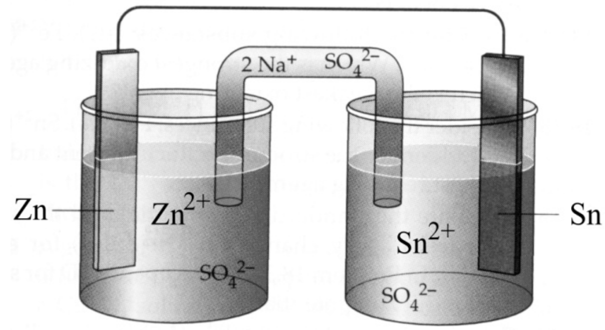
CHEM1612 Worksheet 12: Using Electrical Energy and Introduction to Kinetics

Model 1: Galvanic Cells



In worksheet 9, you saw how the electrical energy in a redox reaction can be harnessed to make a battery, by setting up the **voltaic cell** opposite. The potentials for the two reactions are:

$Sn^{2+}(aq) + 2e^- \rightarrow Sn(s)$ $\quad E^0_{red} = -0.14$ V

$Zn(s) \rightarrow Zn^{2+}(aq) + 2e^-$ $\quad E^0_{ox} = +0.76$ V

The overall reaction is spontaneous as the reaction has a positive E^0_{cell} value:

$$E^0_{cell} = E^0_{ox} + E^0_{red} = +0.62 \text{ V.}$$

Critical thinking questions

1. Which electrode (Zn or Sn) will *lose* mass and which one will *gain* mass?

2. What is the overall reaction that occurs when the cells are connected?

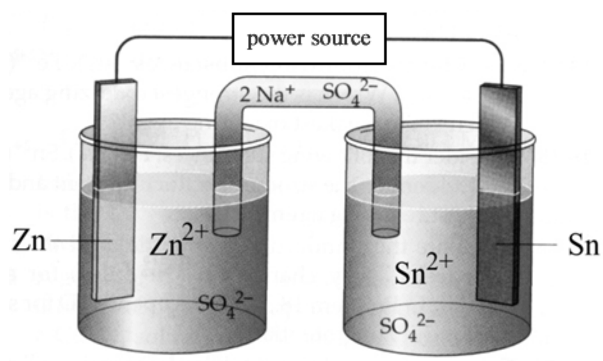
3. Oxidation always occurs at the anode. Label the anode and cathode on the cell.

4. Which way do the electrons flow? Draw an arrow on the diagram to show this.

5. Electrons flow from the *negative* electrode to the *positive* electrode. Which is positive, the anode or the cathode? Label the electrodes as positive or negative.

6. The salt bridge contains $Na^+(aq)$ and $SO_4^{2-}(aq)$. In which direction(s) do these ions move?

Model 2: Electrolytic Cells



The *reverse* reaction can be made to happen if a power from an external source with potential *greater* than E^0_{cell} is applied.

Critical thinking questions

1. Which electrode (Zn or Sn) will now *lose* mass and which one will *gain* mass?

2. What is the overall reaction that now occurs when the cells are connected?

3. Oxidation always occurs at the anode. Label the anode and cathode on the cell.

4. Which way do the electrons flow? Draw an arrow on the diagram to show this.

5. The power source supplies electrons to the electrode where reduction occurs, so it becomes negative. The power sources removes electrons from the electrode where oxidation occurs, so it becomes positive. Which is positive, the anode or the cathode? Label the electrodes as positive or negative.

6. The salt bridge contains $Na^+(aq)$ and $SO_4^{2-}(aq)$. In which direction(s) do these ions move?

Model 3: Electrolysis of Water

Electrolytic cells can be used to perform many useful tasks. A particular useful one is the electrolysis of water as this has the potential to convert electricity generated using solar energy into hydrogen gas, a combustible fuel. The reactions at the cathode and anode are:

Cathode:	$2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$	$E^0_{red} = -0.83$ V
Anode:	$2H_2O(l) \rightarrow O_2(g) + 4H^+(aq) + 4e^-$	$E^0_{ox} = -1.23$ V

The amount of a substance produced in an electrolytic cell is directly proportional to the amount of electricity that passes through the cell. The number of moles of electrons that pass when a current I is applied for a time t is given by:

number of moles of electrons = $I \times t / F$

Critical thinking questions

1. What is the overall reaction for the electrolysis of water?

2. F is Faraday's constant. It is the charge of one mole of electrons. The charge of one electron is 1.602×10^{-19} C. What is the charge of one mole?

3. If a current of 10.0 A is applied for 2.00 hours, how many moles of electrons are supplied? (*Hint*: remember to convert t into seconds).

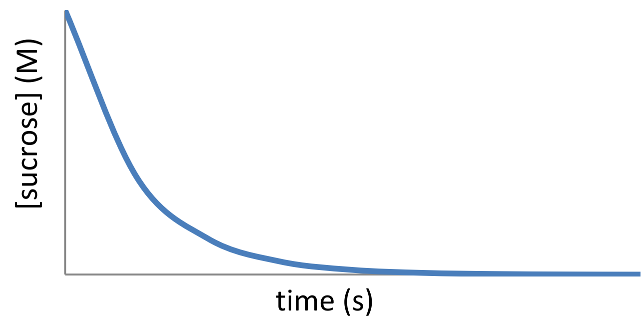
4. How many moles of $H_2(g)$ will be generated from this amount? (*Hint*: look at the stoichiometry of the reaction at the cathode.)

5. How many moles of $O_2(g)$ will be generated from this amount?

6. Water is a poor conductor so a salt is usually added to increase the conductivity. The salt must contain ions that are harder to reduce or oxidise than water. Using the standard reduction potentials, select a suitable salt.

Model 4: Rate of Reaction

The figure opposite shows how the sucrose concentration changes when it reacts with acid according to the reaction below:



sucrose + H_3O^+ → fructose + glucose

The rate of the reaction can be measured by measuring the *change* in the concentration of sucrose, H_3O^+, fructose or glucose over *time*:

$$\text{rate} = -\frac{\Delta[\text{sucrose}]}{\Delta t} = -\frac{\Delta[H_3O^+]}{\Delta t} = +\frac{\Delta[\text{fructose}]}{\Delta t} = +\frac{\Delta[\text{glucose}]}{\Delta t}$$

Critical thinking questions

1. What are the units of rate?

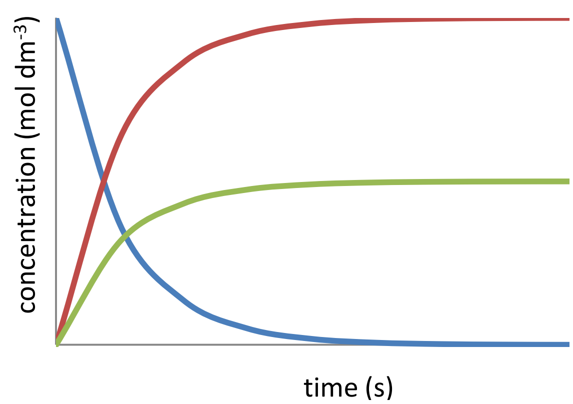
2. Sketch on the figure above how the concentration of *fructose* will be changing over the same time period.

3. Why is there a minus sign before $\Delta[\text{sucrose}]/\Delta t$ and $\Delta[H_3O^+]/\Delta t$ and a plus sign in front of $\Delta[\text{fructose}]/\Delta t$ and $\Delta[\text{glucose}]/\Delta t$ in the equation above for the rate?

4. The change in concentration with time of the reactants and products for the reaction below is shown in the figure opposite.

   $2NO_2(g) \rightarrow 2NO(g) + O_2(g)$

   Label each curve with the chemical it represents.



Model 5: The Rate Law

The rate of reactions are often found to be proportional to the concentration of each *reactant* raised to some power:

rate $\propto$ [reactant]^x

x is called the order of the reaction and is commonly an integer such as 0, 1 or 2.

The relationship between the rate of a reaction and the concentration of the reactants is known as the rate law. For the hydrolysis of sucrose in Model 4, for example, it is found to be

rate $\propto$ [sucrose][H_3O^+] or rate = k [sucrose][H_3O^+]

k is the rate constant and is simply the proportionality constant.

Critical thinking questions

1. What happens to the rate of a reaction if the initial concentration of the reactant is doubled for each value of x below?

   (a) $x = 2$ (b) $x = 1$ (c) $x = 0$

2. For the hydrolysis of sucrose, what happens to the rate of the reaction for each of the changes to the initial concentrations of the reactants below?

(a) [sucrose] is doubled but $[H_3O^+]$ is not changed.

(b) [sucrose] is not changed but $[H_3O^+]$ is doubled.

(c) Both [sucrose] and $[H_3O^+]$ are doubled.

3. Lactose can be decomposed into galactose and glucose through acid hydrolysis or using the enzyme lactase. In the basic environment of the intestine, only the enzyme catalysed decomposition is possible and lactose intolerance in humans arises from a deficiency of lactase. In the acidic environment of the stomach, however, hydrolysis should still occur and much research has been devoted to its study.

The table below shows the results from 3 experiments in which the initial rate of lactose decomposition was measured at different initial concentrations of lactose and acid.

experiment	initial rate ($M\ s^{-1}$)	$[\text{lactose}]_0$ (M)	$[H_3O^+]_0$ (M)
(1)	0.00116	0.01	0.001
(2)	0.00232	0.02	0.001
(3)	0.00464	0.01	0.004

(a) Between experiments (1) and (2), how were $[\text{lactose}]_0$ and $[H_3O^+]$ changed? What effect did this have on the rate?

(b) Between experiments (1) and (3), how were $[\text{lactose}]_0$ and $[H_3O^+]$ changed? What effect did this have on the rate?

(c) Using your answers to Q1 and to parts (a) and (b), determine the values of *x* and *y* in the rate law.

$$\text{rate} = k[\text{lactose}]^x[H_3O^+]^y$$

(d) Between experiments (2) and (3), how were $[\text{lactose}]_0$ and $[H_3O^+]$ changed and what effect did this have on the rate? Check that this is consistent with your rate law.

(e) Using your rate law and any one of the experiments, determine the value of the rate constant, *k*. Remember that a measurement is meaningless without a unit.