy is available to the cells.

3. Your calculation should be as follows:
   [(-335.96) + (-352.63) + (0)] – [(-181.75) + (-369.41) + (-394.4)] = +256.97kJ/mol. This positive value indicates that the organism cannot obtain sufficient energy to survive by this fermentation reaction if all reactants are at Standard Conditions. Indeed, *C. kluyveri* can only grow by this fermentation if another organism is present to remove the H_2 to drive the reaction.

4. The electron acceptor is fumarate and electron donor is H_2. The first calculation is done as follows: (+0.033 V) – (-0.41 V) = 0.443 V. Note that this is a positive number, so energy is available. When converted to $\Delta G^{o'}$ (with n = 2) one gets –85.48 kJ/mol.

5. Here, the electron acceptor is oxygen with the electron donor still being H_2. More energy is available: (+0.82 V) – (-0.41 V) = 1.23 V or –237.3 kJ/mol.

6. This question is a bit tougher. Sulfate is clearly the acceptor and hydrogen the donor, but this is an 8 electron reaction (four molecules of H_2) are needed. From values in the table, (-0.217 V) - (-0.41 V) = +0.193 V for each 2 electron step. This corresponds to –37.24 kJ/mol for each 2 electrons or –148.96 kJ/mol for the total reaction. For comparison, you can directly calculate $\Delta G^{o'}$ from values in Table A1.1 for the balanced reaction:

   $$4\ H_2 + 2\ H^+ + SO_4^{2-} \rightarrow H_2S + 4\ H_20$$

   [(-27.87) + 4(-237.17)] – [4(0) + 2(-39.83) + (-744.6)] = -152.29 kJ/mol. This is pretty close, but not exactly what we calculated based on the electron transfer reactions. This example illustrates that all of the values are estimates that will depend on the experimental conditions.