



UNIVERSITY OF  
**ILLINOIS**  
URBANA - CHAMPAIGN

**ME 330: Engineering Materials**

Lab - 10

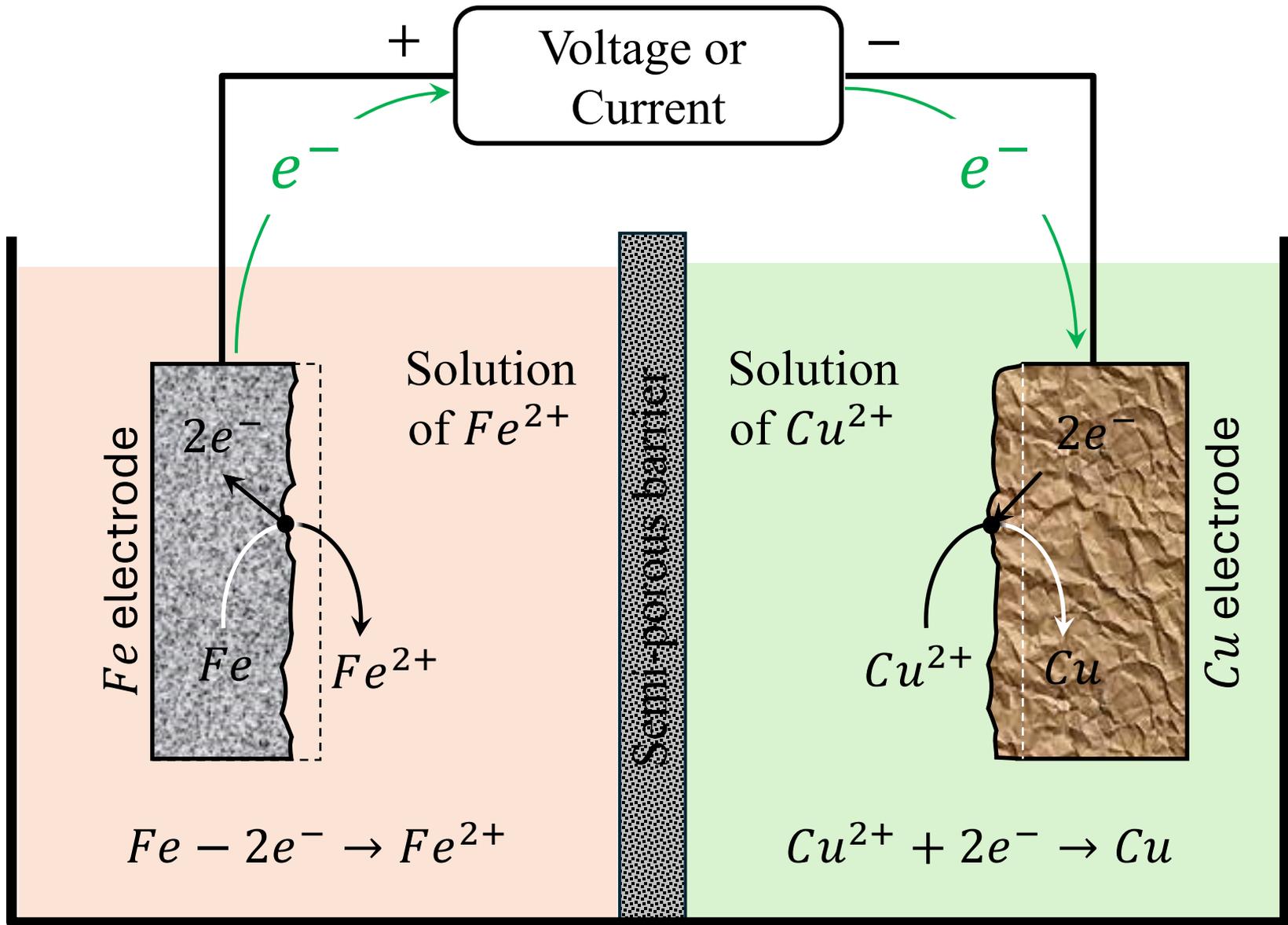
# Corrosion



**Grainger College  
of Engineering**

UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

# Electrochemical Cell



■ Electrochemical reaction: chemical reaction in which there is a transfer of electrons

- Anode  $M - ne^- \rightarrow M^{n+}$  (oxidation -loss of electron)
- Cathode  $M^{n+} + ne^- \rightarrow M$  (reduction -gain of electron)

❖ Limit of voltage

- $H_2$  Evolution:  $2H^+ + 2e^- \rightarrow H_2$  ( $E_{SHE} = 0 V$ )
- $O_2$  Evolution:  $2H_2O - 4e^- \rightarrow O_2 + 4H^+$  ( $E_{SHE} = +1.23 V$ )

## Electromotive force series



↑  
More inert  
(cathodic)

↓  
More active  
(anodic)

When two materials form a corrosion cell:

- More positive will plate
- More negative will corrode
- Driving Potential:

$$\Delta E = \Delta V = V_{red} - V_{ox}$$

What does current represent:

- Reaction rate

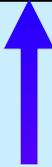
Voltage tells you which direction,  
and current tells you how fast the  
reaction will be.



# Galvanic Series of Engineering Materials

## Electromotive force series

## Galvanic series

$\text{Au}^{3+} + 3\text{e}^- \Rightarrow \text{Au}$	+1.420V	 <p>More inert (cathodic)</p>  <p>More active (anodic)</p> 	Platinum
$\text{Pt}^{2+} + 2\text{e}^- \Rightarrow \text{Pt}$	+1.200V		Gold
$\text{Ag}^+ + \text{e}^- \Rightarrow \text{Ag}$	+0.800V		Graphite
$\text{Cu}^{2+} + 2\text{e}^- \Rightarrow \text{Cu}$	+0.340V		Stainless steel
$2\text{H}^+ + 2\text{e}^- \Rightarrow \text{H}_2$	+0.000V		Bronzes/Brasses/Copper
$\text{Pb}^{2+} + 2\text{e}^- \Rightarrow \text{Pb}$	-0.126V		Tin
$\text{Ni}^{2+} + 2\text{e}^- \Rightarrow \text{Ni}$	-0.250V		Lead
$\text{Fe}^{2+} + 2\text{e}^- \Rightarrow \text{Fe}$	-0.440V		Cast Iron
$\text{Cr}^{3+} + 3\text{e}^- \Rightarrow \text{Cr}$	-0.744V		Iron/Steel
$\text{Al}^{3+} + 3\text{e}^- \Rightarrow \text{Al}$	-1.662 V		Aluminum alloys
$\text{Mg}^{2+} + 2\text{e}^- \Rightarrow \text{Mg}$	-2.363V		Cadmium
$\text{K}^+ + \text{e}^- \Rightarrow \text{K}$	-2.924V		Zinc
			Magnesium

- How does potential depend on solution concentration

- Nernst equation: 
$$E = E_0 + \frac{RT}{nF} \ln \left( \frac{c_{ox}}{c_{red}} \right) \quad (\text{log})$$

- How does current depend on solution concentration

- Butler-Volmer: 
$$i = \sum i_0 e^{\left( \frac{\alpha n F}{RT} \eta \right)} \quad (\text{exp})$$

- ✓ “Almost” linear relation between current and concentration.

Rudolph Arthur Marcus  
July 21, 1923



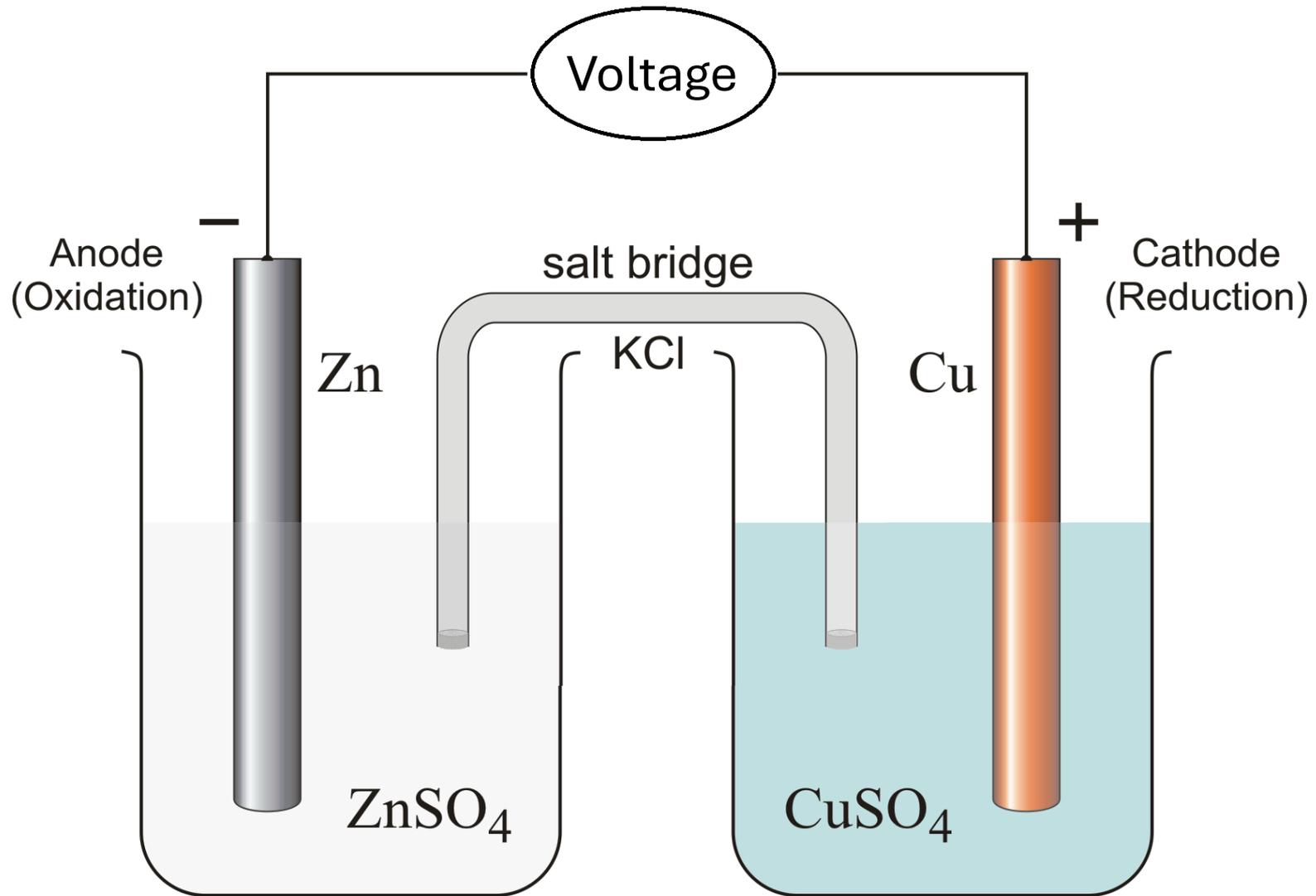
1992 Nobel prize  
in Chemistry

## Nobel Prize motivation

“for his contributions to the theory of electron transfer reactions in chemical systems”

$$k_{ox/red}^{MHC} = A \int_{-\infty}^{\infty} \exp\left(-\frac{(x - \lambda \pm e\eta^0)^2}{4\lambda k_B T}\right) \frac{dx}{1 + \exp\left(\frac{x}{k_B T}\right)}$$

# Understanding Rust Formation



# Rust Formation Mechanism

