

# **Electrochemical Engineering**

## **Lecture 01 Basic Concepts**

**Dr. Zhe Cheng**



# Electrochemistry - Definition

## □ Definition

“Electrochemistry is the branch of physical chemistry that studies the relationship between **electricity**, as a measurable and quantitative phenomenon, and identifiable **chemical change**, with either electricity considered an outcome of a particular chemical change or vice versa. These reactions involve electric charges moving between **electrodes** and an **electrolyte** (or ionic species in a solution). Thus electrochemistry deals with the interaction between electrical energy and chemical change.” <https://en.wikipedia.org/wiki/Electrochemistry>

“Electrochemistry is the branch of chemistry concerned with the **interrelation of electrical and chemical effects**. A large part of this field deals with the study of chemical changes caused by the passage of an electric current and the production of electrical energy by chemical reaction” Bard & Faulkner (2001).

“Electrochemistry is a branch of chemistry that studies the **chemical changes** that occur due to the flow of **electrical current** or, conversely, the production of electricity from chemical changes” Fuller & Harb (2018)



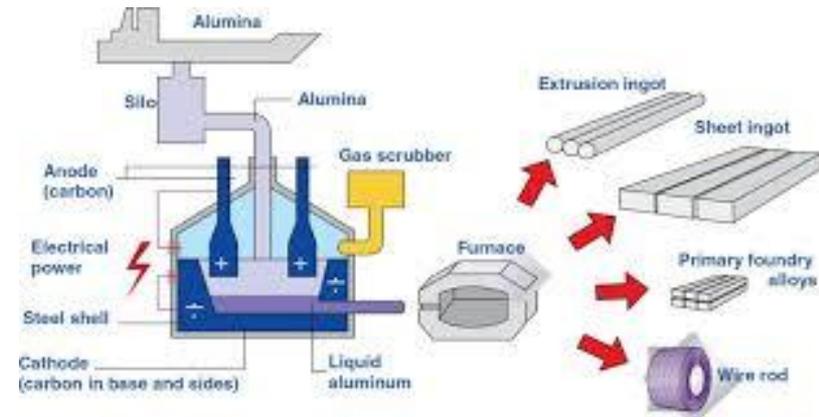
# Electrochemistry - Applications

## History aspect

- Early Cu-Zn battery, by Volta in late 1790s

## Major applications

- Energy storage/conversion via batteries, fuel cells, and more
- Electrolytic production of chemicals or materials
  - Chlorine & sodium hydroxide
  - $2\text{NaCl (aq)} + 2\text{H}_2\text{O} = 2\text{NaOH (aq)} + \text{Cl}_2(\text{g}) + \text{H}_2(\text{g})$
  - Aluminum
- Electroplating/electro-deposition
- Sensors
  - Glucose sensor for blood sugar monitoring
- Obtaining basic thermodynamic properties



[https://www.researchgate.net/figure/262148554\\_fig3\\_Flow-sheet-of-the-aluminum-production-process](https://www.researchgate.net/figure/262148554_fig3_Flow-sheet-of-the-aluminum-production-process)

**Benefits from accurate measurement of electrical signal (current)**



# Solution

## □ Solution

A uniform, homogeneous mixture of two or more substances (or components)

- Example: HCl solution

## □ Solvent

The continuous (often majority) substance (or component) that forms the medium in a solution

- Example:
  - H<sub>2</sub>O in the HCl aqueous solution

## □ Solute

The dissolved substance (or component) in a solution

- Example:
  - HCl in the HCl aqueous solution

<https://en.wikipedia.org/wiki/Solution>

HCl aqueous **solution**  
2 substances  
Homogeneous



<http://www.carolina.com/specialty-chemicals-d-1/hydrochloric-acid-in-plastic-coated-safety-bottle-121-m-reagent-ac-grade-25-l/867793.pr>

<http://carpinteriavalleyassociation.org/2013/07/oil-and-water-do-not-mix/>

Water-Oil **mixture**  
2 substances  
NOT homogenous



# Electrolyte

□ A substance or phase that primarily conducts electrically charged ions (not so much electrons or holes) or that, upon dissolution in a solvent, form charged ions.

## □ Categories

- Molten/Liquid electrolyte – no solvent
  - Molten NaCl
- Electrolyte solution in a (liquid) solvent/solvents
  - KCl in water (hydrated  $K^+$  and  $Cl^-$ )
- Solid electrolyte
  - AgI –  $Ag^+$  &  $I^-$
  - $Y_2O_3$ -stabilized  $ZrO_2$  (YSZ) – oxide ion  $O^{2-}$  (or oxygen vacancy  $V_O^{2+}$ )
  - Nafion® polymer – proton  $H^+$



# Electrolyte Solution vs. Nonelectrolyte Solution

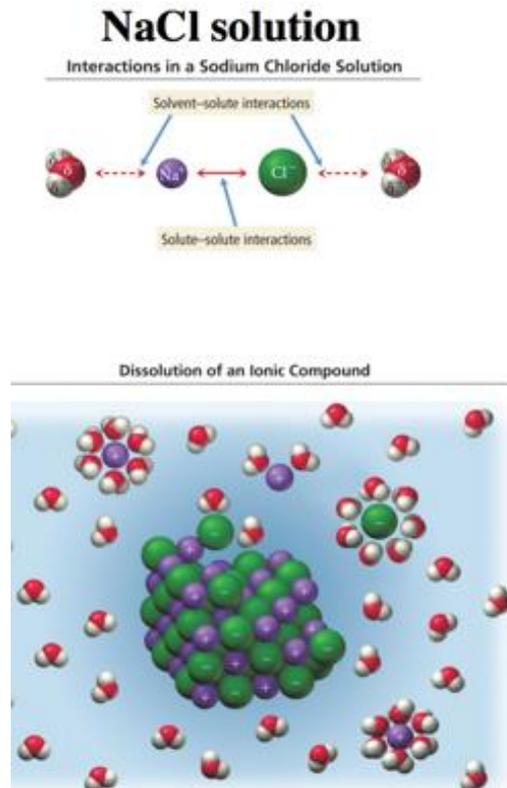
## Electrolyte solution –

solute, polar or ionic, upon dissolution in the liquid solvent (or solvents), dissociate (completely or partially) into positively and negatively charged ions surrounded by solute molecules

Example:  
NaCl in water:

Both + and - ions surrounded by (polar) solvent molecules

Weak electrolyte solutions have both ions and molecules



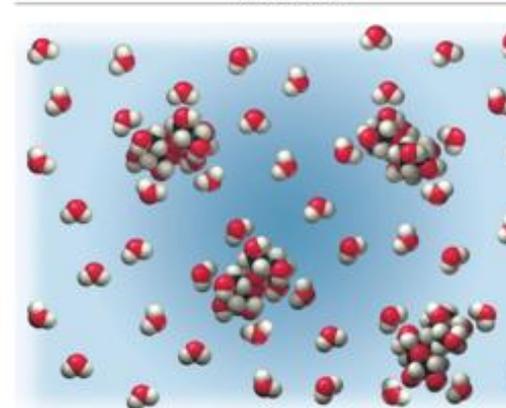
## Nonelectrolyte solution –

solute remains as molecules (electrically neutral) in solvent

Example:

## **Sugar-water solution**

Interactions between Sugar and Water Molecules



# Strong & Weak Electrolyte Solutions

## □ Strong electrolyte solutions

Complete dissociation of cations and anions

- $\text{NaCl} = \text{Na}^+ + \text{Cl}^-$
- $\text{HCl} = \text{H}^+ + \text{Cl}^-$

## □ Weak electrolyte solution

Incomplete dissociation of molecules into cations and anions

- Acidic acid solution



Solution contains  $\text{H}^+$ ,  $\text{CH}_3\text{COO}^-$  ions as well as significant  $\text{CH}_3\text{COOH}$  molecules



# Different Forms of Solution Concentration (1)

## □ Mass fraction

Ratio (or fraction) of mass for substance of interest to total mass of substances in the system, unitless

$$10 \text{ g NaCl} + 90 \text{ g H}_2\text{O}, \quad m_{\text{NaCl}} = \frac{w_{\text{NaCl}}}{w_{\text{NaCl}} + w_{\text{H}_2\text{O}}} = \frac{10 \text{ g}}{10 \text{ g} + 90 \text{ g}} = 10.0\%$$

## □ Mole fraction

Ratio (or fraction) of moles for substance of interest to total moles of substances in the system, unitless

$$0.171 \text{ mol NaCl} + 5.00 \text{ mol H}_2\text{O}, \quad X_{\text{NaCl}} = \frac{n_{\text{NaCl}}}{n_{\text{NaCl}} + n_{\text{H}_2\text{O}}} = \frac{0.171 \text{ mol}}{0.171 \text{ mol} + 5.00 \text{ mol}} \approx 3.31\%$$

## □ Molarity

Moles of substance of interest per unit total system volume, mol/L

93.56 ml (or cc) NaCl solution (at 25°C) containing 0.171 mol NaCl,

$$C_{\text{NaCl}} = \frac{n_{\text{NaCl}}}{V_{\text{NaCl solution}}} = \frac{0.171 \text{ mol}}{0.09356 \text{ L}} \approx 1.83 \text{ mol} \cdot \text{L}^{-1}$$

## □ Molality

Moles of substance of interest per 1 kg of solvent, mol/kg (of solvent)

$$0.171 \text{ mol NaCl} + 90 \text{ g H}_2\text{O}, \quad b_{\text{NaCl}} = \frac{n_{\text{NaCl}}}{w_{\text{H}_2\text{O}}} = \frac{0.171 \text{ mol}}{90 \text{ g}} \approx 1.90 \text{ mol/kg (of water)}$$

# Different Forms of Solution Concentration (2)

## □ 10 wt.% NaCl solution in water

- from mass fraction  $w_{NaCl}$  to mole fraction

$$X_{NaCl} = \frac{n_{NaCl}}{n_{NaCl} + n_{H_2O}} = \frac{\frac{0.1}{58.44 \text{ g/mol}}}{\frac{1 - 0.1}{18.02 \text{ g/mol}} + \frac{0.1}{58.44 \text{ g/mol}}} \approx 0.0331 \text{ or } 3.31\%$$

## □ NaCl solution in water with NaCl mole fraction of 3.31%

- from mole fraction  $X_{NaCl}$  to mass fraction

$$m_{NaCl} = \frac{w_{NaCl}}{w_{NaCl} + w_{H_2O}} = \frac{0.0331 \times 58.44 \text{ g/mol}}{0.0331 \times 58.44 \text{ g/mol} + (1 - 0.0331) \times 18.02 \text{ g/mol}} \approx 0.0999 \text{ or } 10.0 \text{ wt. \%}$$

# Different Forms of Solution Concentration (3)

- 10 wt.% NaCl solution in water,  
- from mass fraction to molarity (knowing density 1.06879 g/ml at 25°C)

<http://butane.chem.uiuc.edu/pshapley/genchem1/l21/1.html>

$$C_{NaCl} = \frac{n_{NaCl}}{V_{NaCl\ solution}} = \frac{\left(\frac{0.1}{58.44\text{g/mol}}\right)}{\left(\frac{1}{1068.79\text{g/L}}\right)} \approx 1.83\text{mol} \cdot \text{L}^{-1} = 1.83\text{ M}$$

- 10 wt.% NaCl solution in water,  
- from mass fraction to molality

$$b_{NaCl} = \frac{n_{NaCl}}{w_{H_2O}} = \frac{\left(\frac{0.1}{58.44\text{g/mol}}\right)}{(1 - 0.1)}$$

$\approx 0.00190\text{ mol per g (of water)}$

$= 1.90\text{ mol per kg (of water)}$

# Different Forms of Solution Concentration (4)

- 1.90 mol/kg NaCl solution in water,  
- from molality to molarity (knowing density 1.06879 g/ml at 25°C)

<http://butane.chem.uiuc.edu/pshapley/genchem1/l21/1.html>

$$C_{NaCl} = \frac{n_{NaCl}}{V_{NaCl\ solution}} = \frac{1.90\text{mol}}{\left(\frac{1.90\text{mol} \times 58.44\text{g/mol} + 1000\text{g}}{1068.79\text{g/L}}\right)}$$
$$\approx 1.83\text{mol} \cdot \text{L}^{-1} = 1.83\text{ M}$$

- 1.90 mol/kg (of water volent) NaCl solution,  
- from molality to mass fraction

$$m_{NaCl} = \frac{w_{NaCl}}{w_{NaCl} + w_{H_2O}} = \frac{1.90\text{mol} \times 58.44\text{g/mol}}{1.90\text{mol} \times \frac{58.44\text{g}}{\text{mol}} + 1000\text{g}}$$
$$\approx 0.0999 \text{ or } 10.0 \text{ wt. \%}$$

# Molten Electrolyte (Salt)

- The electrolyte, upon heating to above the melting point, dissociates (completely or partially) into positively and negatively **charged ions** without the need for a liquid solvent

- **Examples:**

- Salts in the molten state  
example:



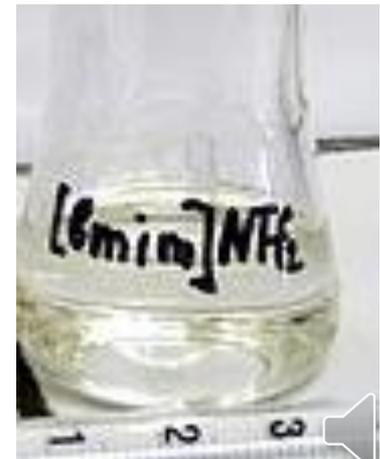
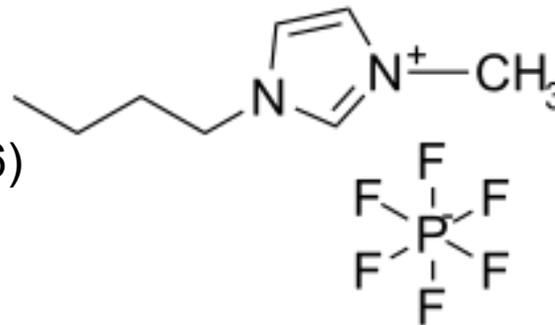
$$T_m = 290^\circ\text{C}$$

<https://youtu.be/LwwwRP8Zpaw>



- Ionic liquid - (electrolyte with melting point below  $\sim 100^\circ\text{C}$ )  
example:

1-butyl-3-methylimidazolium  
hexafluorophosphate ([BMIM]PF<sub>6</sub>)



[https://en.wikipedia.org/wiki/Ionic\\_liquid](https://en.wikipedia.org/wiki/Ionic_liquid)

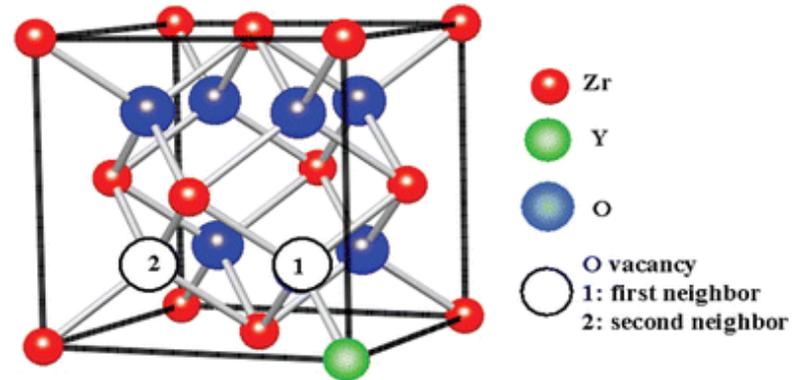
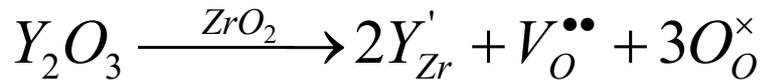
# Solid Electrolyte

□ A solid phase containing **charged ions** and/or **vacancies**.

□ **Examples:**

**Yttria-stabilized zirconia** (YSZ or  $Y_2O_3$  doped in  $ZrO_2$ )

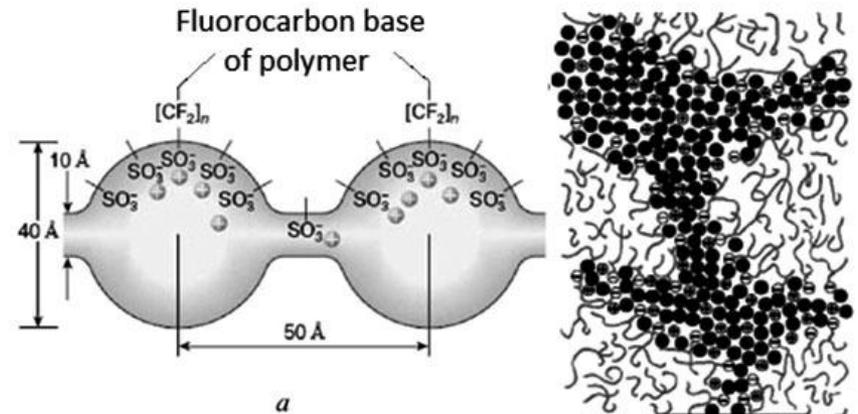
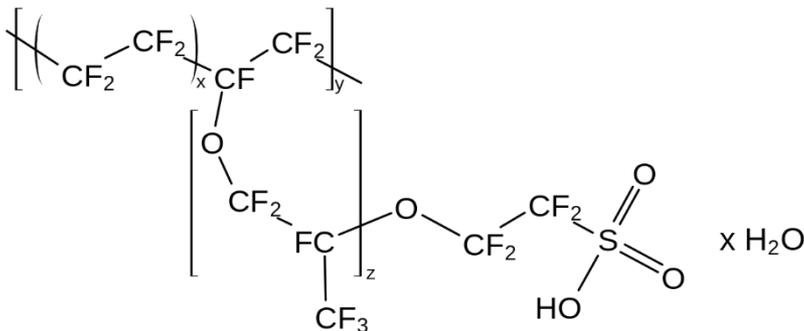
- $Y_2O_3$  uniformly & randomly “dissolved” in  $ZrO_2$
- Charged species (ions) of  $V_O^{\bullet\bullet}$  and  $Y_{Zr}'$



<http://pubs.rsc.org/en/content/articlelanding/2005/jm/b417143h/unauth#!divAbstract>

**Nafion®**

- Charged species of  $H^+$  and  $-SO_3^-$  (on backbone)



<https://en.wikipedia.org/wiki/Nafion>

<http://www.orientjchem.org/vol32no5/proton-exchange-membranes-based-on-sulfonated-polymer/>

# Electrode

□ A substance that primarily conducts electrons  $e^-$  (can also be electron holes  $h^\bullet$ ) in an electrochemical system.

- Connects electrolyte with the external circuit
- At the electrode/electrolyte interface, the reduction or oxidation reactions (or simply redox reactions) occur

## □ Categories

- Metallic electrode
  - Ni, Au, Pt, Cu ...
- Non-metallic electrodes
  - Ceramics:
    - Carbon (as graphite or carbon black)
    - Conducting oxides:  $\text{La}_{1-x}\text{Sr}_x\text{MnO}_3$ , etc.
  - (Conducting) polymers
    - PEDOT, PANI...



# Electrochemical Cell & Cell Potential

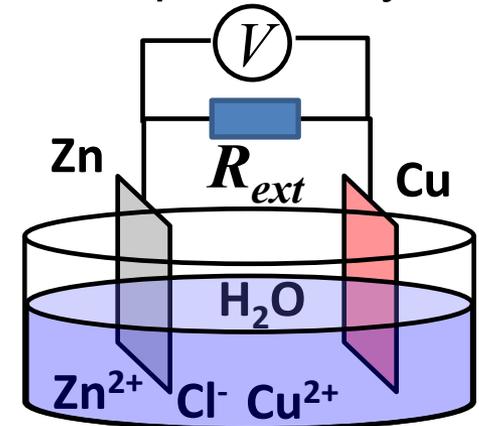
□ A basic electrochemical cell consists of “**two electrodes** separated by **at least one electrolyte**”

- Example 1

Zn & Cu immersed in a  $\text{ZnCl}_2 + \text{CuCl}_2$  mixed solution and connected through an external circuit (can be open circuit)

- Example 2

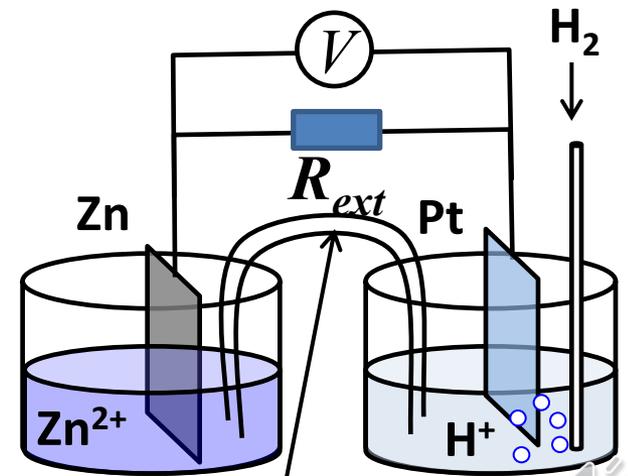
Zn immersed into  $\text{ZnCl}_2$  solution, while Pt immersed into dilute HCl solution with bubbling  $\text{H}_2$ , with the two metal connected through an external circuit and the two solutions are connected by a KCl salt bridge.



□ Electrochemical **cell potential**

- Without applying any external power source, a potential difference could often be measured between the two electrodes
- The measured cell potential depends on cell construction (e.g., materials, concentration, T, P)

& the external circuit resistance  $R_{ext}$



Bard & Faulkner (2001)

KCl salt bridge

# Half Cell & Overall (Full Cell) Reactions

## ❑ Electrochemical reaction

Once an electrochemical cell is formed (either intentionally or naturally), the electrochemical reaction(s) might happen, in certain way.

## ❑ Two half (cell) reactions

The overall electrochemical reaction always involve/ consists of two half (cell) reactions with each half (cell) reaction at one of the electrode/electrolyte interfaces

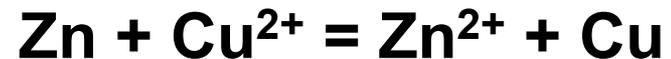
### Reduction/cathodic half (cell) reaction:



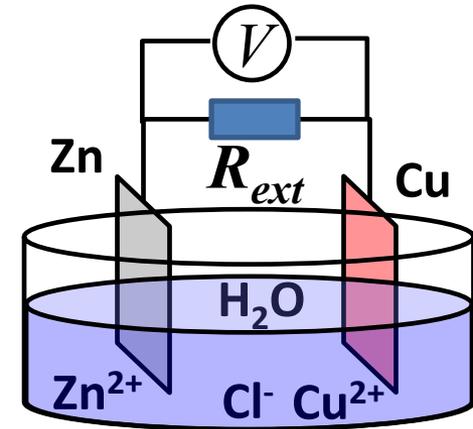
### Oxidation/anodic half (cell) reaction:



### Overall/Full cell reaction



Full cell and both half cell reactions must satisfy BOTH mass & charge balance!



## ❑ Overall/full cell reaction

Combination of the reduction (cathodic) half (cell) and oxidation (anodic) half (cell) reaction with elimination of electrons in the formula

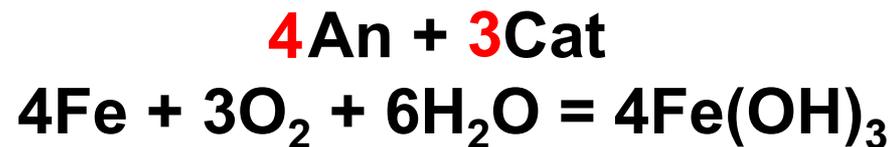
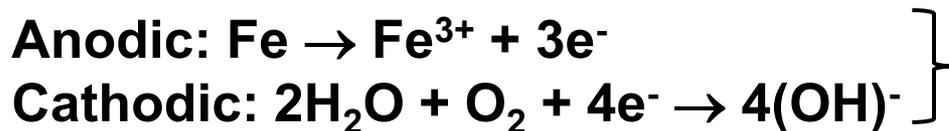
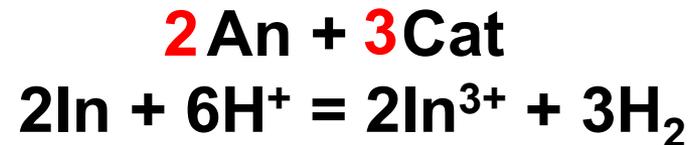
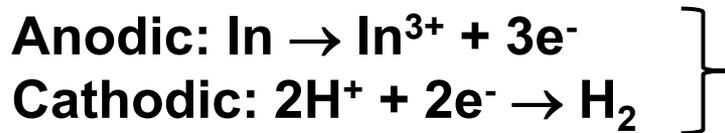
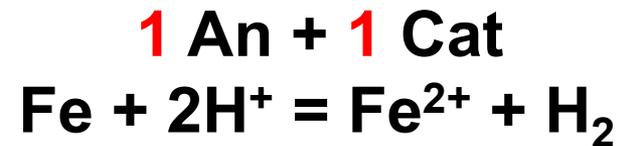
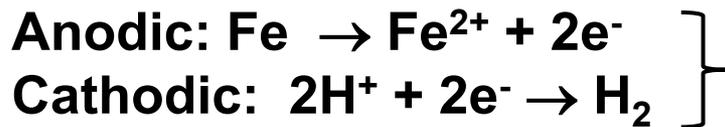
## ❑ Electrochemical reaction vs. general chemical reaction

- Always involve oxidation/reduction or change of valence
- $\text{e}^-$  must go from the anode where oxidation occurs through an “external” circuit (at least for a short distance) to the cathode where reduction occurs

# Half Cell & Full Cell Reactions - Class Examples

For the given pair of reduction (cathodic) and oxidation (anodic) half (cell) reactions, write the overall or full cell reactions

Notes: (1) Mass & Charge balance      (2) Elimination of electrons!



# Active Electrode vs. Inert Electrode

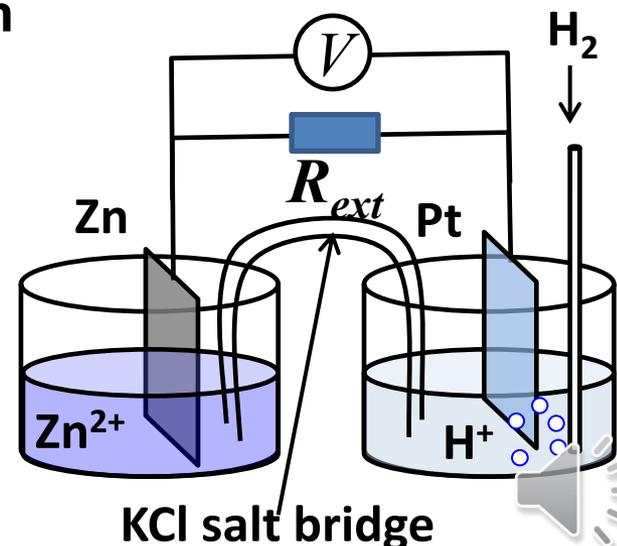
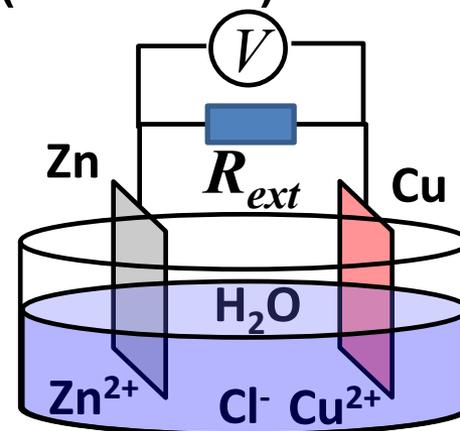
❑ The actual electrode material (electron conductor) may or may not be the actual species going through the oxidation (for anode) or reduction (for cathode) half (cell) reaction

❑ Active electrode - electrode material is also the substance that goes through the electrode reactions:

- Zn anode:  $\text{Zn} = \text{Zn}^{2+} + 2\text{e}^-$
- Cu cathode:  $\text{Cu}^{2+} + 2\text{e}^- = \text{Cu}$

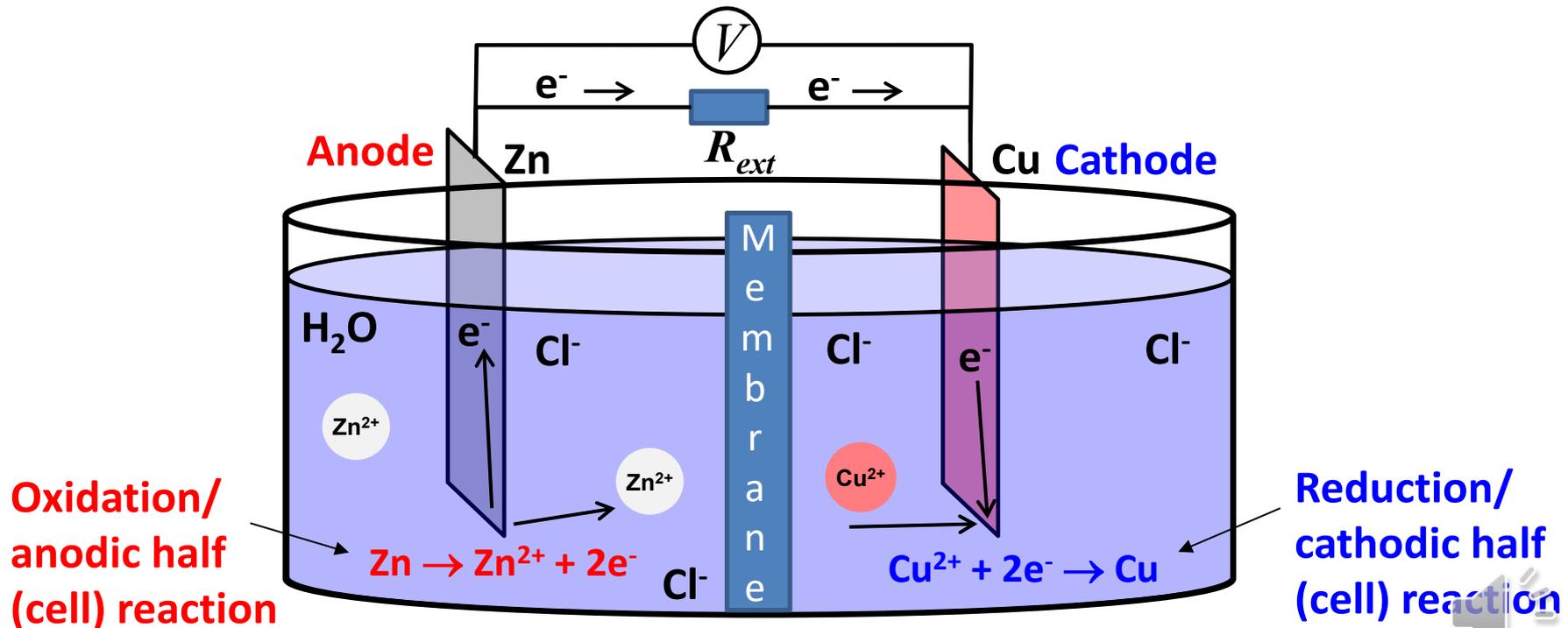
❑ Inert electrode - the species that goes through half cell reaction (cathodic or anodic) is **NOT** the electrode material

- On Pt cathode:  
Actual reduction/cathodic reaction:  $2\text{H}^+ + 2\text{e}^- = \text{H}_2$
- Pt remains inert (does NOT change valence). It only conducts electrons and provides the (catalytic) interface between ionic (electrolyte) and electronic (electrode) conductors



# Separation of Oxidation & Reduction in an Electrochemical Cell

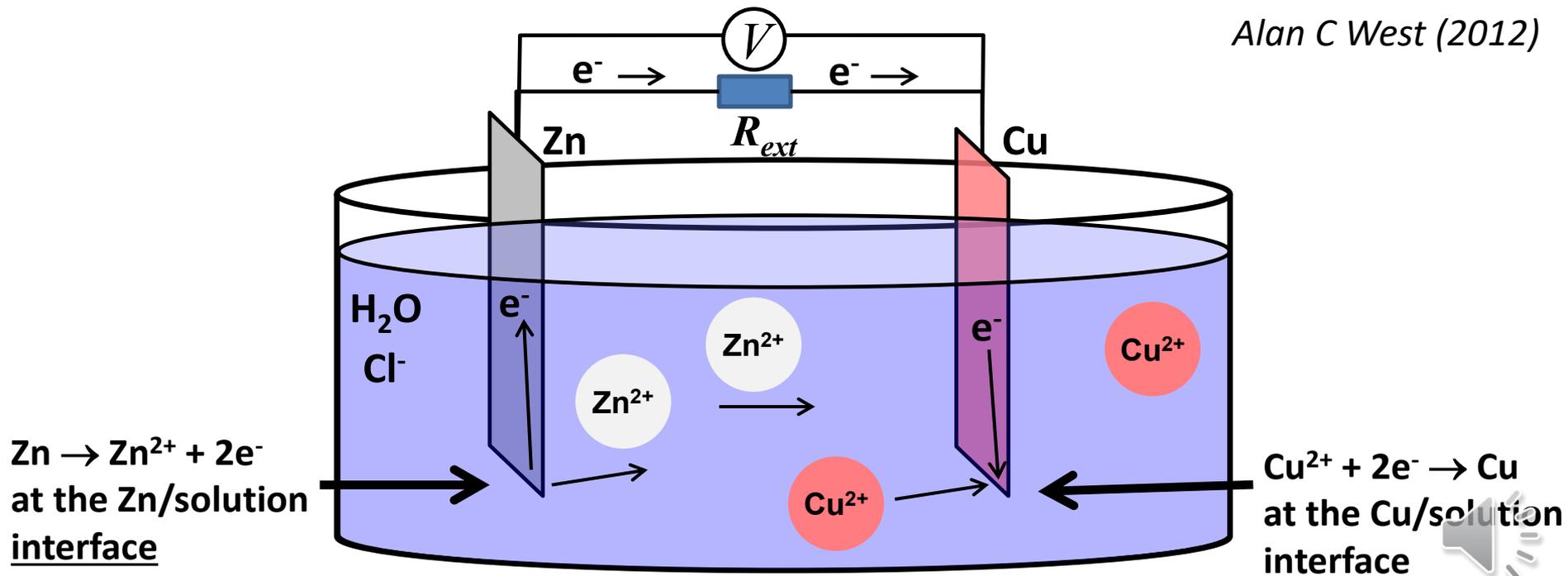
- ❑ Electrochemical cell, e.g., Zn(s)/Zn<sup>2+</sup>, Cu<sup>2+</sup>, Cl<sup>-</sup>/Cu(s) cell
- ❑ Anode - where oxidation or anodic half (cell) reaction occurs
- ❑ Cathode - where reduction or cathodic half (cell) reaction occurs
- ❑ Two half-cell reactions (reduction/cathodic vs. oxidation/anodic) are geometrically separated!



# Transition between Electronic and Ionic Conduction at Electrode/Electrolyte Interface

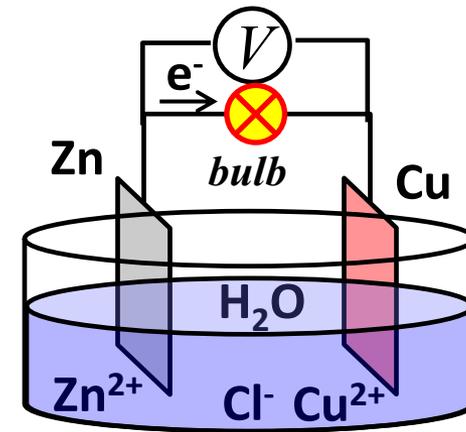
## □ Electronic condition in electrode vs. ionic conduction in electrolyte

- In an electrochemical cell, both the cathode (e.g., Cu) and the anode (e.g., Zn), conduct primarily electrons, while, in between the two electrodes, the electrolyte (e.g., ZnCl<sub>2</sub>-CuCl<sub>2</sub> water solution here) primarily conducts charged ions
- For the electrochemical reaction to occur, there must be transition(s) from electronic conduction to ionic conduction, which occur through the half (cell) reaction(s) across the **electrode (cathode or anode)/electrolyte interface(s)**



# Electrochemical Reactions - Additional Features

- ❑ Always involve electrical current & work
- ❑ Direct measurement of reaction rate (from current) possible
- ❑ Control of direction and rate of reaction
  - Use vs. charging of an Li ion battery
  - Electroplating vs. electropolishing



# Open Circuit & Equilibrium Cell Potential

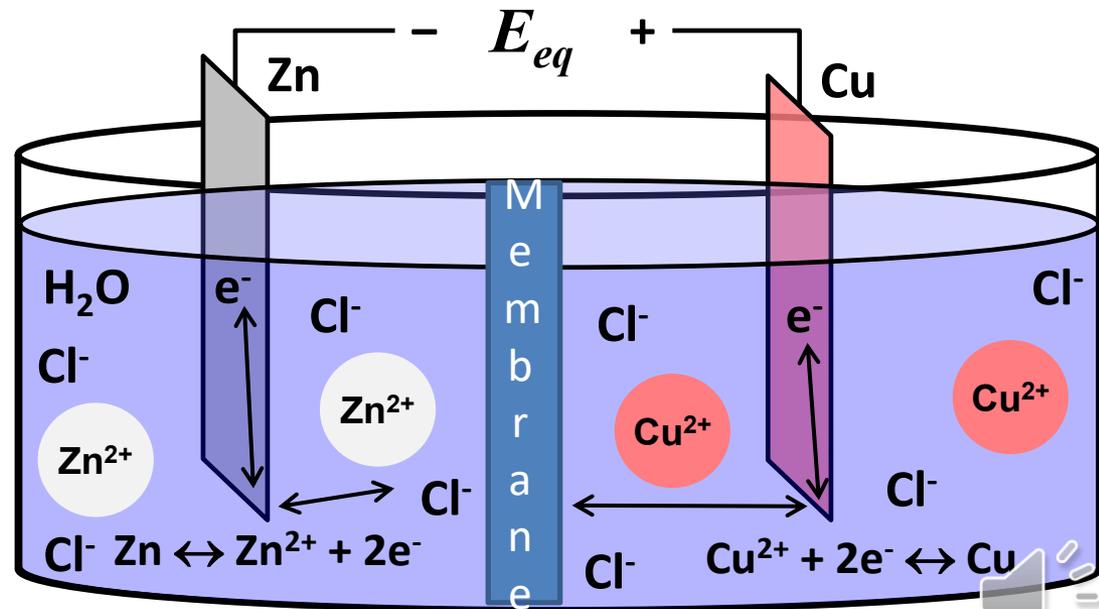
Without applying an external power source, when the external circuit connecting the two electrodes is **open** (open circuit or when external resistance  $R_{ext}$  goes to **infinity**), the resulting external current is zero.

If the followings can also be **assumed**:

- Reversible reactions at both electrodes
- No internal electronic leakage through the electrolyte
- Only a single electrochemical reaction occurs at each electrode

Then

- The electrochemical cell will reach **equilibrium**
- A reversible & stable potential between the two electrodes is obtained, called equilibrium (cell) potential  $E_{eq}$



# Galvanic Cell

Without applying any external power source, while the external resistance is **finite**, the overall electrochemical reaction would proceed in a **spontaneous** way:  $e^-$  flow out from anode where oxidation half (cell) reaction occurs through the external circuit to the cathode where the reduction half (cell) reaction occurs.

- Such a cell is called a **galvanic cell**
- In a **galvanic cell**, (stored) chemical energy converts to electrical work
- Encountered in the **discharge** of a battery or fuel cell

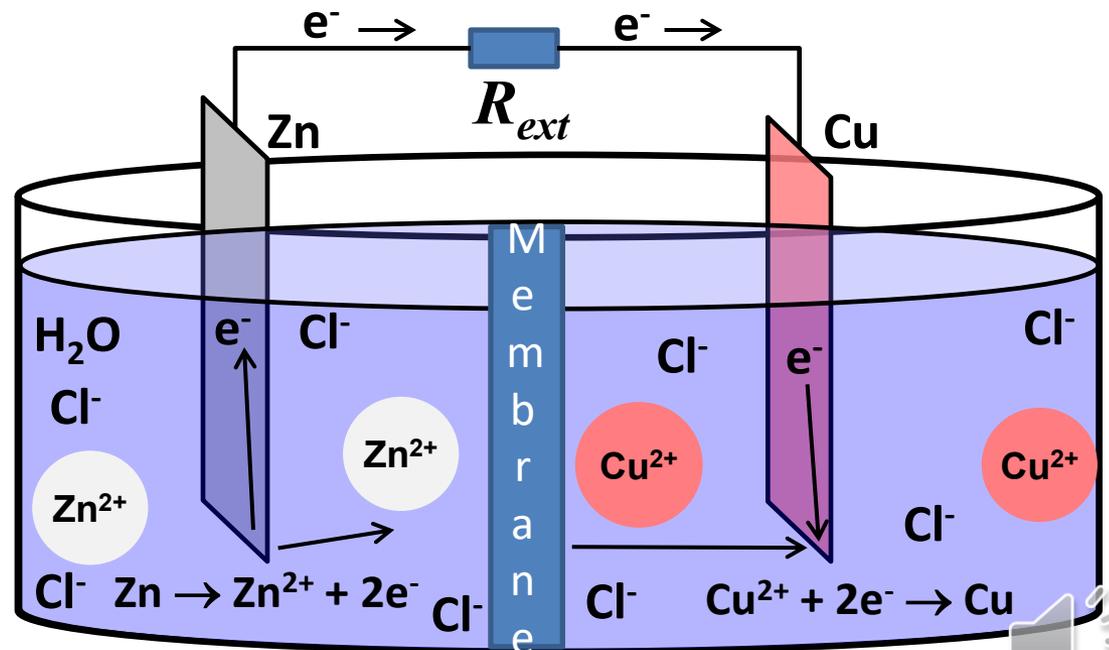
If  $I$  is net current through the cell, based on Ohm's Law and addition of potential:

$$E_{eq} = I(R_{int} + R_{ext})$$

$R_{int}$  and  $R_{ext}$  are cell internal resistance and external circuit resistance, respectively

Cell (external circuit) potential

$$E_{ext} = IR_{ext} = E_{eq} - IR_{int}$$



# Electrolytic Cell

By applying an external potential  $E_{app}$  in the reverse direction w/ value larger than  $E_{eq}$  cell current will be reversed  $\rightarrow$

the overall electrochemical reaction would proceed in the reverse direction

- Such a cell is called an **electrolytic cell**
- Electrical energy (consumed) converts to chemical energy (stored)**
- Encountered in battery **charging** or electrolytic production of chemicals/metals

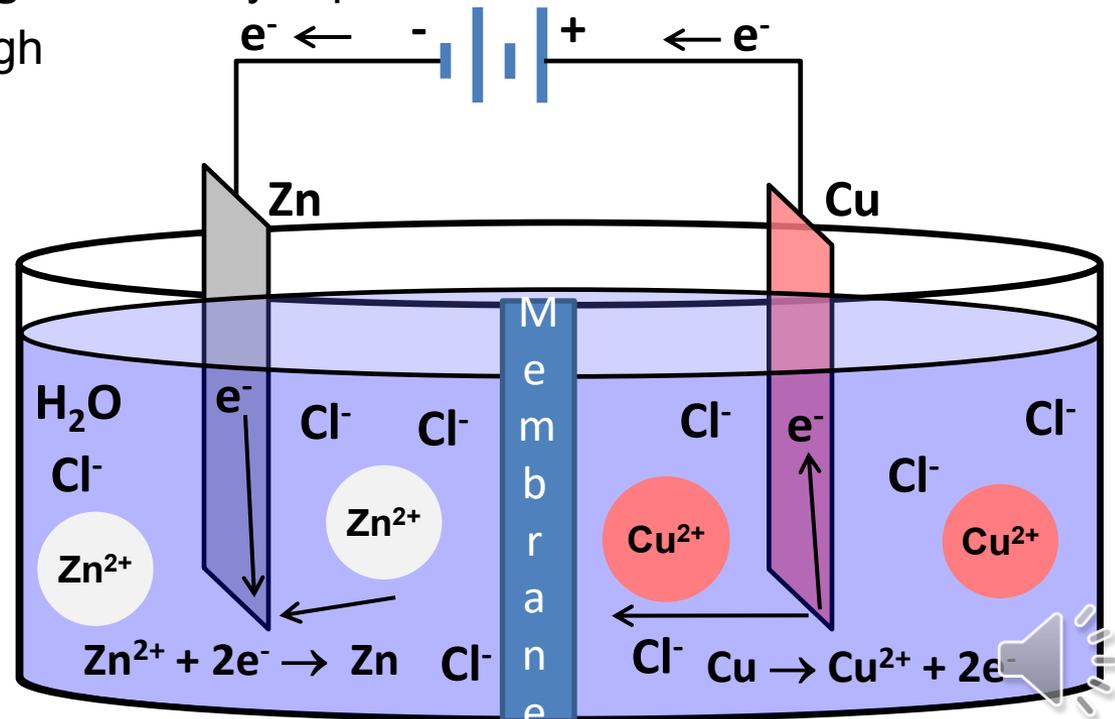
If  $I$  is the net current flowing through the electrolytic cell,

based on Ohm's Law and addition of potential:

the applied potential  $E_{app}$

$$E_{app} = E_{eq} + IR_{int}$$

$R_{int}$  is cell internal resistance



# Faraday Constant & Faraday's Law

- For a simple electrochemical cell, the amount of charge transferred in the reaction is linearly related to the amount of product generated or reactant consumed

$$1 \text{ coulomb (or 1 C)} = 6.24 \times 10^{18} \text{ of } e^- \quad \rightarrow \quad e^- = 1 / (6.24 \times 10^{18}) \text{ C}$$

$$1 \text{ mole of } e^- = 6.02 \times 10^{23} \text{ of } e^-$$

Faraday constant: **the electrical charge (in C) per mole of electron**

$$F = 1 / (6.24 \times 10^{18}) \text{ C} \times 6.02 \times 10^{23} / \text{mol} = \mathbf{96485 \text{ C/mol}}$$

## □ Faraday's Law

The mass (of metal) deposited in a simple electrolytic reaction is given by

$$m = \frac{MQ}{z \cdot F}$$

$M$  atomic mass, g/mol

$Q$  total passed charge, C

$z$  valence of the metal ion, unitless

$F$  Faraday constant 96485C/mol



# An Example of Faraday's Law

For electrolytic deposition of Cu from  $\text{Cu}^{2+}$  solution, assuming no other species got reduced, if the reduction current is constant at 1 A and the total time is 1 min, what is the amount of Cu deposited, in mole?

$$n_{\text{Cu}} = \frac{Q}{z \cdot F} = \frac{I \cdot t}{z \cdot F} = \frac{1\text{A} \cdot 60\text{sec}}{2 \cdot 96485\text{C/mol}} = 3.1 \times 10^{-4}\text{mol}$$

Cu has atomic mass of 63.55 g/mol →

The mass of Cu deposited will be  $3.1 \times 10^{-4} \text{ mol} \times 63.55 \text{ g/mol} = 0.0197 \text{ g} = 19.7 \text{ mg}$



# Faradaic Efficiency

❑ Actual electrode might have additional half-cell reactions in addition to the desired one

❑ Example of an electrolytic cell  
 $\text{Zn}|\text{Zn}^{2+}, \text{Cl}^-|\text{KCl}|\text{Cu}^{2+}, \text{Cl}^-|\text{Cu}$

Primary cathodic/reduction half cell reaction:

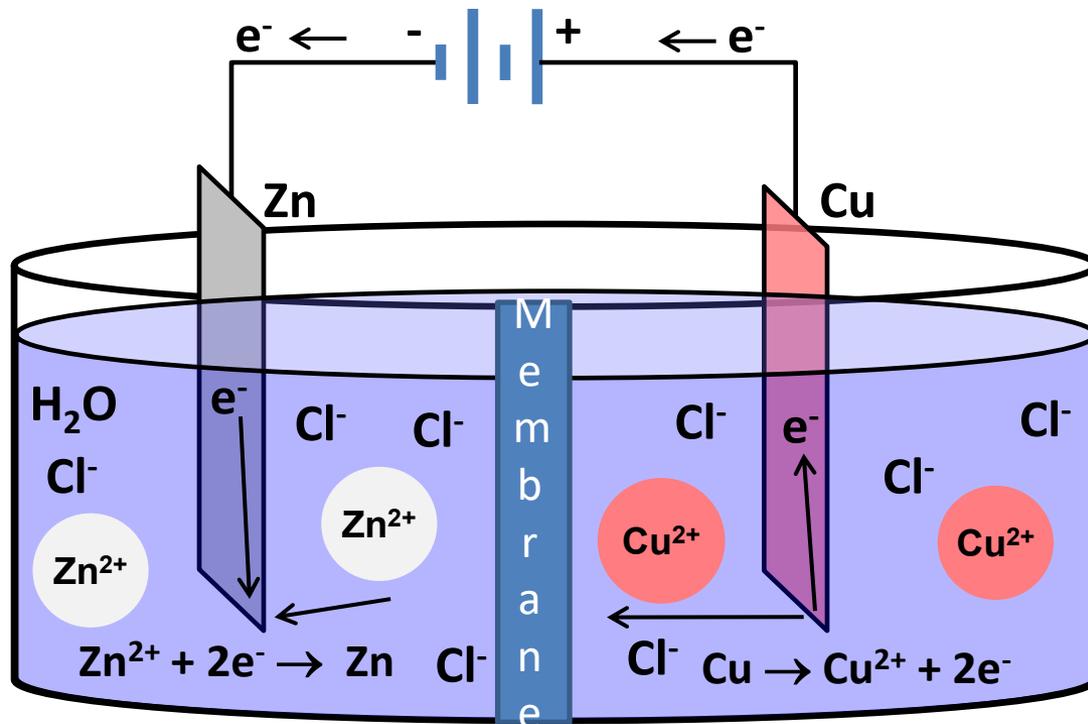


Additional (parasitic) cathodic/reduction half cell reaction:



❑ Faradaic efficiency

$$\eta_F = \frac{\text{Amount of desired material produced}}{\text{Amount that could be produced with the total charge supplied}}$$



# Faradaic Efficiency Example

## Example

Nickel is electrodeposited from  $\text{NiSO}_4$  solution. A constant current of 1 A is passed for 1 h and 1.05 g of metallic Ni was deposited. What is the Faradaic efficiency of the deposition?

## Solution

$$\eta_F = \frac{\text{Amount of desired material produced}}{\text{Amount that could be produced with the total charge supplied}}$$

From Faraday's Law, the amount of Ni that could be produced under ideal condition

$$m_{\text{Ni}_{ideal}} = \frac{M_{\text{Ni}} \cdot Q}{z_{\text{Ni}} \cdot F}$$

Therefore,

$$\begin{aligned} \eta_F &= \frac{m_{\text{Ni}_{actual}}}{m_{\text{Ni}_{ideal}}} = \frac{m_{\text{Ni}_{actual}}}{M_{\text{Ni}} Q / z_{\text{Ni}} F} \\ &= \frac{1.05 \text{ g}}{58.69 \text{ g/mol} \cdot \frac{1 \text{ A} \cdot 3600 \text{ s}}{2 \cdot 96485 \text{ C/mol}}} = \frac{1.05 \text{ g}}{1.095 \text{ g}} = 0.959 \text{ or } 95.9\% \end{aligned}$$

# Lecture 1 Homework

1. Read textbook Chapter 1 and give an honor statement confirm reading

2. Questions for the instructor

Raise **FOUR (4)** question that you don't fully understand for lecture videos

In case you have understood everything and don't have that many questions, please give corresponding number of multiple-choice problem (together with your answer) that you feel can be used to check a student's understanding.

An example multiple-choice problem could be:

*Which of the units below can be the unit for current density  $j$ ?*

- a) A
- b)  $A/cm^2$  (Answer)
- c) V
- d) C

3. Problems (see later)

# Homework 1.1

**For electrolytic deposition of silver (Ag) at constant current of 1 A, how much silver metal could be obtained after 1 sec? Assuming NO parasitic reactions**

# Homework 1.2

For electrolytic deposition of Mo from a molten salt, 12.85 g are deposited in 1 hour using a constant current of 7 A. How many electrons are passed per mole of Mo reacted? What is the average oxidation state (or valence) of Mo in the molten salt? If Mo valence is assumed to be +2, then, based on the actual amount of Mo produced, what would be the Faradic efficiency?

# Homework 1.3

How much hydrogen gas is needed to operate a hydrogen oxygen fuel cell for 3 hour at constant power of 50 kW? Knowing during the operation, the cell voltage is kept constant of 0.7 V, and the anodic half cell reaction is  $\text{H}_2 = 2\text{H}^+ + 2\text{e}^-$

# Homework 1.4

Calculate the daily aluminum production of 150,000 A aluminum electrolytic cell that operates at a Faradaic efficiency of 89%. The overall cell reaction is  $2\text{Al}_2\text{O}_3 + 3\text{C} = 4\text{Al} + 3\text{CO}_2$

# Homework 1.5

**The annual production of Cl<sub>2</sub> is about 45 million tons. Assume a typical plant is operational 90% of a year, and the operating voltage is 3.4 V.**

- Write down the anodic (or oxidation) half-cell reaction to produce Cl<sub>2</sub>
- Determine the total current needed world wide to generate the global supply of Cl<sub>2</sub>
- Calculate the electrical power needed

# Homework 1.6

Continuous sheet copper is made by electrodeposition from a solution containing  $\text{CuSO}_4$  onto a rotating drum of lead. For condition given below, what should be the rotation speed of the drum (revolution per hour)? Knowing cathodic current density =  $1750 \text{ A/m}^2$ , Faradaic (or current) efficiency = 95%, desired thickness =  $1.22 \text{ kg/m}^2$ , angle of cathodic immersion =  $165^\circ$ .

# Homework 1.7

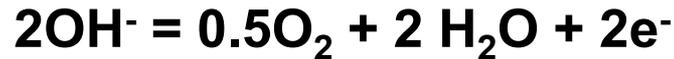
**How many grams of Li are in a 1320 (mAh) cell phone battery? Note 1320 mAh is a unit of charge**

# Homework 1.8

**A plate of steel has lost 50 g due to corrosion over the past year. Estimate the corrosion current that would be associated with this corrosion rate**

# Homework 1.9

Corrosion of steel in concrete is an important problem. Under accelerated corrosion testing condition, the current efficiency may be low. In competition with the oxidation of Fe to Fe<sup>2+</sup>, oxygen gas can be evolved following:



If a current 1.4 mA is passed for 100 h for the corrosion experiment and the mass loss for Fe is 0.11 g,

- What is the Faradaic efficiency for Fe oxidation in the experiment?
- How many moles of O<sub>2</sub> are evolved?
- What is the volume of O<sub>2</sub> under standard condition?

# Homework 1.10

**Find out (i) the half cell and full cell reactions, (ii) show how the full cell reaction is obtained from the half-cell reactions, (iii) identify which is the anodic (oxidation) and which is the cathodic (reduction) half cell reaction, for the following processes:**

- Industrial production of  $\text{Cl}_2$  and  $\text{NaOH}$  from  $\text{NaCl}$  solution
- Proton exchange membrane fuel cell running on  $\text{H}_2$  and air
- Discharge of a lead acid battery for automobiles
- Alkaline battery