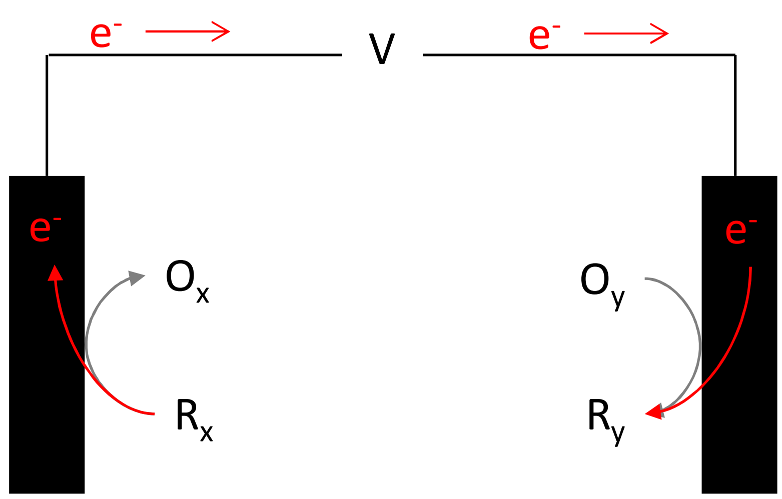
Microbial electrochemical technologies – fundamental aspects and methods of analysis

Week 1 – Basic concepts

- Units
  - Charge
  - Current
  - Voltage, potential
  - Energy, power
- Electrical circuits
  - Ohm’s law
  - Resistors in series and parallel
- Electrochemical systems
  - Terminology
  - Uses
  - Movement of ions

Before we start…

- Electrochemical systems convert energy between electrical and chemical forms…
  Thus, we need a basic understanding of electrical units and circuits



Electric charge

- Plus or minus
- Measured in units of coulomb (C)
- Protons have positive charge (+e), electron have negative charge (-e)
- $e \approx 1.602 \times 10^{-19}$ C
- Total electric charge in an isolated system is constant
- **<u>Faraday's constant, F = 96485.3 C/mol electrons</u>**

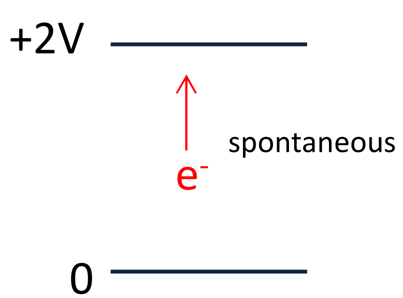
Electric current, I

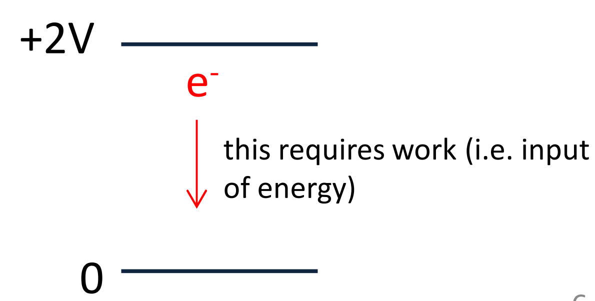
- Flow of electric charge
- In a circuit, electrons carry the charge
- In an electrolyte, ions carry the charge
- Measured in units of ampere, A
- **1 A = 1 C/s**

- Direct current – flow in one direction (this is what we are usually dealing with in electrochemical systems)
- Alternating current – periodically reverses direction (this is what is coming out from the wall)

Voltage or potential

- Difference in electric potential between two points
- Measured in volts, V
- Always measured in reference to something
- 1 V = 1 J/C





Power and energy

- Energy is measured in joules, J
- Power is the rate of energy consumed per unit time. It is measured in watts, W
- 1 W = 1 J/s

- Note:
  - V x A = W [(J/C)x(C/s) = (J/s)]
  - Power x time = Energy
    Thus, 1 kWh is a unit of energy that is commonly used

Other units of energy

- Small calorie (cal): energy needed to raise temperature of 1 g of water by 1°C

  1 cal = 4.184 J

- Large calorie (kcal or Calorie):

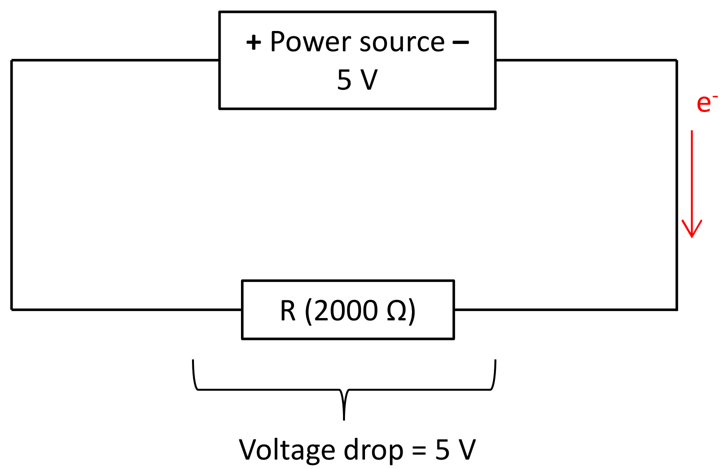
  1 kcal = 4.184 kJ

- Electronvolt (eV): amount of energy needed to move an electron against 1 V potential difference

  1.602×10^{-19} C * 1 J/C = 1.602×10^{-19} J

Electrical circuits

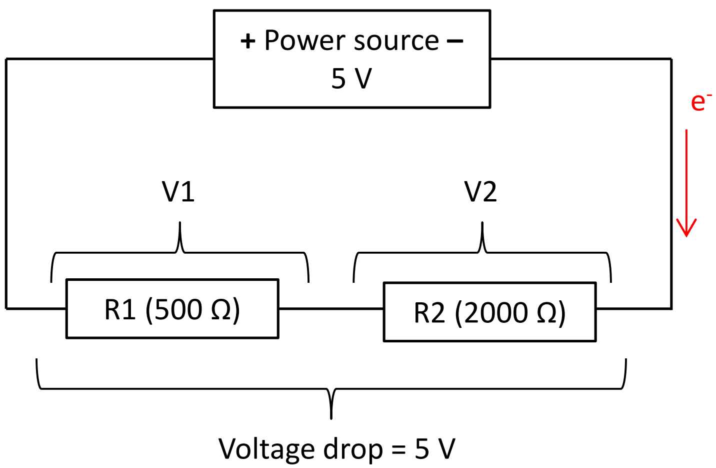
- Power source – e.g. a battery
- Resistors – provides a resistance to flow of electrical current, i.e. flow of current through a resistor results in energy dissipation



Ohm's law: I = V/R

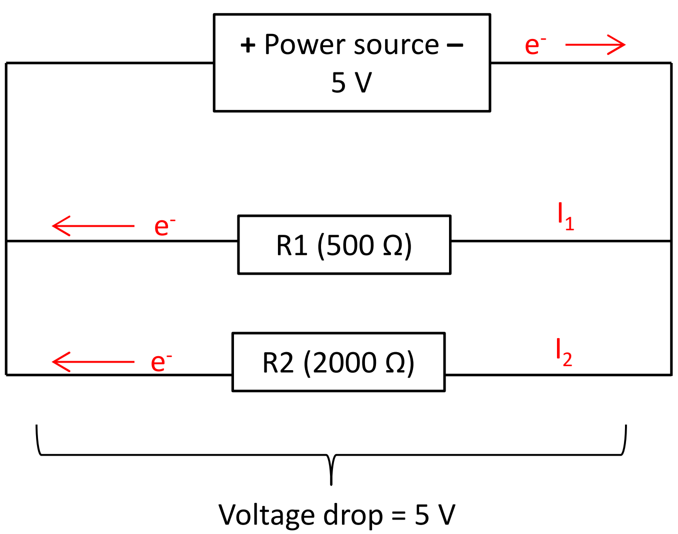
$I = 5V / 2000\Omega = 0.0025A$
$I = 2.5\ mA$

Resistors in series and parallel



Equivalent resistance = R1 + R2
Current in system = 5/2500 = 0.002 A

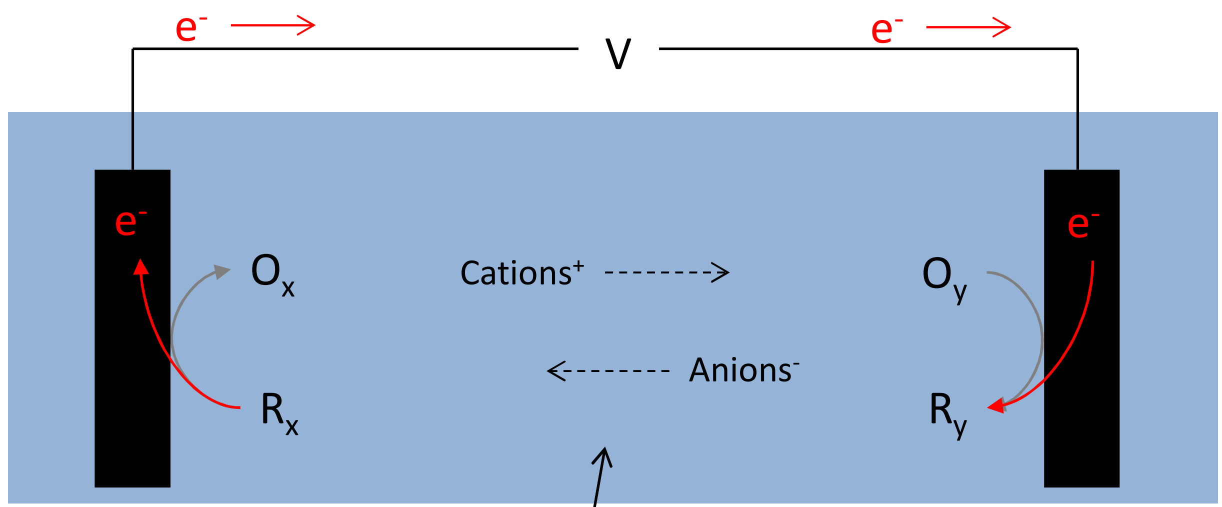
V1 = R1 x I = 500x0.002 = 1 V
V2 = R2 x I = 2000x0.002= 4 V



I_1 = 5/500 = 0.01 A
I_2 = 5/2000 = 0.0025 A
I_{total} = 0.01+0.0025 = 0.0125 A

Equivalent resistance:
$1/R_{eqv} = 1/R1+1/R2$

Electrochemical systems



Anode:
Oxidation reaction take place
Oxidation = gives off electrons

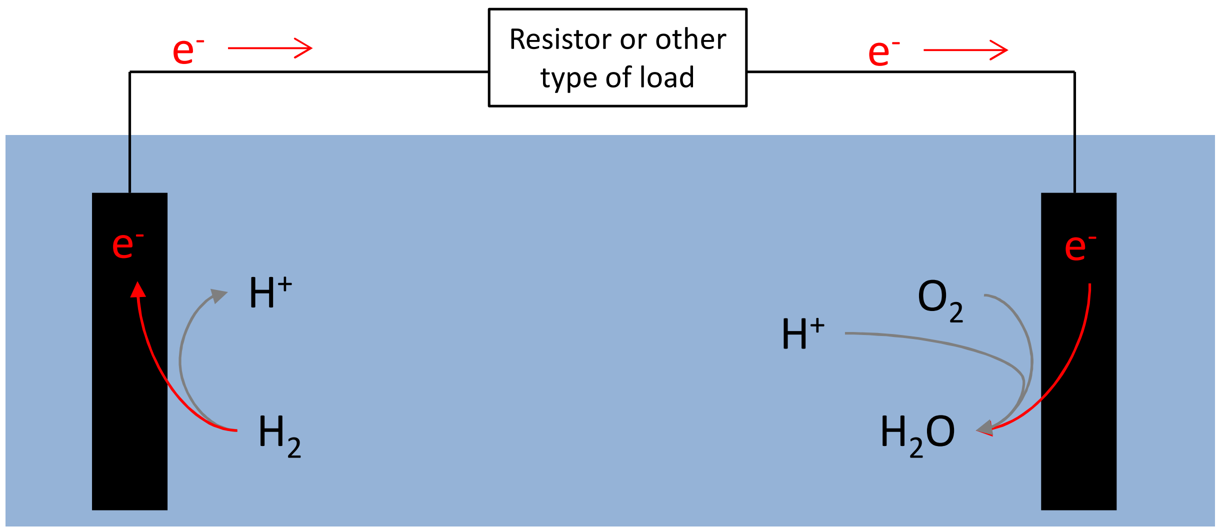
Cathode:
Reduction reaction take place
Reduction = takes up electrons

Electrolyte:
Solution in which electrodes are submerged.
Contains ions, which carry charge.
Ions **migrate** to maintain charge balance in the system

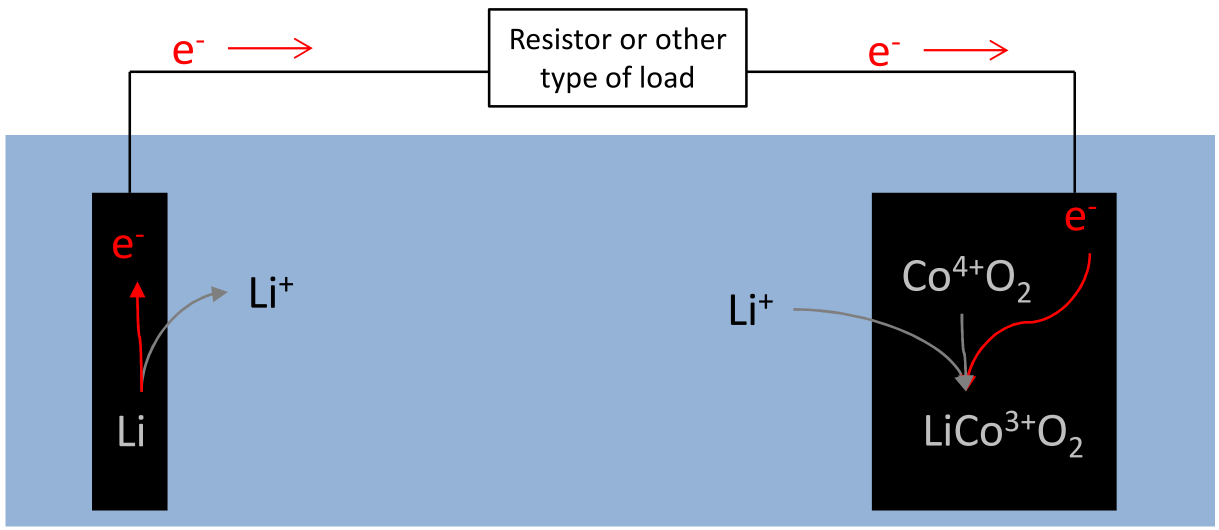
Types of electrochemical systems

- **Galvanic cells**
  - Reactions occur spontaneously at the electrodes when they are connected
  - Chemical energy can be converted into electrical energy
  - E.g. fuel cells, batteries
- **Electrolytic cells**
  - An external voltage must be applied to drive reactions at the electrodes
  - Electrical energy can be converted into chemical energy

Examples of galvanic cells

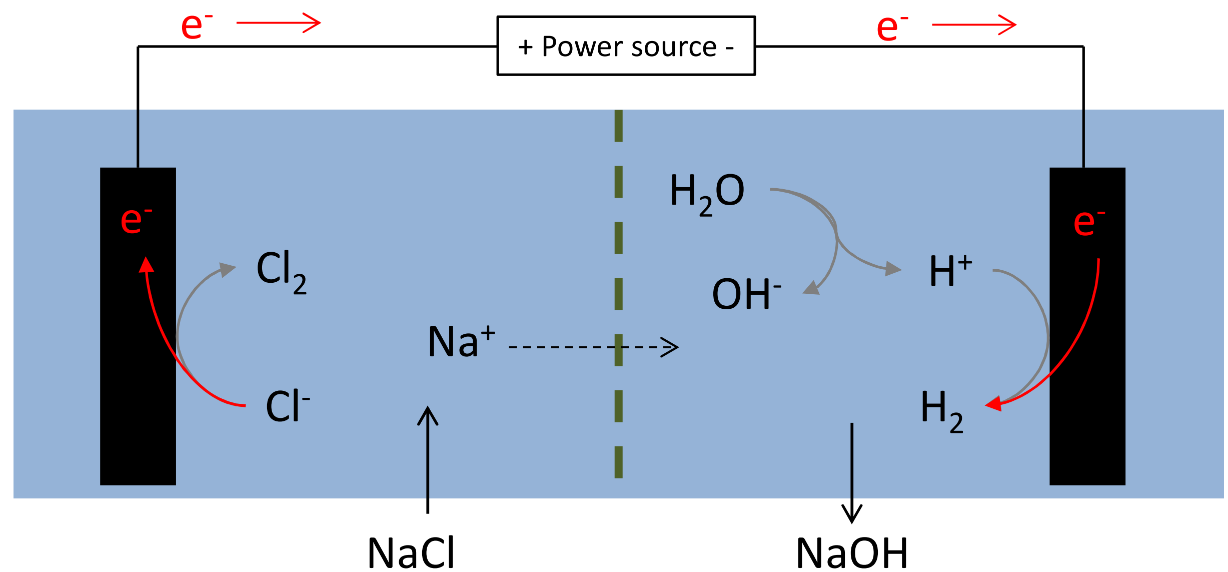


Hydrogen fuel cell

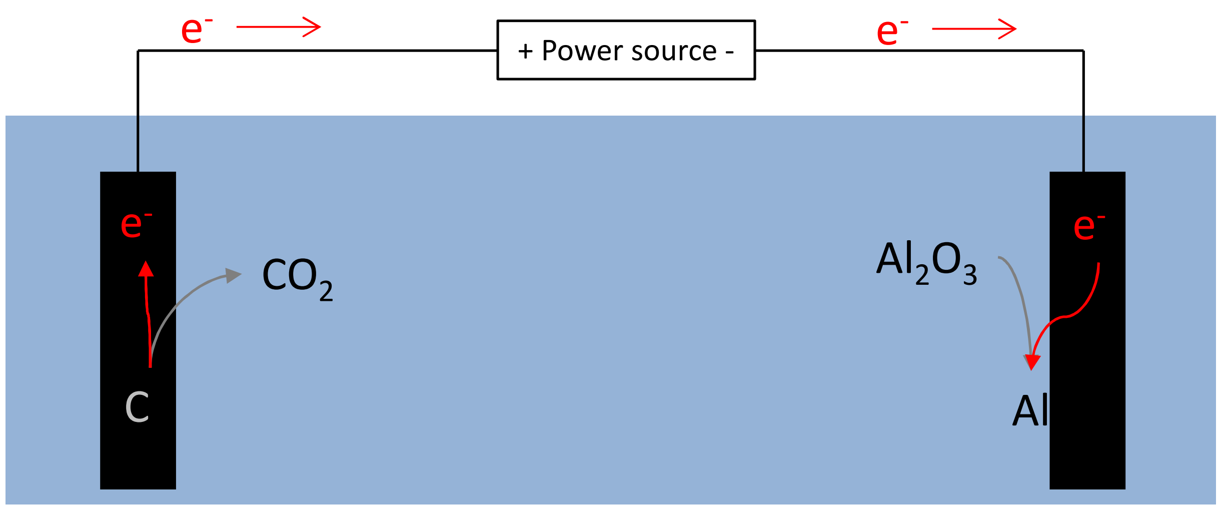


Lithium ion battery

Examples of electrolytic systems



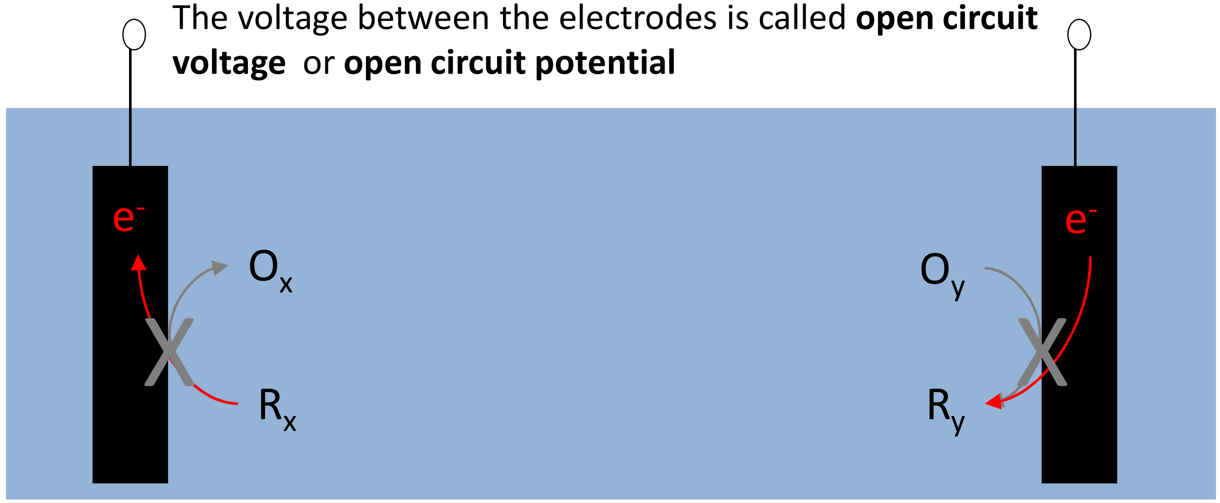
Chlor-alkali process



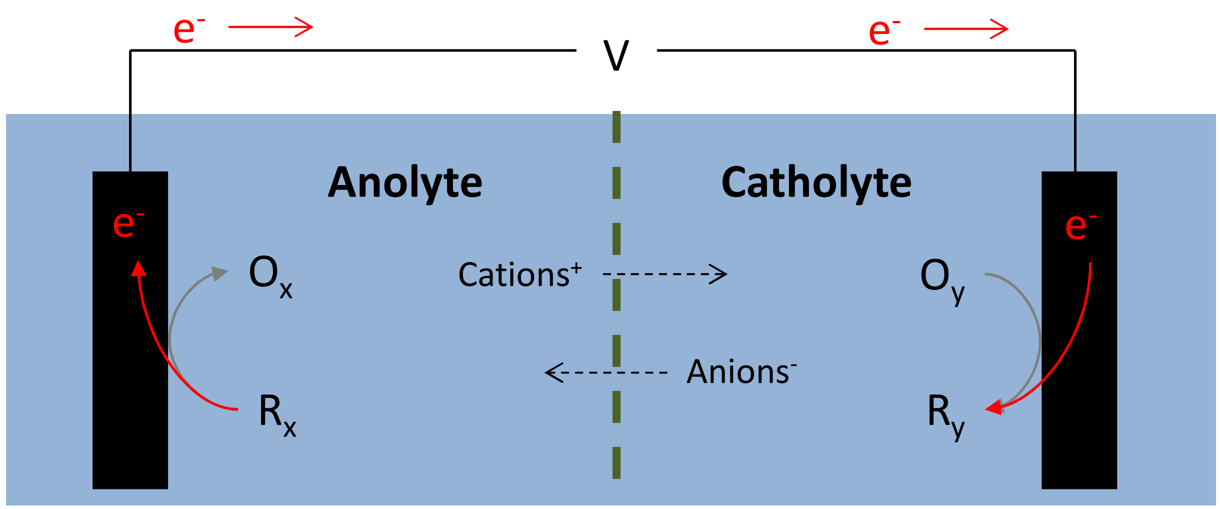
Aluminium electrowinning

Some more terminology

When disconnected, no net current will flow in the system
The voltage between the electrodes is called **open circuit voltage** or **open circuit potential**



Open circuit

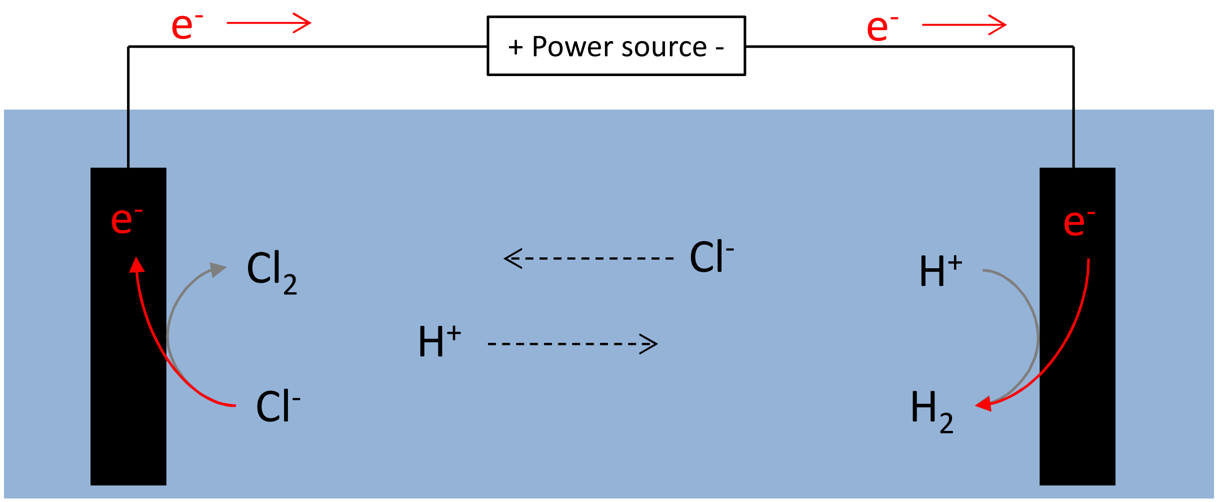


Two-chamber vs single-chamber cells
Two-chamber cells can be separated by an ion conductive membrane

Movement of ions

- If the liquid is stagnant, two processes contribute:
  - Migration (because of potential difference)
  - Diffusion (because of concentration difference)

Migration of ions

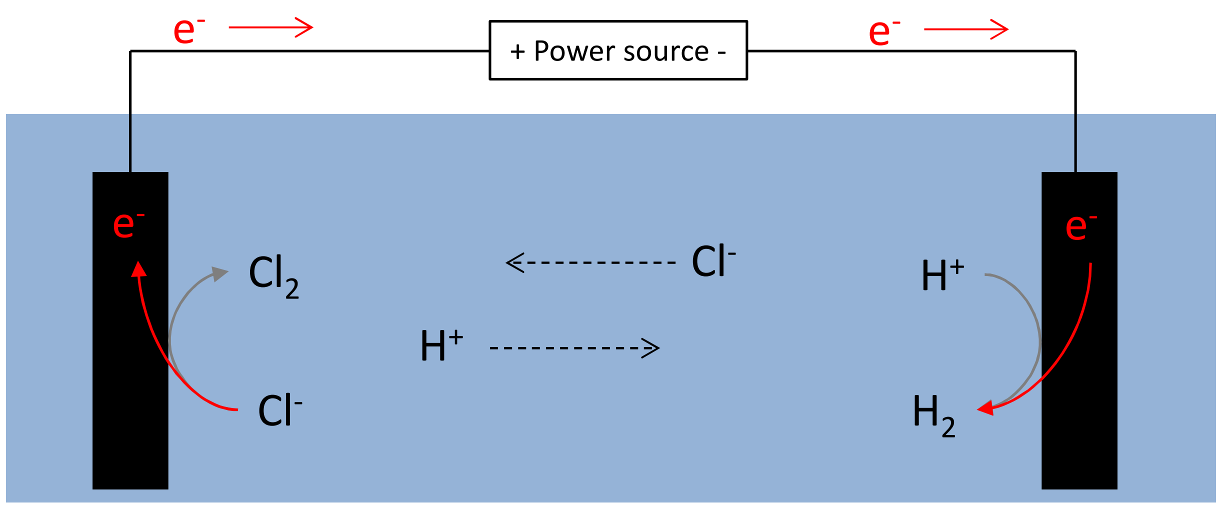


How much of the current is carried by different ions?

$$t_j = \frac{i_j}{i} = \frac{|z_j| \cdot C_j \cdot \lambda_j}{\sum_k |z_k| \cdot C_k \cdot \lambda_k}$$

t_j = transference number of ion j
z_j = charge
C_j = Concentration
λ_j = Equivalent ionic conductivity

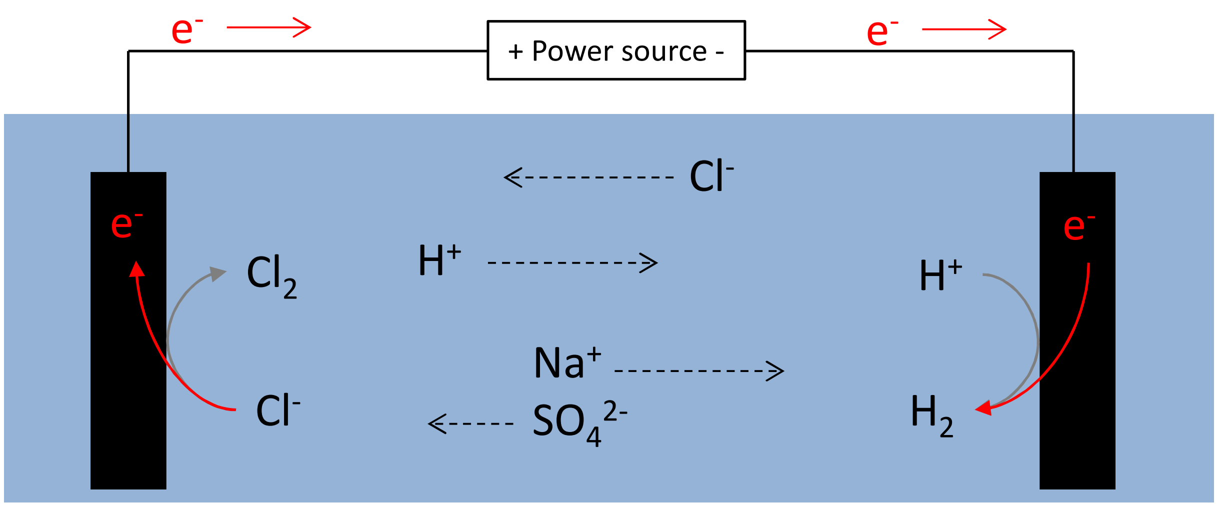
An example



$t_{H+} = 0.8$
$t_{Cl-} = 0.2$

*If 100 e^- has passed through the circuit, 80 H^+ have migrated to the cathode and 20 Cl^- have migrated to the anode to compensate for the imbalance in charge.
*However, 100 H^+ are consumed at the cathode and 100 Cl^- at the anode. Thus, diffusion must also contribute to the movement of ions.

Supporting electrolyte



Assume 0.1 M HCl and 1 M Na_2SO_4
Calculate transference numbers:

$t_{H+} = 0.08$
$t_{Cl-} = 0.02$
$t_{Na+} = 0.20$
$t_{SO42-} = 0.70$

If 100 e^- has passed through the circuit, 90% of the charge transfer has been accomplished by migration of Na^+ and SO_4^{2-} ions.
This means that the transport of the reactive ions, H^+ and Cl^-, is mainly caused by diffusion.