1. Negative plate reaction: \( \text{Pb}(s) + \text{HSO}_4^-(aq) \rightarrow \text{PbSO}_4(s) + \text{H}^+(aq) + 2e^- \)

Positive plate reaction:

\( \text{PbO}_2(s) + \text{HSO}_4^-(aq) + 3\text{H}^+(aq) + 2e^- \rightarrow \text{PbSO}_4(s) + 2\text{H}_2\text{O}(l) \)

→ conduction e−'s go from the neg. plate, through the external circuit to the pos. plate

→ when discharged, the electrolyte solution is mostly water: the discharged battery is subject to freezing in low temperatures

When Charging

Negative plate becomes Pb

\[ \text{reaction: PbSO}_4(s) + \text{H}^+(aq) + 2e^- \rightarrow \text{Pb}(s) + \text{HSO}_4^-(aq) \]

Positive plate becomes PbO₂

\[ \text{reaction: PbSO}_4(s) + 2\text{H}_2\text{O}(l) \rightarrow \text{PbO}_2(s) + \text{HSO}_4^-(aq) + 3\text{H}^+(aq) + 2e^- \]

Electrolyte becomes ~ 35% sulphuric acid (H₂SO₄)

→ during charging, the externally applied voltage forcibly removes e−'s from the positive plate and forcibly introduces them to the negative plate

→ Overcharging (with high voltage) generates oxygen and hydrogen gas by electrolysis of water

\[ \text{note: } \text{O}_2(g) + \text{H}_2(g) + \text{energy} \rightarrow "\text{boon,}" \Rightarrow \text{potentially dangerous} \]
2. Lead-Acid Battery Structures

1) Flooded or Wet → liquid electrolyte solution must be regularly topped off with distilled water → H₂ gas given off → adequate ventilation is necessary

2) Sealed or Valve-Regulated → sealed with a gas-tight valve (only opens in an over-pressure situation) → O₂(g) and H₂(g) recombine → H₂O → topping off is unnecessary → alternative type uses a gel electrolyte → less maintenance the Flooded type → requires a strict charging regime

PV Deep Cycle batteries

→ typically use special tubular plate electrodes
→ if discharged no more than 30% will survive several thousand charge-discharge cycles
→ if discharged by 80% will survive about 1000 cycles

3. Battery Capacity

→ Typically measured in Ampere Hours (Ah)
→ product of current supplied and time it flows
ex: 12V 200 Ah battery → 20A at 12V for 10 hrs
energy stored = 200 × 12 = 2.4 kWh
Note: an Ah rating is only specified for a particular discharge time

→ you get more energy out of a battery when discharging it as slow as possible
→ A 10 hr rate is a typical discharge rate
→ A 100hr rate is often more appropriate for PV applications → ex: 3 nights + 2 cloudy days
→ rated capacity normally applies to 20° C
→ " " reduces about 1% for every ° C drop in temperature

4. **Charging Pb-acid batteries**

→ show Fig 5.3

→ The battery voltage varies according to how charged the battery is

✓ Fully Discharged: $V_{bat} \approx 12V$

✓ Fully charged: $V_{bat} > 14V$

→ The charge controller monitors $V_{bat}$ to regulate charging current flow

a. **Flooded Battery Type**

→ when the battery is nearly fully charged, the liquid electrolyte gasses → i.e. it produces free oxygen and hydrogen
→ : Adequate ventilation is necessary to avoid risk of explosion !
Figure 5.3 Typical charging characteristic of a 12 V lead–acid battery.

Figure 5.4 Typical discharge characteristics of a 12 V lead–acid battery.
Note: Occasional, controlled overcharging is helpful
→ Gassing stirs up the electrolyte to prevent stratification into different levels of acid concentration
→ Called "equalization charging"
→ Too much overcharging can cause damage to the plates
b. Sealed Battery Type
→ Never overcharged
c. Charging Scheme
→ Keeps battery in top condition
① "Initial Boost Charge" → Uses all available current
   → Done to close to 100% SOCl
   * "SOC" → State Of Charge
② "Absorption Charge" → At constant voltage and low current
③ "Float Charge" → To keep the battery gently topped off
5. Discharging Pb-acid Batteries
→ Show Fig 5.4 × → For a typical 12V 200Ah battery
→ When $V_{Bat} \approx 11V$ → Must disconnect load to avoid damaging the battery
→ Notice that drawing current at the 2A for 100hr rate results in $V_{Bat}$ staying higher longer that at the 20A for 10hr rate
→ "Sulphation" → Formation of large lead sulphate crystals on the plates. Leads to damage and capacity loss. A danger if
the battery is left at low SOC for long periods of time.

6. PV Usage

- Summer → batteries more likely to be at high SOC most of the time
- Winter/cloudy periods → batteries more likely to have periods of low SOC