Review Definitions

- **Ion**: Charged particle (molecule / atom)
- **Cation**: + Ion
- **Anion**: - Ion
- **Valence**: # of e⁻ neutral atom may accept / lose
- **Oxidation**: Loss of e⁻ by molecule / atom / ion
- **Reduction**: Gain of e⁻ by molecule / atom / ion
- **Electrolyte**: Ionic solution

Current Carriers

- **Body**
  - Na⁺ ions
  - K⁺ ions
  - Cl⁻ ions
    - Present but not involved in nerve stimulation
- **Electric Circuit**
  - Electrons e⁻
  - Holes h⁺
- **Electrode**
  - Electron / ion transducer
Polarizable Electrodes

- No chemical reaction / electron / ion exchange
- Charge accumulates on surface of electrode like a capacitor
- High pass filter
- Biosignals: (high or low frequency?)
  - EKG: 150 Hz
  - EEG: 50 Hz
  - EMG: 20 Hz

Percutaneous Electrodes

- Polarizable
- Hook minimizes motion artifact
- Pull hard to remove
Non-Polarizable Electrodes

- **Metal + neutral electrolyte (containing the metal)**
  - Reaction due to concentration imbalance
    - Depends on type of metal, ionic concentration & temperature
  - Diffusion current
    - Ions: metal to gel
    - Electrons: gel to metal
  - Like a charged capacitor

- **Half-cell Potential ($V_{hc}$)**
  - Steady state charge at metal/electrolyte boundary
  - No net current

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**Table 5.1** Half-cell Potentials for Common Electrode Materials at 25 °C

<table>
<thead>
<tr>
<th>Metal and Reaction</th>
<th>Potential $E^0$, V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al $\rightarrow$ Al$^{3+}$ + 3e$^-$</td>
<td>$-1.706$</td>
</tr>
<tr>
<td>Zn $\rightarrow$ Zn$^{2+}$ + 2e$^-$</td>
<td>$-0.763$</td>
</tr>
<tr>
<td>Cr $\rightarrow$ Cr$^{3+}$ + 3e$^-$</td>
<td>$-0.744$</td>
</tr>
<tr>
<td>Fe $\rightarrow$ Fe$^{2+}$ + 2e$^-$</td>
<td>$-0.409$</td>
</tr>
<tr>
<td>Cd $\rightarrow$ Cd$^{2+}$ + 2e$^-$</td>
<td>$-0.401$</td>
</tr>
<tr>
<td>Ni $\rightarrow$ Ni$^{2+}$ + 2e$^-$</td>
<td>$-0.230$</td>
</tr>
<tr>
<td>Pb $\rightarrow$ Pb$^{2+}$ + 2e$^-$</td>
<td>$-0.126$</td>
</tr>
<tr>
<td>H$_2$ $\rightarrow$ 2H$^+$ + 2e$^-$</td>
<td>$0.000$ by definition</td>
</tr>
<tr>
<td>Ag + Cl$^-$ $\rightarrow$ AgCl + e$^-$</td>
<td>$+0.223$</td>
</tr>
<tr>
<td>2Hg + 2Cl$^-$ $\rightarrow$ Hg$2$Cl$_2$ + 2e$^-$</td>
<td>$+0.268$</td>
</tr>
<tr>
<td>Cu $\rightarrow$ Cu$^{2+}$ + 2e$^-$</td>
<td>$+0.340$</td>
</tr>
<tr>
<td>Cu $\rightarrow$ Cu$^+$ + e$^-$</td>
<td>$+0.522$</td>
</tr>
<tr>
<td>Ag $\rightarrow$ Ag$^+$ + e$^-$</td>
<td>$+0.799$</td>
</tr>
<tr>
<td>Au $\rightarrow$ Au$^{3+}$ + 3e$^-$</td>
<td>$+1.420$</td>
</tr>
<tr>
<td>Au $\rightarrow$ Au$^{+}$ + e$^-$</td>
<td>$+1.680$</td>
</tr>
</tbody>
</table>

Over-potential

- Current dependent voltages
  - Concentration ($V_c$)
    - Ion distribution near interface affected by $I$
    - Like a current dependent component of half-cell potential
  - Activation ($V_a$)
    - Atoms must overcome energy barrier before oxidation/reduction occurs
    - Energy barrier different for oxidation & reduction
    - Dependent on direction of current

$$V_{op}(I) = V_c(I) + V_a(sgn(I))$$

Equivalent Circuit

- $V_{hc}$ = half-cell potential
- $V_{op}$ = over-potential
- $CJ$ = junction capacitance
- $RJ$ = junction resistance
- $RE$ = electrolyte resistance
Measured Electrode Impedance

Fig 5.6 (MI): Experimentally Determined Impedance

$\frac{1}{R_C} \approx 110Hz$

$\frac{1}{R_C} \approx 16kHz$

$R_j \approx 30,000 = 90dB$

$\approx 50dB$

$\approx 2$ decades

$\approx -20dB / dec$
Electrode Frequency Response

\[ Z(s) = \frac{s}{(R_E + R_J)^2/R_E R_J C_J} \]

\[ Z(s) \approx R_J \frac{s}{R_E R_J C_J} \quad R_J >> R_E \]

Electrode Connections
EMG Electrodes

- NonPolarizeable
  - Sweat reacts with electrolyte (AgCl)
  - Motion artifact

- Polarizeable
  - Percutaneous (crosses skin boundary)
  - Invasive
  - Reduced motion artifact
  - SS, Platinum or Gold plated