Answers to Exercise 6.5
Free Energy and the Second Law of Thermodynamics

1. $\Delta_r G = -T\Delta S_{universe}$

   As such, if a reaction increases the entropy of the universe ($\Delta S_{universe} > 0$) it must, by definition, have a negative free energy change.

   Thus, any reaction with $\Delta_r G < 0$ is thermodynamically allowed.

2. No. A reaction can be thermodynamically allowed but not proceed in the forward direction if the activation energy is too high.

   e.g. The conversion of diamond to graphite is thermodynamically allowed under standard conditions $\left(\Delta_r G° = -2.866\ \frac{kJ}{mol}\right)$, but diamonds do not tend to decompose into graphite.

3. **<u>Equations to Calculate Standard Free Energy Change ($\Delta_r G°$)</u>**

   $\Delta_r G° = \sum \Delta_f G°(products) - \sum \Delta_f G°(reactants)$

   The standard free energy change for a reaction can be calculated from the standard free energies of formation for the products and reactants.

   $\Delta_r G° = \Delta_r H° - T\Delta_r S°$

   The standard free energy change for a reaction can be calculated from the standard enthalpy change for the reaction ($\Delta_r H°$) and the standard entropy change for the reaction ($\Delta_r S°$) at a given temperature (T) in Kelvin.

   $\Delta_r G° = -RTlnK$

   The standard free energy change for a reaction can be calculated from the reaction's equilibrium constant (K), the ideal gas constant (R) and the temperature (T) in Kelvin.

   $\Delta_r G° = -\nu_e F E°$

   The standard free energy change for a reaction can be calculated from the standard potential ($E°$), Faraday's constant (F) and the stoichiometric coefficient for electrons in the balanced redox equation (ν_e).

   $\Delta_r G = \Delta_r G° + RTlnQ$

   The standard free energy change for a reaction can be calculated from the observed free energy change under nonstandard conditions ($\Delta_r G$), the ideal gas constant (R), temperature (T) in Kelvin and reaction quotient (Q).

Equations to Calculate Free Energy Change ($\Delta_r G$)

$\Delta_r G = \Delta_r G° + RTlnQ$

The free energy change for a reaction under nonstandard conditions can be calculated from the standard free energy change ($\Delta_r G°$), the ideal gas constant (R), temperature (T) in Kelvin and reaction quotient (Q).

$\Delta_r G = \Delta_r H - T\Delta_r S$

The free energy change for a reaction can be calculated from the enthalpy change for the reaction ($\Delta_r H$) and the entropy change for the reaction ($\Delta_r S$) at a given temperature (T) in K under nonstandard conditions as well.

$\Delta_r G = -\nu_e FE$

The free energy change for a reaction under nonstandard conditions can be calculated from the potential (E), Faraday's constant (F) and the stoichiometric coefficient for electrons in the balanced redox equation (ν_e).