PAUL SCHERRER INSTITUT

Electrochemistry

Exercise 1: Faraday's Law

Eibar Flores (eibar.flores@psi.ch)
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Some electrochemical reactions involve the deposition or dissolution of products, resulting in a change of mass of the electrode involved. Faradays law of electrolysis establishes a quantitative relation between changes of electrode mass and the amount of charge transferred during an electrochemical reaction (Wikipedia, 10.1021/ed038p98):

$$\Delta m = \frac{QM}{zF} \qquad \text{Eqn. 1}$$

where Δm [g] is the change of mass, Q [C] is the amount of charge transferred in the course of the reaction, M [g/mol] is the molar mass of the product being deposited/dissolved, z is the number of electrons transfer per mol of product and F = 96 485 C/mol is the Faraday constant representing the amount of charge of one mol of electrons.

1. Fuel cell

The Toyota Mirai is one of the hydrogen-fueled vehicles on the market. It stores 5 kg of high pressure hydrogen gas and uses a fuel cell stack that transforms hydrogen gas into electricity following the half-cell reaction $H_2 \rightarrow 2H^+ + 2e^-$; the other half-cell reaction $O_2 + 4\ H^+ + 4e^- \rightarrow H_2O$ involves oxygen from ambient air.

The electrons travel via an external circuit and power the electric motor of the vehicle. Calculate:

a) The amount of charge [C] available form a full hydrogen gas tank.
b) Assuming that a 13.3 kA output current keeps the vehicle at a constant speed of 50 km/h, calculate how far the vehicle can get with a full tank [km].

2. Electroplating

Electroplating is the process where a metal is coated with a thin layer of another metal via an electrochemical reaction. Figure 1 shows a schematic representation of silver-coating a key. The key to be coated is submerged into an Ag^+ containing electrolyte solution and connected electrically to a Ag metal rod. An applied current promotes the oxidation of the Ag rod and simultaneously the reduction of Ag^+ ions into the surface of the key, forming thus a thin Ag metal coating in its surface.

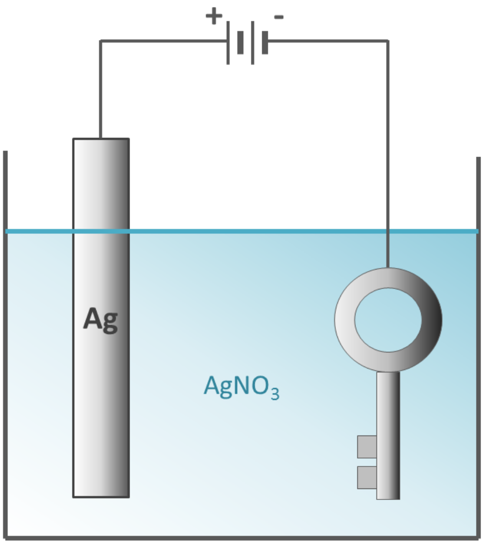

Figure 1. Representation of a silver electroplating setup for a key.

Consider a key with a total surface area of 70 cm^2 that is electroplated with a silver coating using a _ mA current, according to the half-reaction $Ag^+ + e^- \rightarrow Ag$.

a) Calculate the time required to obtain a 10 µm-thick uniform silver coating.

Calculate the times required to produce other 10 µm-thick uniform coatings:

b) A gold coating according to the half-reaction $Au^{3+} + 3e^- \rightarrow Au$.
c) A copper coating according to the half-reaction $Cu^{2+} + 2e^- \rightarrow Cu$.
d) Comment on how the electroplating time is influenced by the molar mass, the density and the number of electrons transferred of the particular plated metal.

3. Lithium-ion battery

A lithium-ion battery is made of a stack of cells, each composed by a negative electrode (low potential), a positive electrode (high potential) and an electrolyte. Most common Li-ion cells have a negative electrode using graphite, a positive electrode using $LiCoO_2$ and an electrolyte consisting on a lithium salt dissolved in organic solvents. During discharge (Fig. 2) –when the battery powers your device- lithium ions and electrons are released by the negative electrode by an oxidation reaction of graphite (Rx. 1). Lithium ions enter into the electrolyte and electrons are supplied to the external electrical circuit. At the positive electrode, Li-ions from the electrolyte and electrons from the electrical circuit are supplied to $Li_{0.5}CoO_2$ during its reduction reaction (Rx. 2). The electrons traveling in the external circuit provide an electrical current that is used by a device. During charge, the process is reversed by applying an external potential.

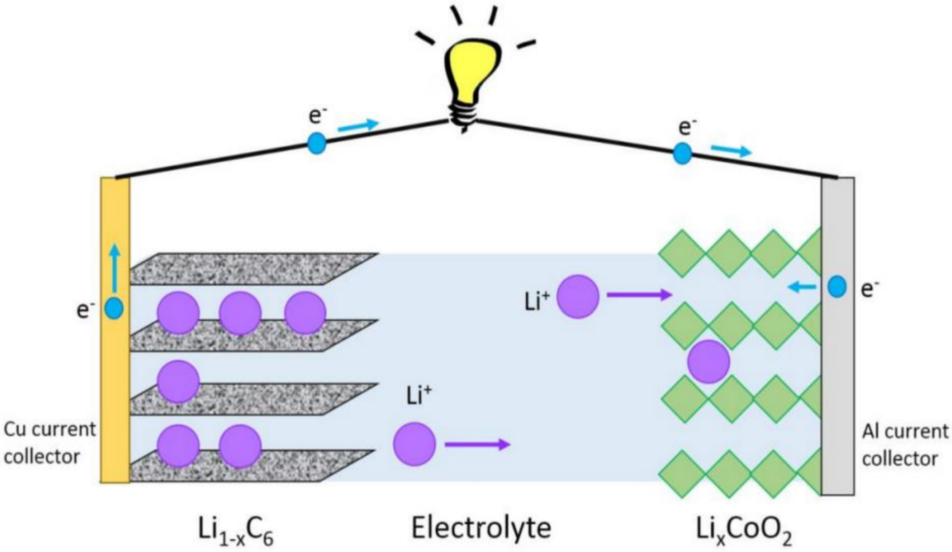

Figure 2. Representation of a Li-ion cell during discharge.

Rx. 1. Anode: $LiC_6 \rightarrow Li^+ + C_6 + e^-$

Rx. 2. Cathode: $2Li_{0.5}CoO_2 + Li^+ + e^- \rightarrow 2LiCoO_2$

The amount of charge a battery can store is measured in miliampere-hours. As an example, the battery of a Samsung Galaxy J7® mobile phone stores 3 000 mAh. Using Faraday's law (Eqn. 1), calculate:

a) The mass of graphite contained in a Samsung Galaxy J7® battery, considering Rx. 1, i.e. 6 carbon atoms per electron transferred.

b) The mass of cobalt oxide contained in the same battery, considering Rx. 2, i.e. two $Li_{0.5}CoO_2$ units present per electron transferred.

c) The battery not only contains the active materials, but also separators and current collectors to form electrical contacts, guarantee mechanical stability and safe performance. If the battery weights 82 g in total, calculate how much (in percentage) each active material contribute to the total battery weight.