1. Batteries: Classification, Components, Characteristics

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BATTERIES

Luigi Galvani (1737 - 1798) ⟶ "Animal electricity"
Alessandro Volta (1745 - 1827) ⟶ Two different metals are connected
John Frederic Daniel (18th century) ⟶ Daniell cell
⟶ 100 years

- Chemical energy $\xrightarrow{\text{conversion}}$ electrical energy ⟶ alternate source of energy
- Variable sizes

Applications: laptops, electric vehicles, electronic equipment etc.

CLASSIFICATION OF BATTERIES

PRIMARY

- discharging only
  CE ⟶ EE
  $A+B \longrightarrow C+D$
- Electroactive material
  ↓
  Electroinactive material
- EAM not regenerated, discarded after consumption
- Eg: Dry cell, $Li\text{-}MnO_2$

SECONDARY

- discharging (galvanic cell)
  CE ⟶ EE
- charging (electrolytic cell)
  EE ⟶ CE
  $A+B \rightleftharpoons C+D$
- EAM can be regenerated, can be used several times
- Eg: Li-ion, Ni-Cd

RESERVE

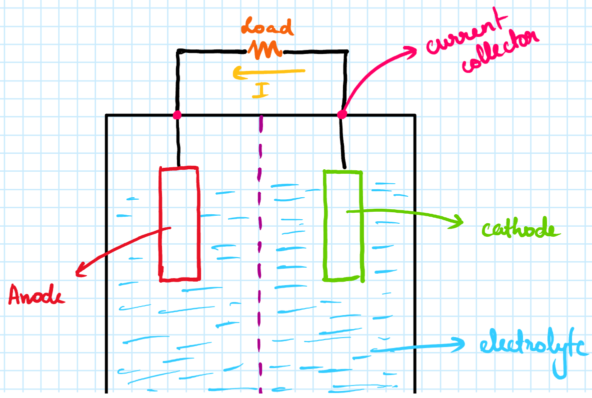
- electrolyte is separated or isolated from rest of components until usage
- unlimited shelf life
- Eg: Mg-AgCl activated by H_2O/seawater

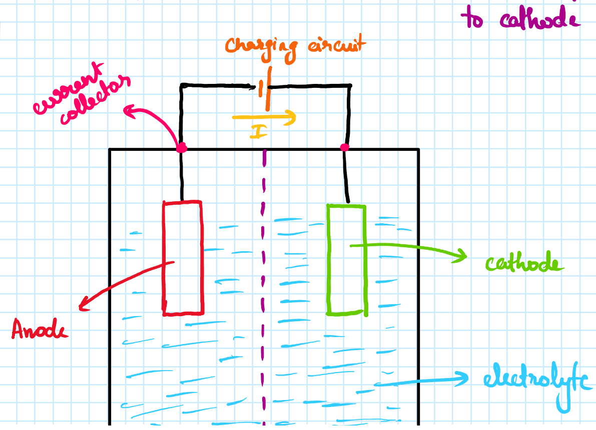
Advantages
- emergency conditions
- quick discharge
- unlimited shelf life
- produces high voltage

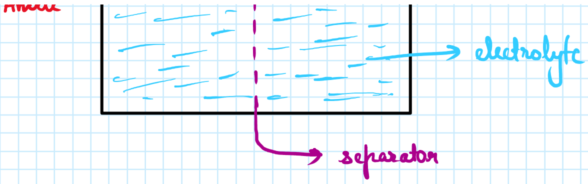
Applications
- Pyrotechnic devices
- Marine markers
- Weather balloons

COMPONENTS OF BATTERIES

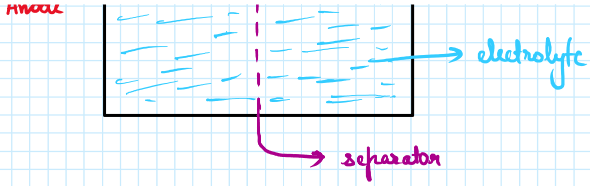
Anode: oxidation (loss of e^-); made of EAM that undergoes oxidation easily (Zn, Pb, Li)
Cathode: reduction (gain of e^-); made of EAM that undergoes reduction easily (PbO_2, MnO_2, O_2)
Electrolytic soln: acid, alkali or salt solutions; polymers, doped oxides ⟶ undergo ionic conduction easily
Separators: polypropylene, cellophane, etc. ⟶ ROLE: to prevent internal short circuit; transport ions from anode to cathode compartments & vice versa







DURING DISCHARGING



DURING CHARGING

CHARACTERISTICS OF BATTERIES

- Voltage
- Current
- Capacity
- Cycle life (secondary batteries)
- Electricity storage density
- Energy efficiency (secondary battery)
- Power density
- Energy density
- Shelf life
- Tolerance and service
- Conditioning

VOLTAGE

$$E_{cell} = E^{\circ}_{cell} - \frac{0.0591}{n} \log Q$$

$$E^{\circ}_{cell} = E^{\circ}_{cath} - E^{\circ}_{anode}$$

$$\Delta G = -nEF$$

$\boxed{emf \propto \frac{1}{Q}}$ $\boxed{emf \propto \frac{1}{T}}$ $\boxed{emf \propto E^{\circ}_{cell}}$

CURRENT

Measure of rate of discharging → Current

UNITS: Ampere (A)

FACTORS:

- Sufficient amount of electroactive material (EAM)
- Conductivity of the electrolyte
- Inner electrode distance → less

CAPACITY

Current measured in unit time → capacity

$$\boxed{C = I \times t}$$

UNITS: Ampere x hour = A-hr

$$\boxed{C = \frac{wnF}{M}}$$

w → weight of electroactive material
F → Faraday = 96500 C
n → no. of electrons
M → molar mass of compound

Formula result units: A-sec
Divide by 3600 to convert to A-hr

FACTORS:

- Size of battery
- Weight of EAM
- Molar mass of EAM

CYCLE LIFE (secondary battery)

No of cycles of discharging and charging before the failure of the battery

Reasons for failure of battery

- Corrosion of current collector

Reasons for failure of battery

- Corrosion of current collectors
- Shedding of EAM
- Morphological conditions ⟶ external conditions like temperature, moisture etc.

ELECTRICITY STORAGE DENSITY

$$\boxed{ESD = \frac{\text{Capacity}}{\text{Total weight of battery}}}$$

UNITS: $\frac{\text{Amp-hr}}{\text{kg}}$

$$\boxed{\text{ESD units: Amp-hr-kg}^{-1}}$$

NOTE: Why lithium-ion battery ESD is high

7g of Li ⟶ 1F

104g of Pb ⟶ 1F

lighter amount of Li has much higher charge than Pb (or most other compounds)

ENERGY EFFICIENCY (secondary batteries)

$$\boxed{EE = \frac{\text{energy released on discharging}}{\text{energy consumed in charging}} \times 100}$$

⟶ Result is a percentage

POWER DENSITY

$$PD = \frac{\text{power available from battery}}{\text{total weight of battery}}$$

$$\boxed{PD = \frac{I \times E_{cell}}{W}}$$

UNITS

$$\frac{\text{Ampere} \times \text{Volt}}{\text{Kg}} = \frac{\text{watt}}{\text{kg}} = \text{watt - kg}^{-1} \quad (W\text{-}kg^{-1})$$

ENERGY DENSITY

$$ED = \frac{\text{energy available from battery}}{\text{total weight of battery}} = PD \times \text{time}$$

$$\boxed{ED = \frac{I \times E_{cell} \times t}{W}}$$

UNITS

$$\text{watt - hour - kg}^{-1} \quad (W\text{-}hr\text{-}kg^{-1})$$

SHELF LIFE

- Maximum amount of time battery can be stored without loss in performance (current, voltage etc.)
- Shelf life lowers due to self discharge

TOLERANCE & SERVICE CONDITIONS

Optimal condition for usage of battery; battery has to be tolerant to different conditions like variation in temperature, vibration, shock

Eg: Li-ion battery $\longrightarrow$ operated in $-40°C - 70°C$ temp

LKG PROBLEMS

① Calculate the capacity (A-hr), energy density (watt-hr-kg^{-1}) and electricity storage density (A-hr-kg) for Zn-air battery, if 2.6 g Zn is stored in the battery and the weight of the battery is 72 g. [Voltage = 1.39 V, molar mass of Zn = 65.38)

Soln:

$$C = \frac{WnF}{M}$$

$$= \frac{2.6 \times 2 \times 96500}{65.38 \times 3600} = 2.131 \text{ A-hr}$$

Formula gives result in As. Divide to get A hr

$$E.S.D. = \frac{C}{W_{battery}} = \frac{2.131}{72 \times 10^{-3}} = 0.029 \times 10^{3} = 29.597 \text{ A-hr-kg}^{-1}$$

$$ED = PD \times t$$

$$= \frac{I \times E_{cell} \times t}{W} \quad [\because C = i \times t]$$

$$= \frac{C \times E_{cell}}{W} = \frac{2.131 \times 1.39}{72 \times 10^{-3}} = 41.14 \text{ W-hr-kg}^{-1}$$

② 150 g of lead is used as anode. It gives voltage of 1.9 V. The weight of the battery is 1200 g and lasts for 600 minutes when a constant current is drawn. Find the capacity, power density, energy density. [M = 207]

Soln:

$$C = \frac{WnF}{M \times 3600}$$

$$= \frac{150 \times 2 \times 96500}{207 \times 3600} = 38.848 \text{ Ahr}$$

$$C = I \times t$$

$$38.848 = I \times 10$$

$$I = 3.8848 \text{ A}$$

NOTE: Pay attention to units, especially for molar mass given values

$$PD = \frac{I \times E_{cell}}{W} \; W kg^{-1}$$

$$PD = \frac{3.8848 \times 1.9}{1.2}$$

$$= \underline{\underline{6.15 \; W kg^{-1}}}$$

$$ED = \frac{I \times E_{cell} \times t}{W} \; W\text{-}hr\text{-}kg^{-1}$$

$$ED = \frac{3.8848 \times 1.9 \times 10}{1.2}$$

$$= PD \times 10 = \underline{\underline{61.5 \; W\text{-}hr\text{-}kg^{-1}}}$$