Solution Conductivity POGIL
How hot will my electrophoresis gel get?

Bioanalytical chemists and biochemists are often faced with the problem of how to best make a gel and buffer solution that provides the optimal separation for an electrophoresis experiment. The problems below help you develop a better understanding of solution conductivity and its relation to electrical resistance.

MODEL 1 Fundamental and Derived Units of Electrical Measurement

1. Charge: the fundamental charge on an electron or proton is given by the symbol q. For an electron, $q_e = e = -1.602 \times 10^{-19}$ coulomb (C). A proton has the same magnitude but opposite charge. What is the charge on one mole of electrons? This number is the **Faraday constant** ($\mathcal{F}$).

2. Potential (E or V) is the amount of work required to move a charge: 1 Joule = 1coulomb-volt. How does electrical potential relate to energy? The magnitude of an electric field is the potential divided by the distance. What is the strength of an electric field when 10 kV is applied across a 50 cm capillary column?

3. Current (i) is the flow of charge and is represented by the amp.

$$1 \text{ amp (A)} = 1 \text{ coulomb / sec}$$

In the electrolysis of aluminum by the following reaction, how may kg of Al can be made when 1 MA (10^6 A) is applied for one hour? Does this suggest why we might consider recycling aluminum cans?

$$Al^{3+} + 3e \rightarrow Al(s)$$

4. Resistance (R) is the resistance to the flow of charge and is given by the unit of the ohm, defined by Ohm's Law

$$V = iR$$

$$1 \text{ ohm } (\Omega) = 1 \text{ V / A}$$

What is the resistance of a capillary filled with buffer when 10kV is applied across the capillary and a 10 μA current results?

5. Power (P) is the amount of energy dissipated per unit time and is defined by the Watt (W)

$$1 \text{ W} = 1 \text{ J / sec}$$

$$P = i^2R = iV$$

How much energy is dissipated in 1 minute when 10 kV is applied across a capillary column run at 10 kV with a current of 10 μA?

MODEL 2 Relation between resistance and mobility

1. Mobility (μ) is the velocity of an ion in a unit electric field, defined by the ratio of velocity (v) and the strength of the electric field (E).

$$\mu \text{ (m}^2\text{ / V-sec)} = v / E$$

Using mobility data from page 303 of your text, calculate the time it takes for a Na^+ ion and a Cl^- ion to migrate 50 cm in an electric field of 50 V/cm.

2. The mobility of an ion can be calculated from fundamental properties of the substance and the solvent through which it moves. Thus, z (charge on the ion) and r (hydrated radius) are properties of the substance, while η (viscosity) is a property of the solvent.

$$\mu_{\text{ion}} = (10^7\, z\, e) / (6\, \pi\, \eta\, r)$$

Would a small, highly charged ion have a smaller or larger mobility than a large similarly charged ion? How about a similarly charged protein? Explain.

3. The electrophoretic mobility is also a related to **conductance** by the following equation

$$\mu_{\text{ion}} = \lambda_{\text{equiv}} / \mathcal{F}$$

Calculate the conductance (λ) of Na^+ ion and Cl^- ions.

4. Molar conductivity is the conductivity of one mole of ions and is represented by Λ which can be computed from individual ions in solution where the dimensionless quantity $\nu_{\pm}$ = # moles to form 1 mole of salt.

$$\Lambda = \nu_{+} \lambda_{+} + \nu_{-} \lambda_{-}$$

Calculate the molar conductivity (Λ) of a NaCl solution.

5. Molar conductivity is related to **solution conductivity** (κ), a function of the concentration (c) of ions.

$$\Lambda = \kappa / c = \kappa / c$$

Calculate the solution conductivity of a 50 mM NaCl solution?

6. Conductivity (κ) is the inverse of **resistance** (R). Thus, a highly conductive solution would not have much resistance to current flow. Conductivity is also a measure of a solution's resistance when a voltage is applied between two plates of area A and distance ℓ .

$$\kappa = 1 / \rho = \ell / R A \ (1 / \Omega\text{–m})$$

Calculate the resistance of a 50 mM NaCl solution in a 50 cm long 50 μm inner diameter capillary tube filled with 50 mM NaCl (Hint: 1 liter = 1 dm^3 = 0.001 m^3).

7. If you apply 10 kV across the capillary column, calculate the expected current and the power?

8. How much power would be dissipated in a 3mm x 5cm x 10cm gel with 50 mM NaCl?

9. Borate has a lower mobility than NaCl. Qualitatively compare a borate buffer with the NaCl solution and comment on why borate is often used in electrophoresis experiments.