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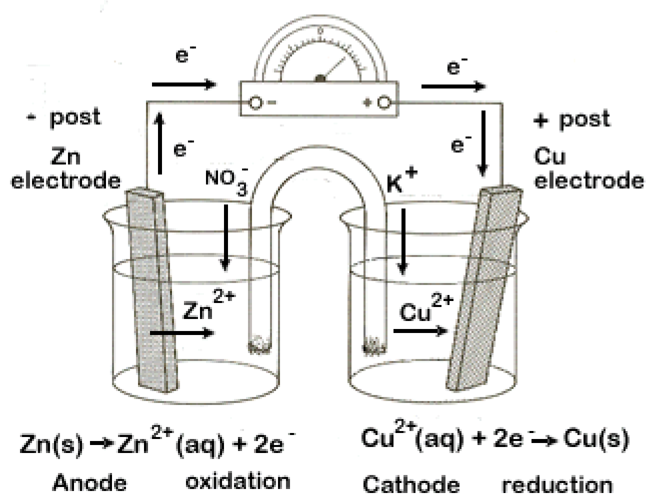
**課題 1：** Explain mechanisms on how the electro-motive force of electric batteries is generated. Take redox reactions, electro-chemical potential, and Gibb' s free energy into consideration.

An electric battery is a device convert chemical energy directly to electrical energy.

A battery consists of some number of voltaic cells. Each cell consists of two half-cells connected in series by a conductive electrolyte containing anions and cations. One half-cell includes electrolyte and the negative electrode, the electrode to which anions (negatively charged ions) migrate; the other half-cell includes electrolyte and the positive electrode to which cations (positively charged ions) migrate.

### Redox reactions




[Fig 1-1] Galvanic cell structure

Redox which is short for reduction–oxidation reaction). Galvanic cell which is typical electronchemical cell based on redox reaction as [Fig 1-1] presented.

The ionic equation for this reaction is:

$$Zn + Cu^{2+} \rightarrow Zn^{2+} + Cu - \Delta G$$

Oxidation is the loss of electrons or an increase in oxidation state by a molecule, atom, or ion.

As two half-reactions in Galvanic cell, it is seen that the zinc is oxidized

$$Zn \rightarrow Zn^{2+} + 2e^{-}$$

Reduction is the gain of electrons or a decrease in oxidation state by a molecule, atom, or ion. And the copper is reduced:

$$Cu^{2+} + 2e^{-} \rightarrow Cu$$

As electrons gain and lose in two poles, there is electro-motive force generated between two poles.

### Electro-chemical potential

In generic terms, electrochemical potential is the mechanical work done in bringing 1 mole of an ion from a standard state to a specified concentration and electrical potential. In the definition of IUPAC, it is the partial molar Gibbs energy, which is also refer to Gibbs free energy, of the substance at the specified electric potential, where the substance is in a specified phase. Electrochemical potential can be expressed as

$$w = p\Delta v + nF\Phi$$

Among them, $w$ is the electrochemical potential, $p\Delta v$ is the mechanical work, $n$ is the number of the ion. $F$ is the Faraday constant, $\Phi$ is the local **electro-motive force**.

### Gibb's free energy

In thermodynamics, the Gibbs free energy is a thermodynamic potential that can be used to calculate the maximum or reversible work that may be performed by a thermodynamic system at a constant temperature and pressure. The Gibbs free energy is defined as:

$$G = H - TS$$

Among them, $H$ is the enthalpy, $T$ is Thermodynamic temperature, $S$ is the entropy. Then we can introduce follow formula:

$$\Delta G = \Delta H - T\Delta S$$

**Summery:**

According to second law of thermodynamics:

$$\Delta S = \frac{q}{T}$$

$$\Delta H = \Delta U + p\Delta v$$

So:

$$\Delta G = \Delta H - T\Delta S = \Delta U + p\Delta v - q$$

According to first law of thermodynamics:

$$\Delta U = w + q + z$$

Then:

$$\Delta G = q - w + p\Delta v - q = -w + p\Delta v$$

According to electro-chemical potential define:

$$\Delta G = -nF\varPhi$$

So electro-motive force $\varPhi$ is:

$$\varPhi = \frac{-\Delta G}{nF}$$

### 課題 2： Explain Faraday' s law on electric current of batteries. Explain gram-equivalent.

Faraday's law on electric current of batteries refer to Faraday's laws of electrolysis which are quantitative relationships based on the electrochemical researches. It can be summarized by

$$m = (\frac{Q}{F})(\frac{M}{z})$$

Among them, $m$ is the mass of the material liberated at an electrode in grams, $Q$ is the total electric charge passed through the material in coulombs, $F$ is the Faraday constant, $M$ is the molar mass of the material in grams per mol, $z$ is the valency number of ions of the material. And $M/z$ is the same as the equivalent weight of the substance altered.

For Faraday's first law, *"The amount of substance liberated at an electrode is directly proportional to the quantity of electricity passed"*, *M*, *F*, and *z* are constants, so that the larger the value of *Q* the larger m will be.

For Faraday's second law, *"If same quantity of electricity is passed through different electrolytes, then the amount of substances liberated at the respective of electrodes are in the ratio of their equivalent masses".*

, *Q*, *F*, and *z* are constants, so that the larger the value of *M/z* (equivalent weight) the larger m will be.

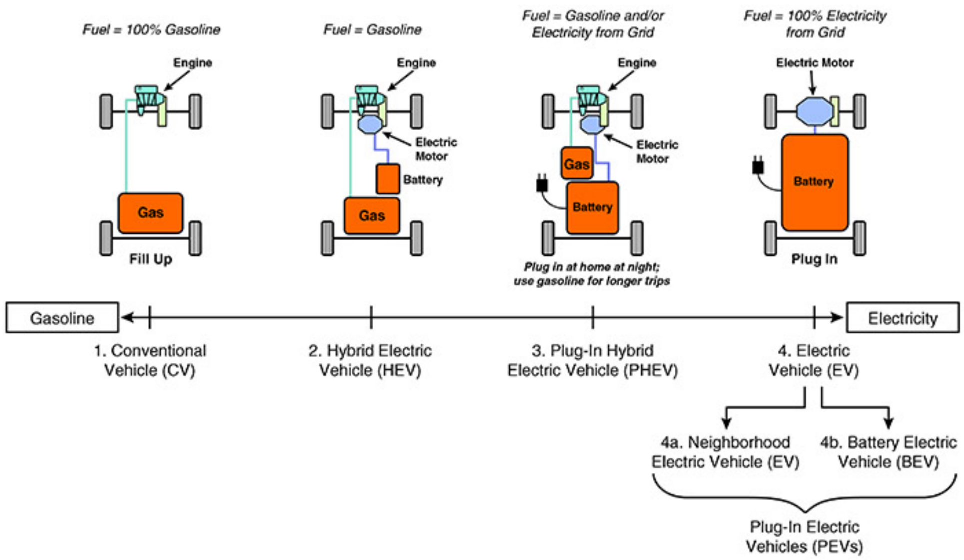
In the simple case of constant-current electronlysis,

$$F = eN_A$$

Among them, $F$ is Faraday constant, $N_A$ is number of ions electric charge per mol.

Gram equivalent is the mass of a given substance which will supply or react with one mole of electrons in a redox reaction.

**課題 3** Describe similarity and difference as for plug-in-hybrid vehicles and (pure) electric vehicles. Focus on energy sources and power trains. From the standpoint of environmental protection and economics, discuss merits and demerits of each of them.




[Fig 3-1]Structure of CV, HEV, PHEV and EV

**Difference:**

1, PHEV use both an electric motor and ICE, while EV using batteries alone to power an electric motor.

2, PHEV use a both a combination of grid electricity, regenerative energy from braking, and power from an internal combustion engine. But EV use a combination of grid electricity and regenerative energy from braking.

**Similarity:**

Both of EV and PHEV use electric energy as the power of the car. Reducing the consumption of fossil energy and emission.

**Merits and Demerits**

Energy density of hydrogen is much higher than energy density of batteries. Which means PHEV is much lighter and save more space.

Since majority of electricity in the world comes from coal, and the grid efficiency is on the order of only 35%, BEVs would lead to much more greenhouse gas emissions than PHEV, as most hydrogen was made by reforming natural gas.

As battery charging is a long chemical reaction progress take at least hours, PHEV's refuel progress is just a few minutes in hydrogen supply station.

**Reference:**

1, Josh Goldman, Comparing Electric Vehicles: Hybrid vs. BEV vs. PHEV vs. FCEV [OL],Union of Concerned Scientists.

2, Sandy Thomas, Fuel Cell and Battery Electric Vehicles Compared [J]. International journal of hydrogen energy, 2009, 34(15): 6005-6020.