1. Negative plate reaction: $Pb(s) + HSO_4^-(aq) \rightarrow PbSO_4(s) + H^+(aq) + 2e^-$

Positive plate reaction:

$$PbO_2(s) + HSO_4(aq) + 3H^+(aq) + 2e^- \rightarrow PbSO_4(s) + 2H_2O(l)$$

→ 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

<u>When Charging</u>

Negative plate becomes Pb

<u>reaction</u>: $PbSO_4(s) + H^+(aq) + 2e^- \Rightarrow Pb(s) + HSO_4^-(aq)$

Positive plate becomes PbO_2

<u>reaction</u>: $PbSO_4(s) + 2H_2O(l) \rightarrow PbO_2(s) + HSO_4^-(aq) + 3H^+(aq) + 2e^-$

Electrolyte becomes ~ 35% sulphuric acid (H_2SO_4)

→ 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

<u>note</u>: $O_2(g) + H_2(g) + \text{energy} \rightarrow$ "boom" ⇒ potentially dangerous

2. Lead-Acid Battery Structures

1) Flooded or Wet → liquid electrolyte solution must be regularly topped off with distilled water
   → H_2 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)
   → $O_2(g)$ and $H_2(g)$ recombine → H_2O
   ∴ 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 = $200 \times 12 = 2.4$ kWh

<u>Note</u>: 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. <u>Charging Pb-acid batteries</u>

→ <u>show Fig 5.3</u> *

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

~ Fully Discharged : $V_{bat} \sim 12V$

Fully charged : $V_{bat} > 14V$

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

a. <u>Flooded Battery Type</u>

→ 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!

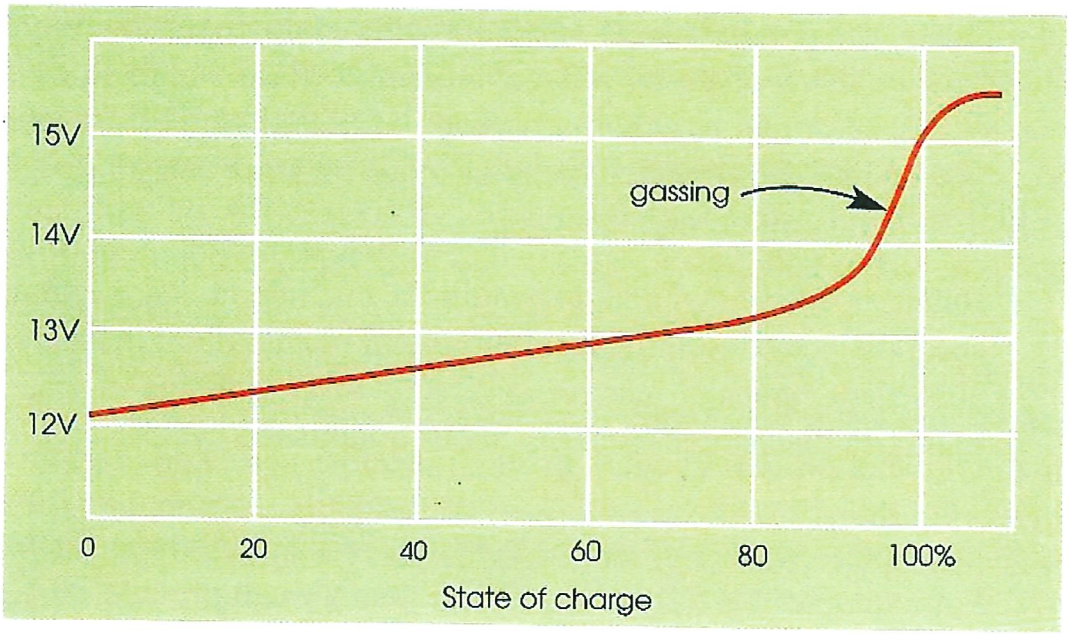

Figure 5.3 Typical charging characteristic of a 12 V lead–acid battery.

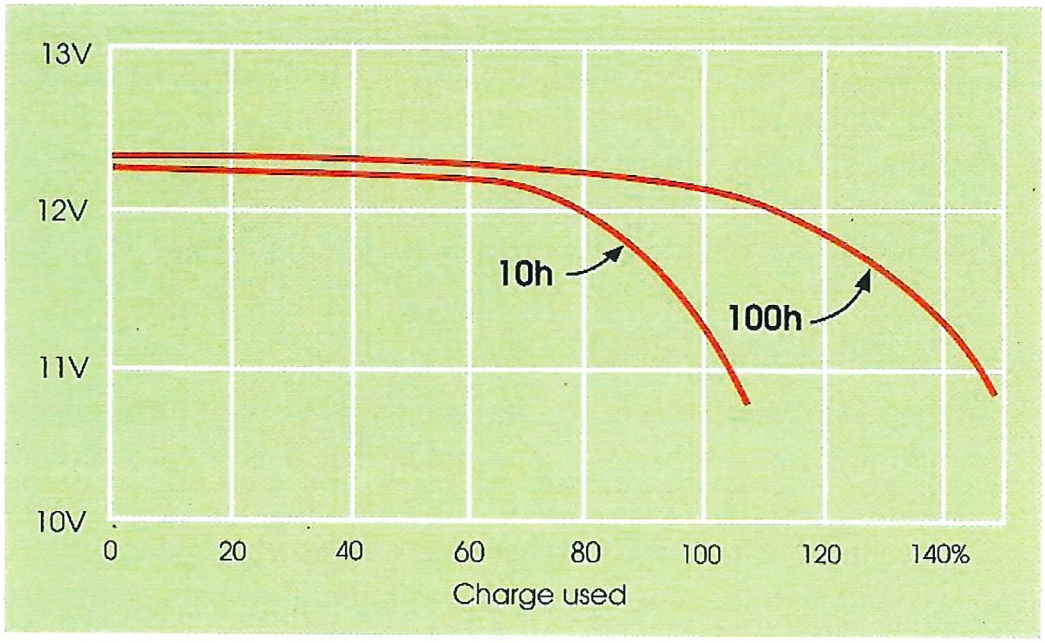

Figure 5.4 Typical discharge characteristics of a 12 V lead–acid battery.

<u>Note</u> : 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 <u>can</u> cause damage to the plates

b. <u>Sealed Battery Type</u>

→ never overcharged

c. <u>Charging Scheme</u>

→ keeps battery in top condition

① "Initial Boost Charge" → uses all available current

→ done to close too 100% SOC

* "SOC" → State Of Charge

② "Absorption Charge" → at constant voltage and low current

③ "Float Charge" → to keep the battery gently topped off

5. <u>Discharging Pb-acid Batteries</u>

→ <u>Show Fig 5.4</u> * → For a typical 12V 200Ah battery

→ when $V_{bat} \sim 11V$ → 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. <u>PV Usage</u>

→ 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