Supplemental Problems: Transmembrane Transport
Use these constants: R = 8.314 J/mol-K; T = 298 K; $\mathcal{F}$ = 96,485 J/V-mol

Absorption of digested food in the small intestine entails transport of the nutrients across cell membranes from the interior of the intestine (the lumen) into the cytoplasm of epithelial cells, which, in turn, pass the nutrients into the bloodstream.

Consider the transport of molecules of the uncharged nutrient C across a cell membrane into an epithelial cell:

$$C_{out} \rightleftharpoons C_{in}$$

1. What is the value of the equilibrium constant K for this process?

2. What is the standard free-energy change ($\Delta G°'$) for this process?

3. After a meal and some absorption of C, the concentration of C inside this cell ($[C]_{in}$) is 24 mM, and the concentration outside ($[C]_{out}$) is 1.2 mM. Calculate ΔG (kJ/mol) for continued transport of C into the epithelial cell from the small intestine.

4. Is movement of C into the cell spontaneous? How do you decide?

5. The concentration of sodium ions inside the epithelial cell ($[Na^+]_{in}$) is 5.0 mM and the concentration of sodium ions outside the cell ($[Na^+]_{out}$) is 140 mM. Calculate ΔG (kJ/mol) for movement of sodium ions from the intestinal lumen into the cell, according to this equation:

$$Na^+_{out} \rightleftharpoons Na^+_{in}$$

6. Is the movement of sodium ions into the cell spontaneous? How do you decide?

7. The intestinal cell brings in C by way of a **symport** protein, which brings in one molecule of C with one sodium ion (Na^+). Calculate ΔG for the co-transport of sodium ions and C molecules, according to this equation:

$$C_{out} + Na^+_{out} \rightleftharpoons C_{in} + Na^+_{in}$$

8. Is co-transport of sodium ions and C molecules spontaneous? How do you decide?

9. Many cells maintain ion gradients that result in a net negative charge inside the cells. If intestinal epithelial cells maintain a voltage gradient in which the interior of the cell is 60 mV more negative than the exterior, what effect will the voltage gradient have on ΔG for co-transport of sodium ions and C molecules? To answer this question, calculate ΔG for the process in question 7, but include the effect of the voltage gradient.

10. Does the voltage gradient make the transport process more favorable or less favorable? How do you decide?

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11. The Na^+ gradient is maintained by a pump that drives sodium ions out of the epithelial cell into the intestinal lumen. Calculate ΔG (kJ/mol) for movement of sodium ions out of the cell into the intestinal lumen. Include the effect of the normal concentrations of Na^+ inside and outside the cell, and the effect of the normal voltage gradient. The process is

$$Na^+_{in} \rightleftharpoons Na^+_{out}$$

12. Is this process spontaneous? Explain, at the molecular level.

13. Under cellular conditions, the free-energy change for the hydrolysis of ATP is - 50 kJ/mol:

$$ATP + H_2O \rightleftharpoons ADP + P_i \quad \Delta G = -50.0 \text{ kJ/mol}$$

The sodium-ion pump couples the movement of sodium ions to the hydrolysis of ATP, as follows:

$$3\ Na^+_{in} + ATP + H_2O \rightleftharpoons 3\ Na^+_{out} + ADP + P_i$$

Calculate the free-energy change for this process.

14. Is this process spontaneous?

15. Summarize the impact of ATP hydrolysis on the movement of sodium ions out of the cell, and on the movement of the nutrient C into the cell. Use the terms *primary active transport* and *secondary active transport* in your description.