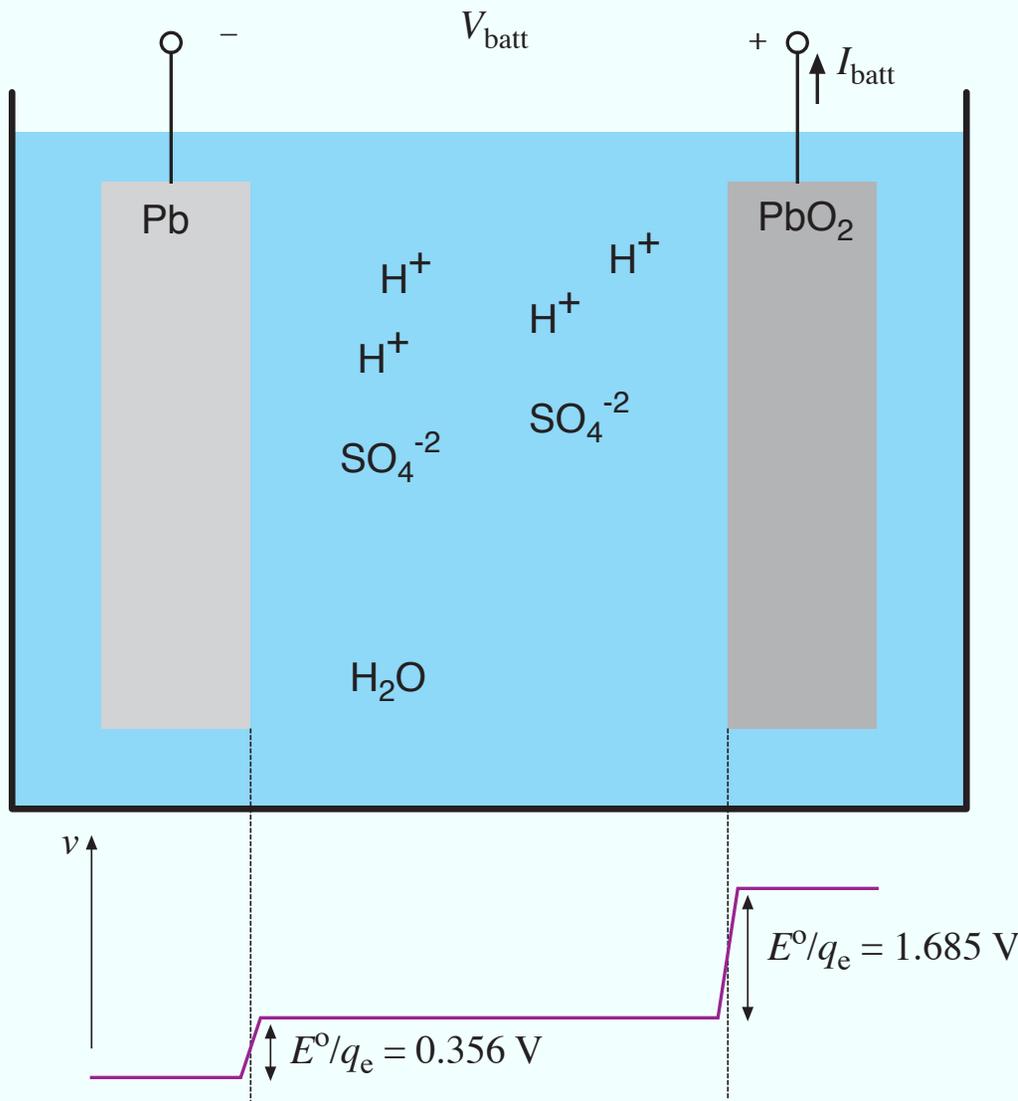


Lead-Acid Batteries: Characteristics



ECEN 2060

Battery voltage at zero current



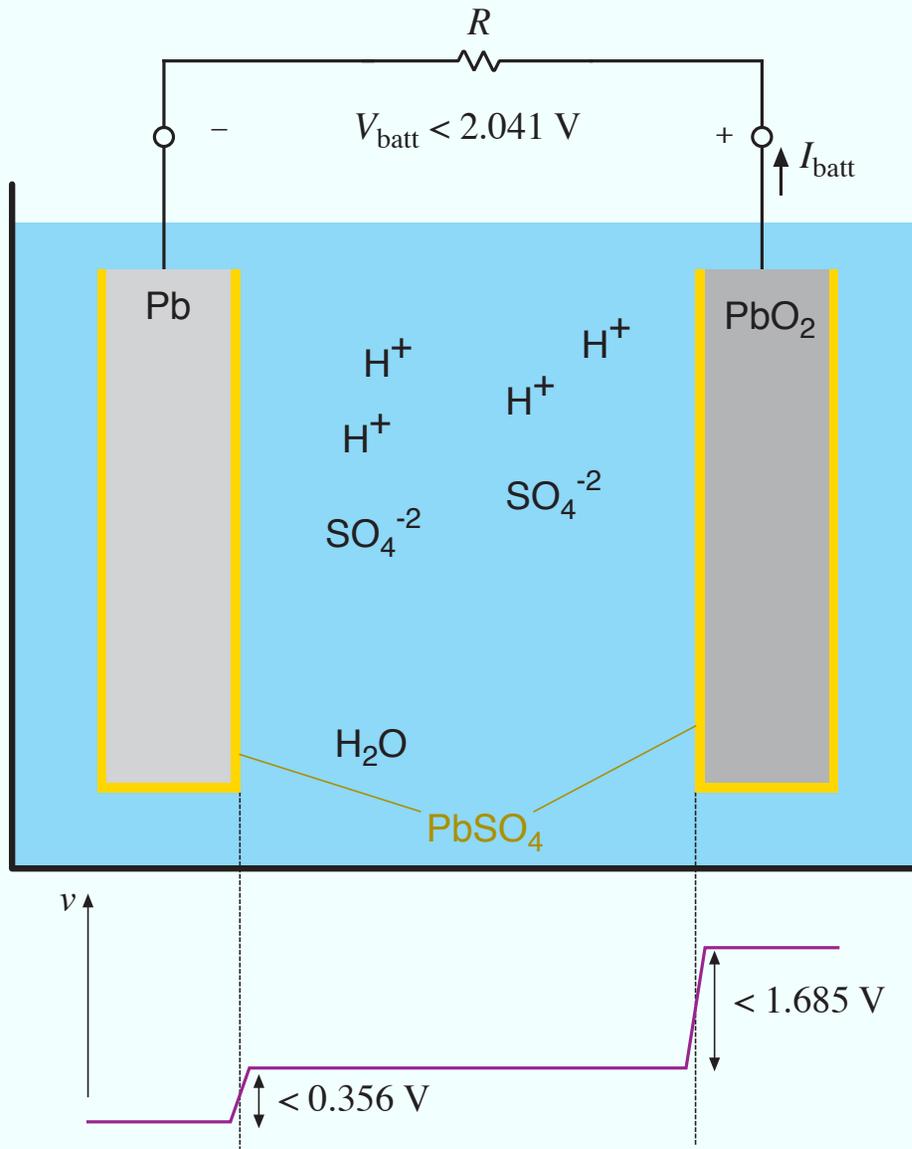
The chemical reactions at the electrode surfaces introduce electrons into the Pb electrode, and create a deficit of electrons in the PbO₂ electrode

These charges change the voltages of the electrodes

The system reaches equilibrium when the energy required to deposit or remove an electron equals the energy generated by the reaction

Total voltage (at $T = 298^\circ \text{K}$ and 1 molar acid electrolyte) is $V_{\text{batt}} = 0.356 + 1.685 = 2.041 \text{ V}$

Discharging



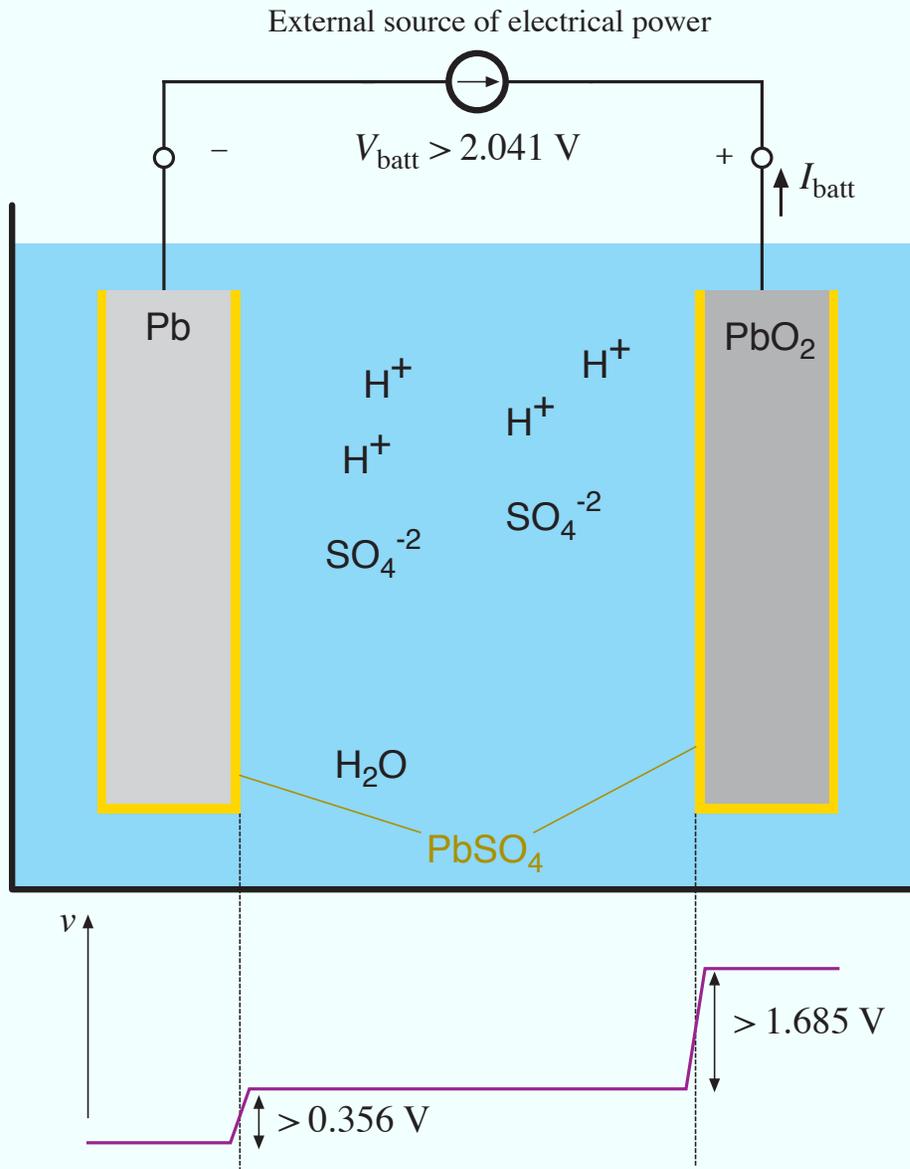
Connection of an electrical load allows electrons to flow from negative to positive terminals

This reduces the charge and the voltages at the electrodes

The chemical reactions are able to proceed, generating new electrons and generating the power that is converted to electrical form to drive the external electrical load

As the battery is discharged, the electrodes become coated with lead sulfate and the acid electrolyte becomes weaker

Charging



Connection of an electrical power source forces electrons to flow from positive to negative terminals

This increases the charge and the voltages at the electrodes

The chemical reactions are driven in the reverse direction, converting electrical energy into stored chemical energy

As the battery is charged, the lead sulfate coating on the electrodes is removed, and the acid electrolyte becomes stronger

Battery state of charge (SOC)

	<u>Fully Charged</u>	<u>Completely Discharged</u>
State of charge:	100%	0%
Depth of discharge:	0%	100%
Electrolyte concentration:	~6 molar	~2 molar
Electrolyte specific gravity:	~1.3	~1.1
No-load voltage:	12.7 V	11.7 V

(specific battery types may vary)

Battery voltage vs. electrolyte concentration

The *Nernst* equation relates the chemical reaction energy to electrolyte energy:

$$E/q = E^0/q + (kT/q) \ln [(electrolyte\ concentration)/(1\ molar)]$$

(idealized)

with

E = energy at a given concentration

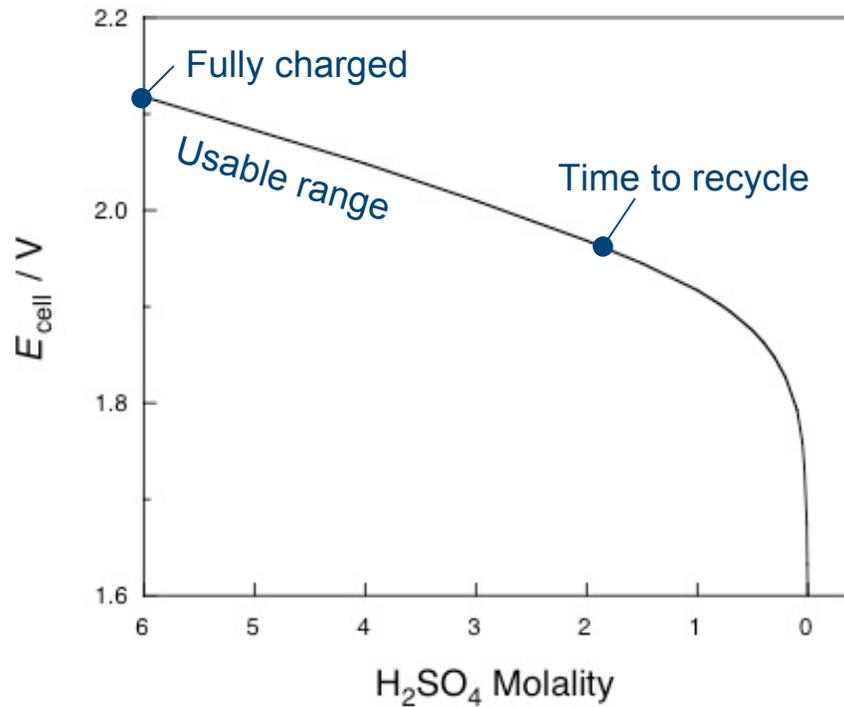
E^0 = energy at standard 1 molar concentration

$kT/q = 26\ mV$ at $298\ ^\circ\ K$

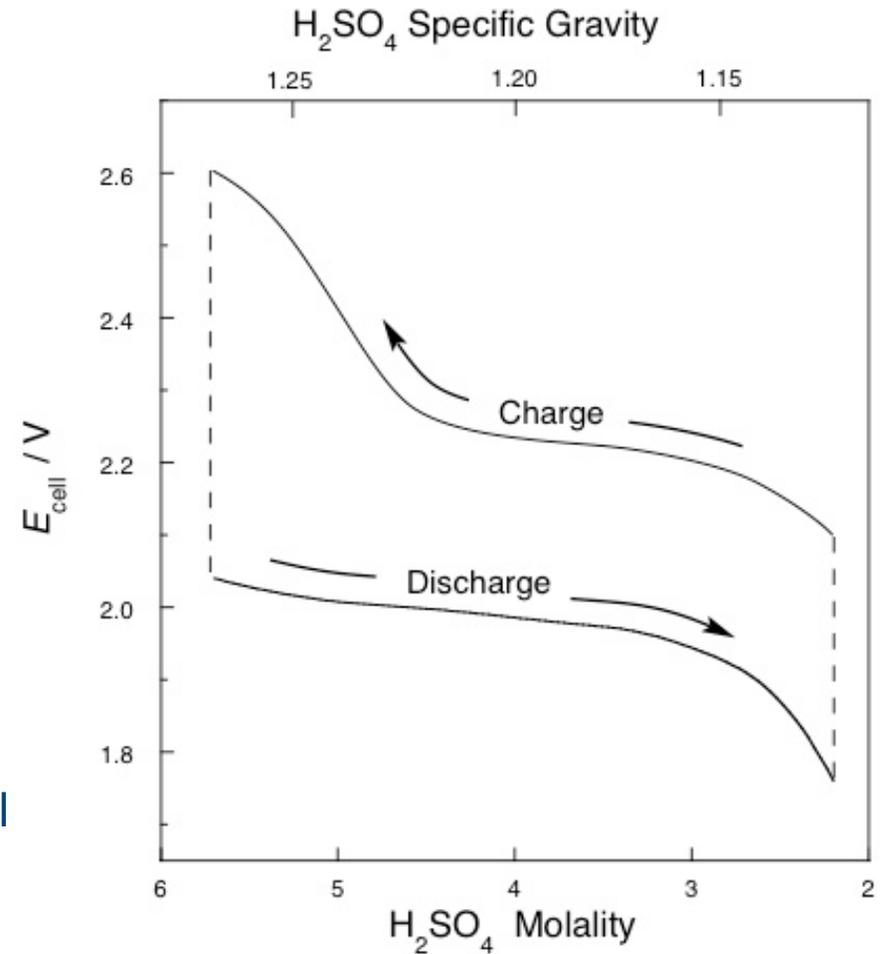
Implications:

- At fully charged state (6 molar), the cell voltage is a little higher than E^0/q
- As the cell is discharged, the voltage decreases

Voltage vs. electrolyte concentration



Voltage of lead-acid electrochemical cell vs. electrolyte concentration, as predicted by Nernst equation



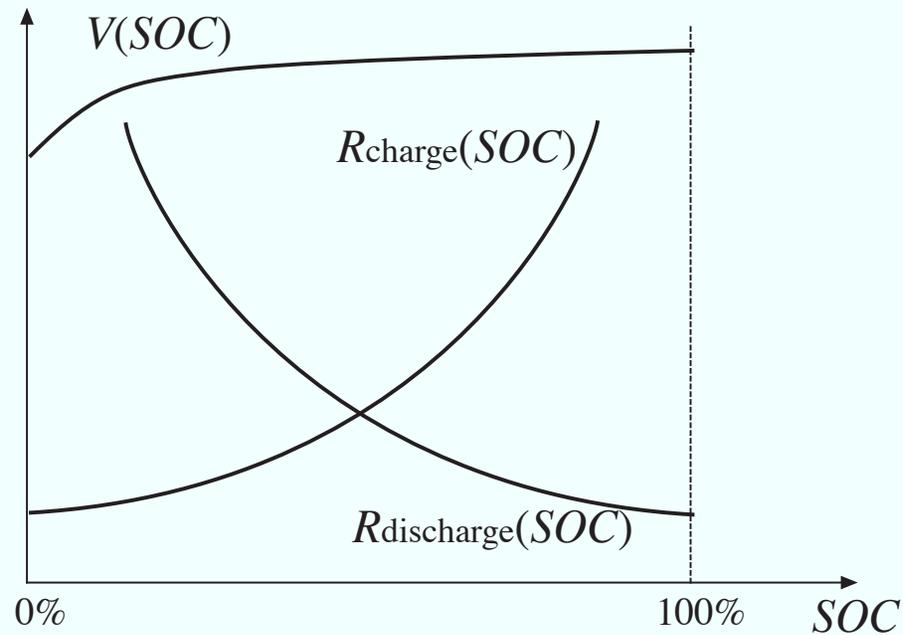
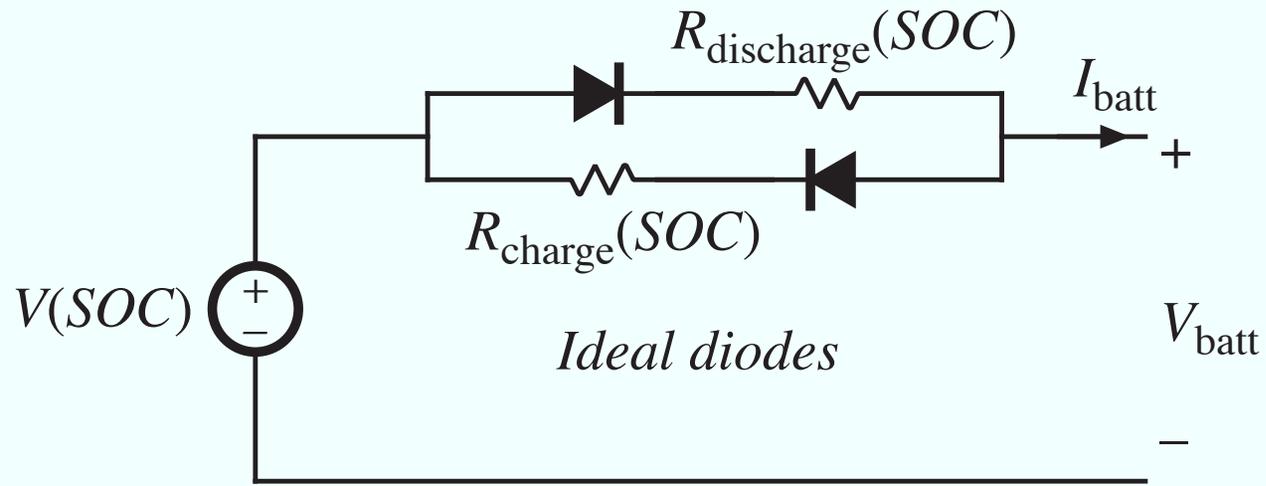
R. S. Treptow, "The lead-acid battery: its voltage in theory and practice," *J. Chem. Educ.*, vol. 79 no. 3, Mar. 2002

Mechanisms that affect terminal voltage

1. Equilibrium voltage changes with electrolyte voltage (as described above – Nernst equation)
2. With current flow, there are resistive drops in electrodes, especially in surface lead-sulfate
3. With current flow, there is an electrolyte concentration gradient near the electrodes. Hence lower concentration at electrode surface; Nernst equation then predicts lower voltage
4. Additional surface chemistry issues: activation energies of surface chemistry, energy needed for movement of reacting species through electrodes
5. Physical resistance to movement of ions through electrodes

(2) - (5) can be modeled electrically as resistances

A basic battery model



Types of lead-acid batteries

1. Car battery

- “SLI” - starter lighting ignition
- Designed to provide short burst of high current
Maybe 500 A to crank engine
- Cannot handle “deep discharge” applications
Textbook quotes lifetime of 500 cycles at 20% depth of discharge

2. Deep discharge battery

- We have these in power lab carts
- More rugged construction
 - Bigger, thicker electrodes
 - Calcium (and others) alloy: stronger plates while maintaining low leakage current
 - More space below electrodes for accumulation of debris before plates are shorted
- Ours are
 - Sealed, valve regulated, absorbent glass mat
 - Rated 56 A-hr at 2.33A (24 hr) discharge rate

Types of lead-acid batteries

3. “Golf cart” or “forklift” batteries

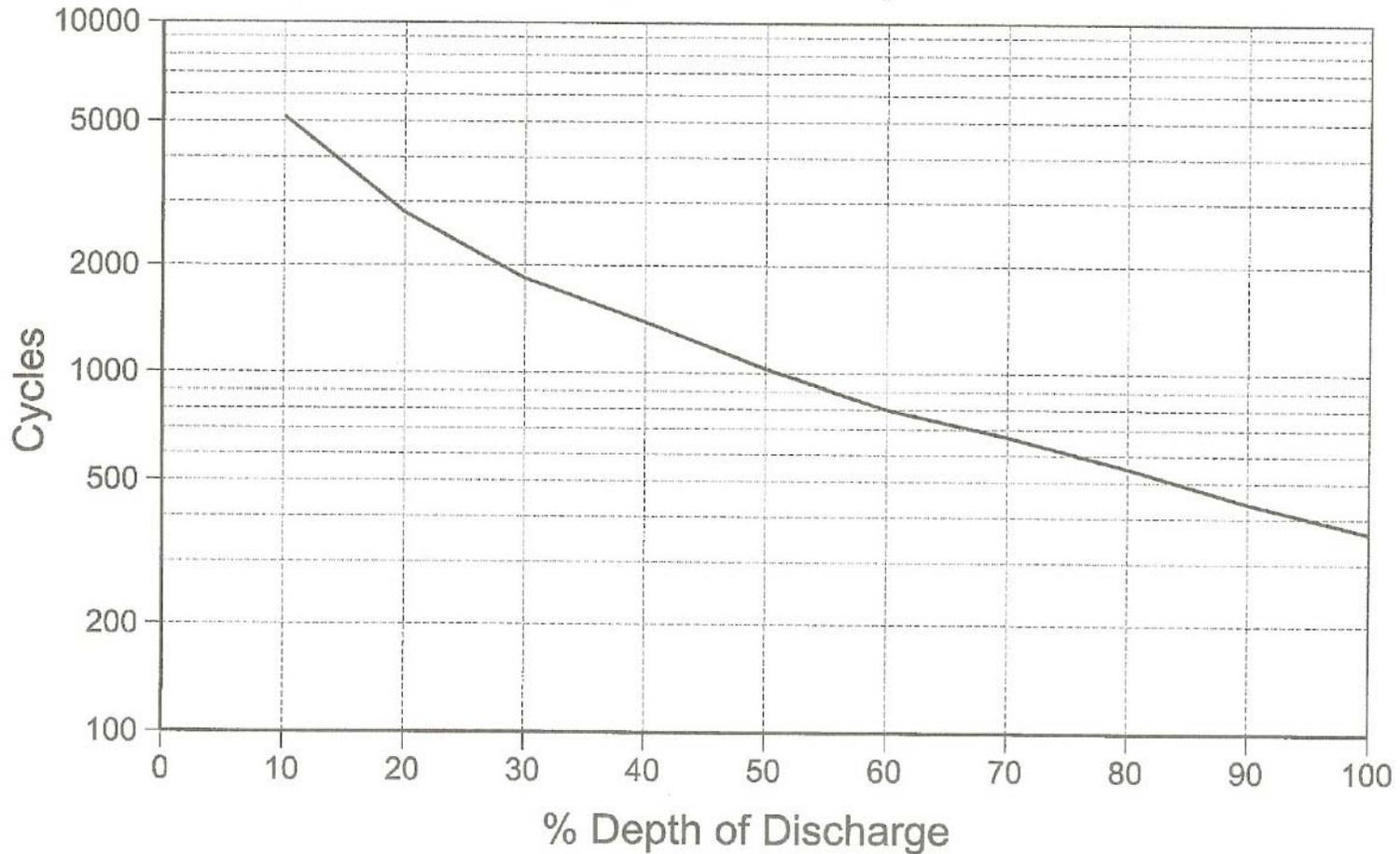
- Similar to #2
- Bigger, very rugged
- Low cost — established industry
- Antimony alloy
 - Strong big electrodes
 - But more leakage current than #2
- Can last 10-20 years

Manufacturer’s specifications for our power lab batteries:

Nominal capacity: A-hrs @ 25°C to 1.75 V/cell				
1 hr	2 hr	4 hr	8 hr	24 hr
36 A-hr	45 A-hr	46 A-hr	49 A-hr	56 A-hr

Battery life

Concorde AGM Battery
Expected Life Cycles



Test Conditions:

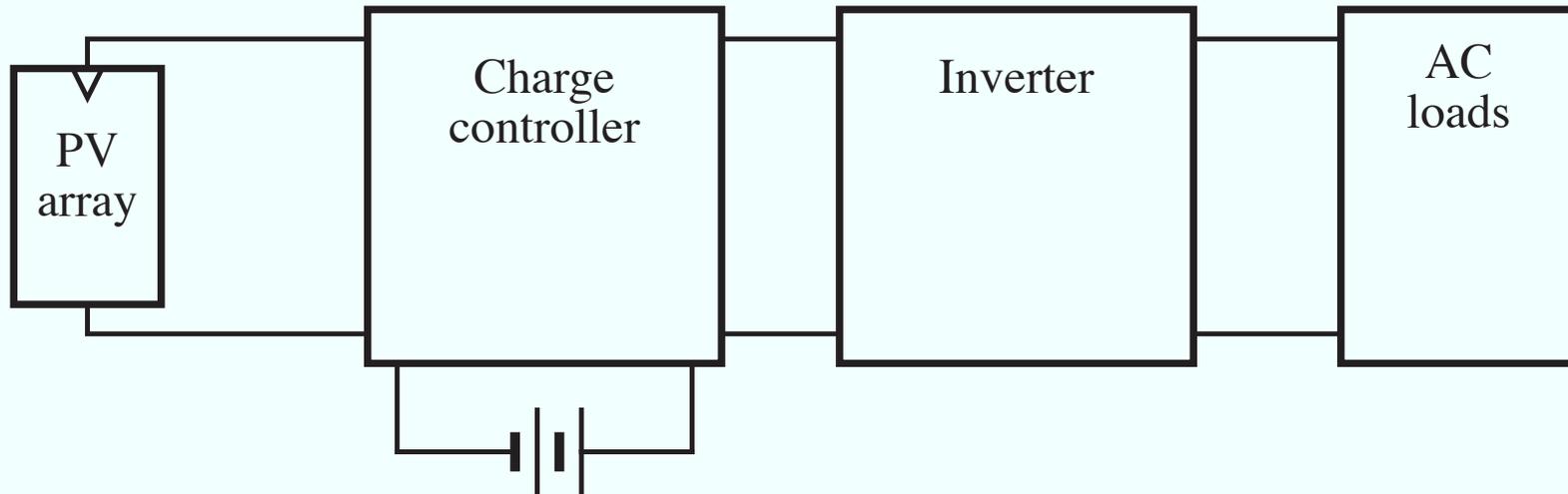
1. Discharge Voltage=1.75 Volts/Cell 2. Charge Voltage=2.40 Volts/Cell 3. DOD=100 % 4. Battery Temperature=25°C 5. End of Life=80 % of Capacity

3306 Concorde Battery Corporation, 2009 San Bernardino Rd, West Covina, CA, 91790 www.concordebattery.com Phone: 626-813-1234

Charge management

- Over-discharge leads to “sulfation” and the battery is ruined. The reaction becomes irreversible when the size of the lead-sulfate formations become too large
- Overcharging causes other undesirable reactions to occur
 - Electrolysis of water and generation of hydrogen gas
 - Electrolysis of other compounds in electrodes and electrolyte, which can generate poisonous gasses
 - Bulging and deformation of cases of sealed batteries
- Battery charge management to extend life of battery:
 - Limit depth of discharge
 - When charged but not used, employ “float” mode to prevent leakage currents from discharging battery
 - Pulsing to break up chunks of lead sulfate
 - Trickle charging to equalize charges of series-connected cells

Battery charge controller



- Prevent sulfation of battery
 - Low SOC disconnect
 - Float mode
- Control charge profile
 - Multi-mode charging, set points
- Nighttime disconnect of PV panel

Direct energy transfer

Charge battery by direct connection to PV array

MPPT

Connect dc-dc converter between PV array and battery; control this converter with a maximum power point tracker