2019 Fall, 4582-608 (WCU Program)
Electrochemical Energy Engineering, 전기화학에너지공학
LECTURER: Professor Yung-Eun Sung (성영은)
Office: Rm #729, Phone: 880-1889, E-mail: ysung@snu.ac.kr

OUTLINE

This class deals with electrochemical principles for the electrochemical technologies and energy devices and systems. This course is followed by "Advanced Electrochemistry" in last semester. However, students who did not attend the course in last semester can take this course. After reviewing the basics of electrochemistry, this course will be continued.

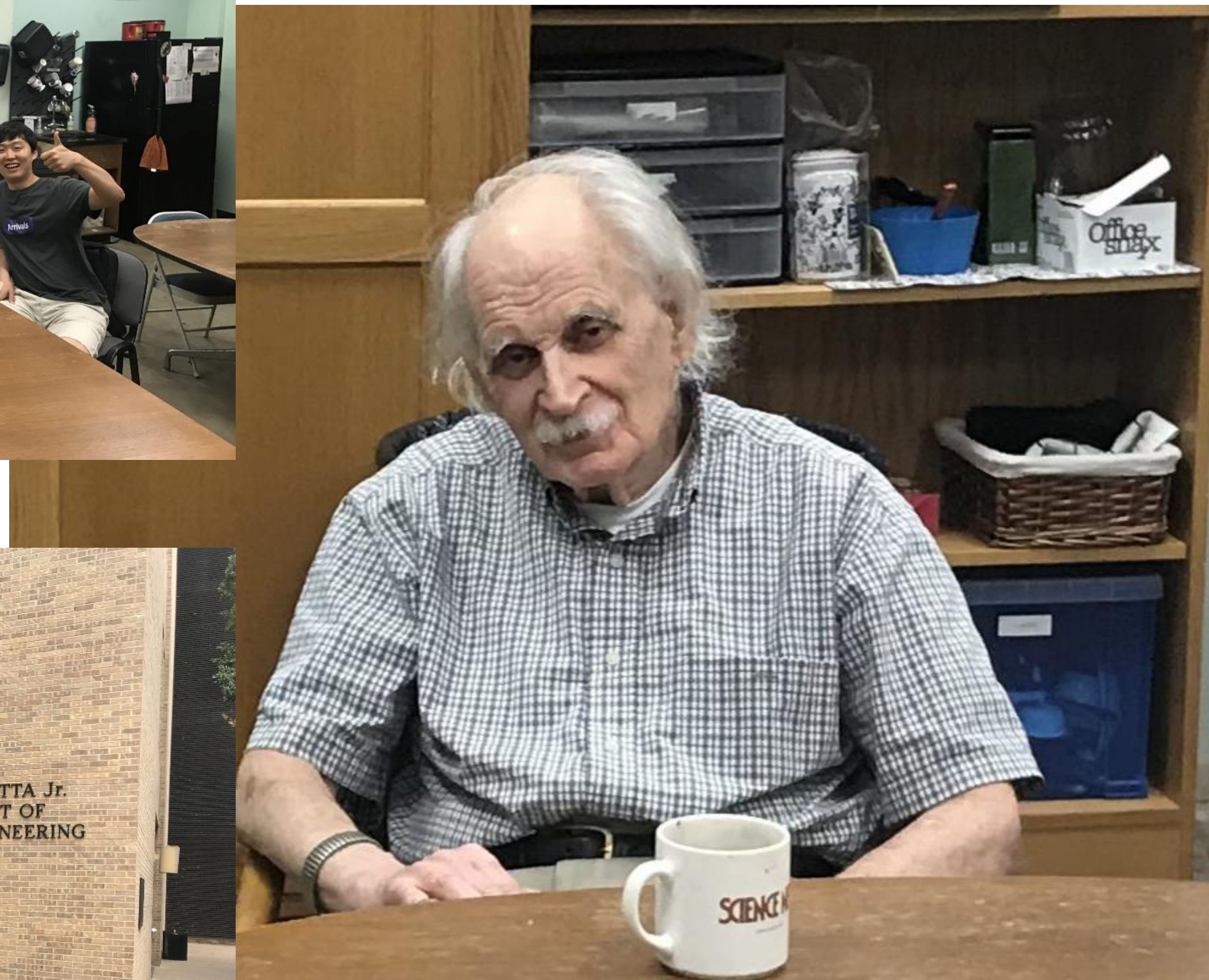
TEXTBOOKS

Allen J. Bard, Larry R. Faulkner, *Electrochemical Methods*, Wiley, 2001. (ch. 11 – 18)

REFERENCES

Heith B. Oldham, Jan C. Myland, Allan M. Bond, *Electrochemical Science & Technology: Fundamentals & Applications*, Wiley, 2013. (e-book, SNU Library)

오승모, 전기화학(3판), 자유아카데미, 2019.




CHEMICAL ENGINEERING
JOHN J. McKETTA Jr.
DEPARTMENT OF
CHEMICAL ENGINEERING

SCHEDULES (will be modified later)

1.Basics of electrochemistry (ch. 1 and so on) (1-4 weeks)

electrochemistry, I, V, conductivity, Faraday law, Nernst equation, voltammetry, I-V curve (polarization plot), Butler-Volmer equation etc

2. Bulk Electrolysis (ch. 11) (5 week)
3. Electrode Reactions (ch. 12) (6 week)
4. Double Layer Structure and Adsorption (ch. 13) (7-8 weeks)
5. Electroactive Layers and Modified Electrodes (ch. 14) (9 week)
6. Electrochemical Instrumentation (ch. 15) (10 week)
7. Scanning Probe Techniques (ch. 16) (11 week)
8. Spectroelectrochemistry (ch. 17) (12-13 weeks)
9. Photoelectrochemistry (ch. 18) (14-15 weeks)

GRADING (B^+ & above ~ 80%, B^0 & below ~ 20%)

Midterm Exam 40%, Final Exam 40%, Homeworks & Attendance 20 %

LECTURE ROOM & TIME: Rm #302-508, 11:00-12:15 Mon. & Wed.

OFFICE HOUR: Rm #302-729, 13:00-16:00 Mon. & Wed.

TA: Jin Ki Kwak(곽진기), Rm#302-1007, Tel: 880-9123, 010-7231-2340, rhkrwlsrl7@snu.ac.kr

1. Basic concept of electrochemistry

Learning subject

1. What is electrochemistry?
2. Electrical quantities

Learning objective

1. To get information on electrochemistry
2. Understanding the definition of electrochemistry
3. Understanding electrical quantities

Heith B. Oldham, Jan C. Myland, Allan M. Bond, *Electrochemical Science & Technology: Fundamentals & Applications*, Wiley, 2013. (e-book, SNU Library)

1. What is electrochemistry?

- **Electrochemistry**: passage of electric current → chemical changes
  chemical reactions → production of electric energy

- **Electrochemistry**:
  the coupling of **chemical changes** to the **passage of electricity**
  → ionic conduction(flow of ions) + electronic conduction (flow of electrons)
  → Electrochemical devices & electrochemical technologies
  → Materials & devices & process

Electrochemistry: chemical change ⇔ electric force
Electrodics: in which the reactions at electrodes are considered
Ionics: in which the properties of electrolytes have the central attention → concentration of ions, their mobilities, interactions etc
Basic laws were developed in systems **with liquid electrolytes** → "solid state" (same and different features of solid electrolyte system)

Ionic solutions

Most important ionic conductor e.g., aqueous solution of electrolyte

Electrolyte; a substance that produces ions so enhance the electrical conductivity

e.g., solid(NaCl), liquid(H_2SO_4), gas(NH_3)

cf) solid electrolyte

Electrode

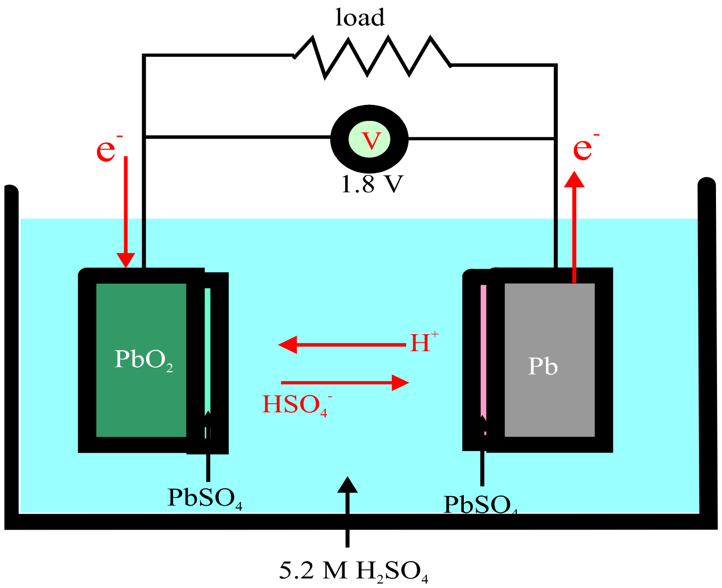
The junction between electronic conductor and ionic conductor that the chemistry of electrochemistry occurs

Electrochemical cell

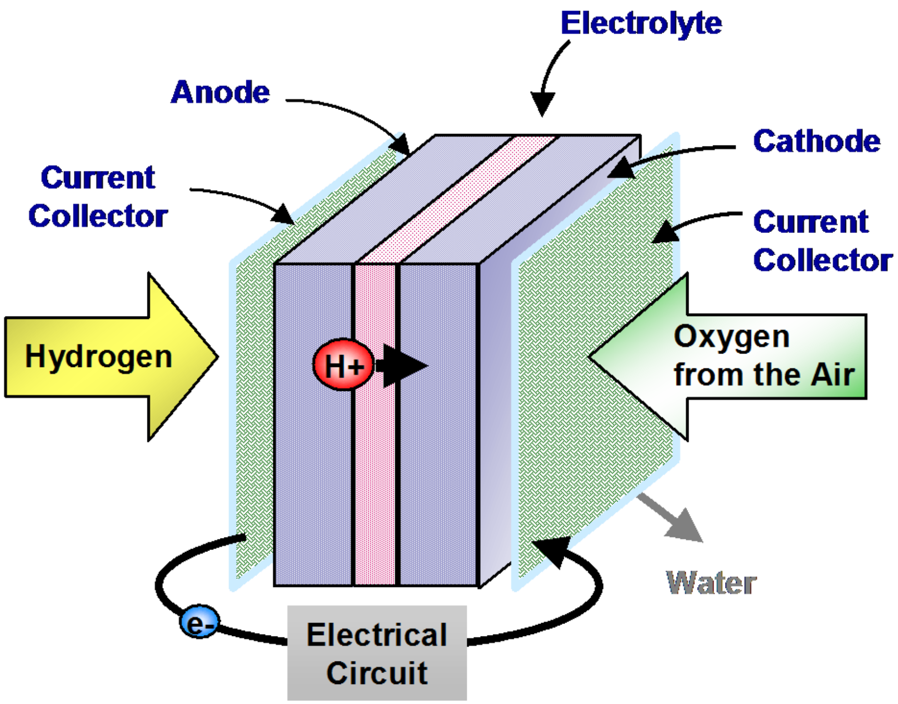
Basic unit: an ionic conductor sandwiched between two electronic conductors e.g., aqueous solution of electrolyte between two pieces of metal, solid electrolyte between two metals

Electronic conductor (electrode)	Ionic conductor (electrolyte)	Electronic conductor (electrode)

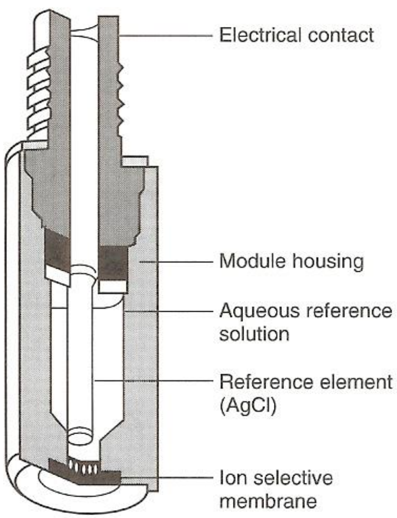
Examples of electrochemical cell 1



Solution electrochemistry



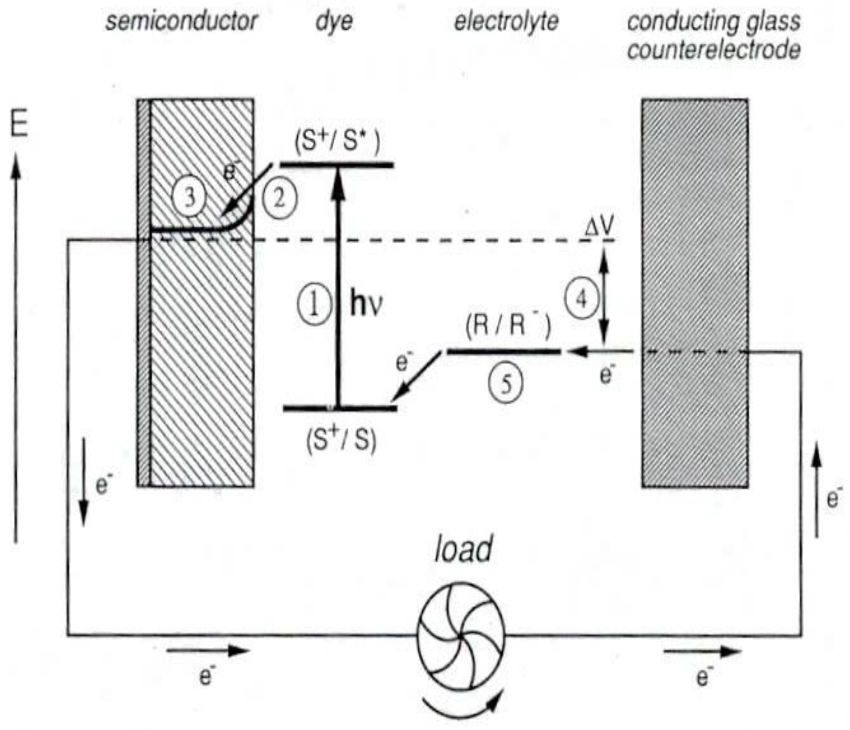
Fuel cell



pH meter (sensor)

Examples of electrochemical cell 2

Battery



Dye-sensitized solar cell

- **Examples of Electrochemical devices/technologies**

Battery or fuel cell: chemical state changes(electrochemistry) → electric power
Supercapacitor: double layer phenomena → electric power
Photoelectrochemical cell (Solar cell): light + electrochemistry → electric power
Photocatalysis: light → hydrogen or chemical reaction
Electrochromic display: chemical state changes by electric signal → coloration
Sensors: chemical state changes by mass → electric signal
Electrolysis: electric power → chemical species by chemical state changes
Electrodeposition: electric power → chemical change: thin film, Cu metallization
Electrochemical synthesis: electric power → chemical change
Corrosion: potential difference → chemical change
Etching

- **Solid State Electrochemistry**

Solid electrolyte: solid substances which can conduct electric current by ionic motion as do electrolyte solutions → "solid state electrochemistry" or "solid state ionics" → "**solid state device"**

2. Electrical quantities

(1) Electric charge & current

Electric charge (= amount of electricity), q (unit: Coulomb, C), time t
Electric current, I (unit: ampere (A)):

$$I = dq/dt$$

$$q = \int Idt$$

Current density (unit: A/cm^2): $i = I/A$, A: surface of area

Ammeter: measuring current

Circuit: electric current flows in a closed path

(2) **Electrical potential & electric field**

Electrical potential (unit; volts, V), ϕ: the pressure of the electric fluid

Voltage: the electrical potential difference ($\Delta\phi$)

Voltmeter: measuring an electrical potential difference

Electric field strength, X (unit: V/m)

$$X = -d\phi/dx$$

(3) Ohm's law: most conductors obey this law
Current density is proportional to the field strength

$$i \propto X$$

$$i = \kappa X = -\kappa \, d\phi/dx$$

κ; electrical conductivity (siemens/m, S = A/V), 1/κ; resistivity

$$\Delta\phi = -RI$$

R; resistance (unit of ohm), G; conductance,

$$G = 1/R = \kappa A/L = -I/\Delta\phi$$

L; conductor length, A; cross section
Ohm's law does not have universal validity. It does not apply to electrochemical cells.
Resistor: a device that is fabricated to have a stable and known resistance

$$\text{Power (watts)} = I^2R$$

Electrical quantities & their SI units

Quantity	Unit
Current (I)	Ampere (A)
Current density (i)	Ampere per square meter (A/m^2)
Charge (q)	Coulomb (C = As)
Charge density (ρ)	Coulomb per cubic meter (C/m^3)
Potential (ϕ)	Volt (V = J/C)
Field strength (X)	Volt per meter (V/m)
Conductivity (κ)	Siemens per meter (S/m)
Resistance (R)	Ohm (Ω =1/S = V/A)
Conductance (G)	Siemens (S = A/V)
Permittivity (ε)	Farad per meter (F/m = C/Vm)
Energy of work (w)	Joule (J = VC)
Power	Watt (W = J/s = AV)
Capacitance (C)	Farad (F = s/Ω = Ss), F = C/V

(4) Electrochemical cell potential (V, volts)

1 V = 1 J/C, energy to drive charge between electrodes
Electrochemical cell notation:

$Zn/Zn^{2+}, Cl^-/AgCl/Ag$ $Pt/H_2/H^+, Cl^-/AgCl/Ag$

slash(/): phase boundary,
comma(,): two components in the same phase

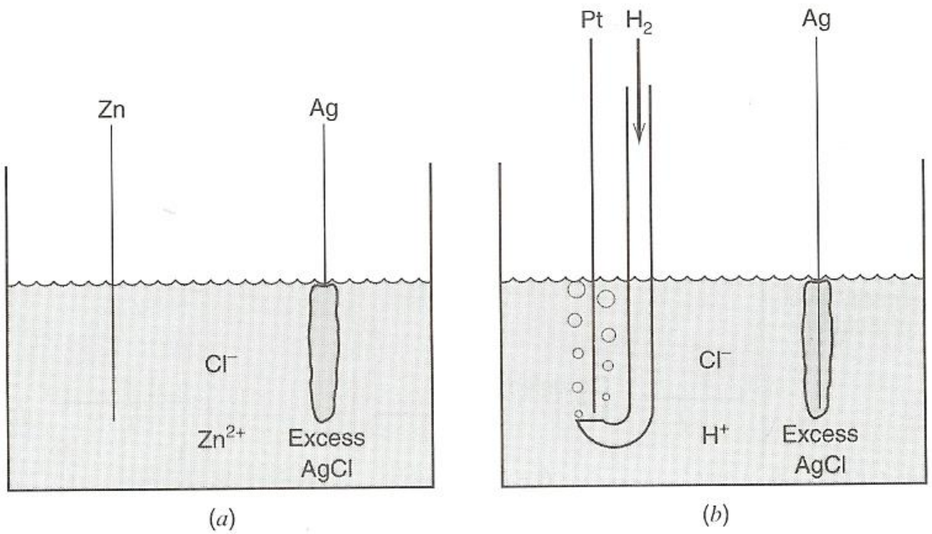


Figure 1.1.1 Typical electrochemical cells. (*a*) Zn metal and Ag wire covered with AgCl immersed in a $ZnCl_2$ solution. (*b*) Pt wire in a stream of H_2 and Ag wire covered with AgCl in HCl solution.

A.J. Bard, L. R. Faulkner, Electrochemical Methods, Wiley, 2001.

(5) energy

Heat: a form of energy

Quantity of heat (Q)

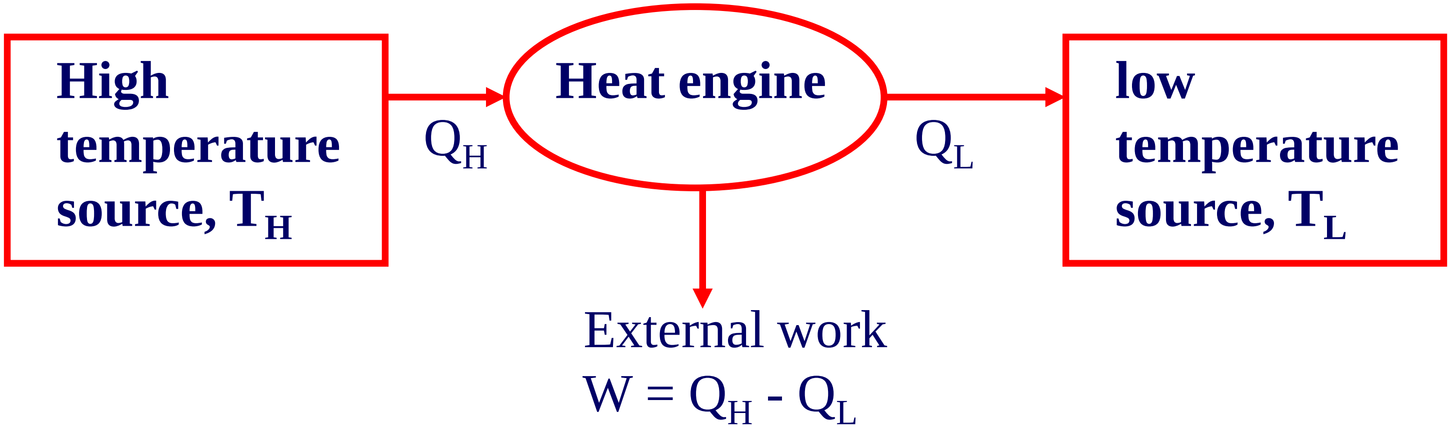
1 calorie: heat to raise 1 g of water through 1℃

1 BTU (British thermal unit): 1 pound (lb) of water through 1℉

Mechanical equivalent of heat

1 cal = 4.186 J   1 BTU = 7718 ft lb = 252 cal = 1054.7 J ~ 0.293 kWh

Ideal heat engine (heat-work converter)



$Q_H - Q_L = W$ (1st law of thermodynamics)

Efficiency η = work output / work input = $W/Q_H = 1 - Q_L/Q_H$

(6) Power

Power: the time rate of doing work or of expending energy

Power = energy/time = work/time

Instantaneous power $P = dW/dt$

Average power $P = W/t$

Unit: watt (W) = J/s

1 horsepower (HP) = 746 W

Power ratings of various devices & animals

10^{18} W solar power input to earth

10^{12} W electricity capacity in USA (2000)

10^{9} W large electric power plant

10^{7} W train

10^{5} W automobile

1000 W horse

100 W man/woman resting

0.1~1 W Si solar cell

0.01 W human heart

e.g., 5933000 BTU = 6259 MJ = 6259 MWs = 6259/3600 MWh (1.739 MWh)

1 kWh = 1000 x 60 x 60 = 3.6 x 10^6 J ~ 3411 BTU ~ 859.6 Kcal

cf. 1 barrel = 42 US gallons ~ 0.136 tonnes ~ 159 L

Fuel equivalence: 1 tonnes oil ~ 1.5 tonnes hard coal ~ 3 tonnes lignite ~ 12000 kWh

Million tonnes of oil equivalent (1 Mtoe = 41.9 PJ)

MW(mega-), GW,(giga-) TW(tera-), PW(peta-), EW(exa-):

10^6, 10^9, 10^{12}, 10^{15}, 10^{18} W

(7) Faraday's law

charge(Q, C(1 C = 6.24 x 10^{18} e^-) vs. extent of chemical reaction

"the passage of 96485.4 C causes 1 equivalent of reaction (e.g., consumption of 1 mole of reactant or production of 1 mole of product in a one-electron rxn)"

$$F = N_A Q_e = (6.02 \times 10^{23}\ \text{mol}^{-1})(1.6022 \times 10^{-19}\ \text{C}) = 96485\ \text{Cmol}^{-1}$$

- Current (i): rate of flow of coulombs (or electrons) (1 A = 1 C/s)