Care & Feeding of Rechargeable Batteries

Lead Acid / Sealed Lead Acid / AGM

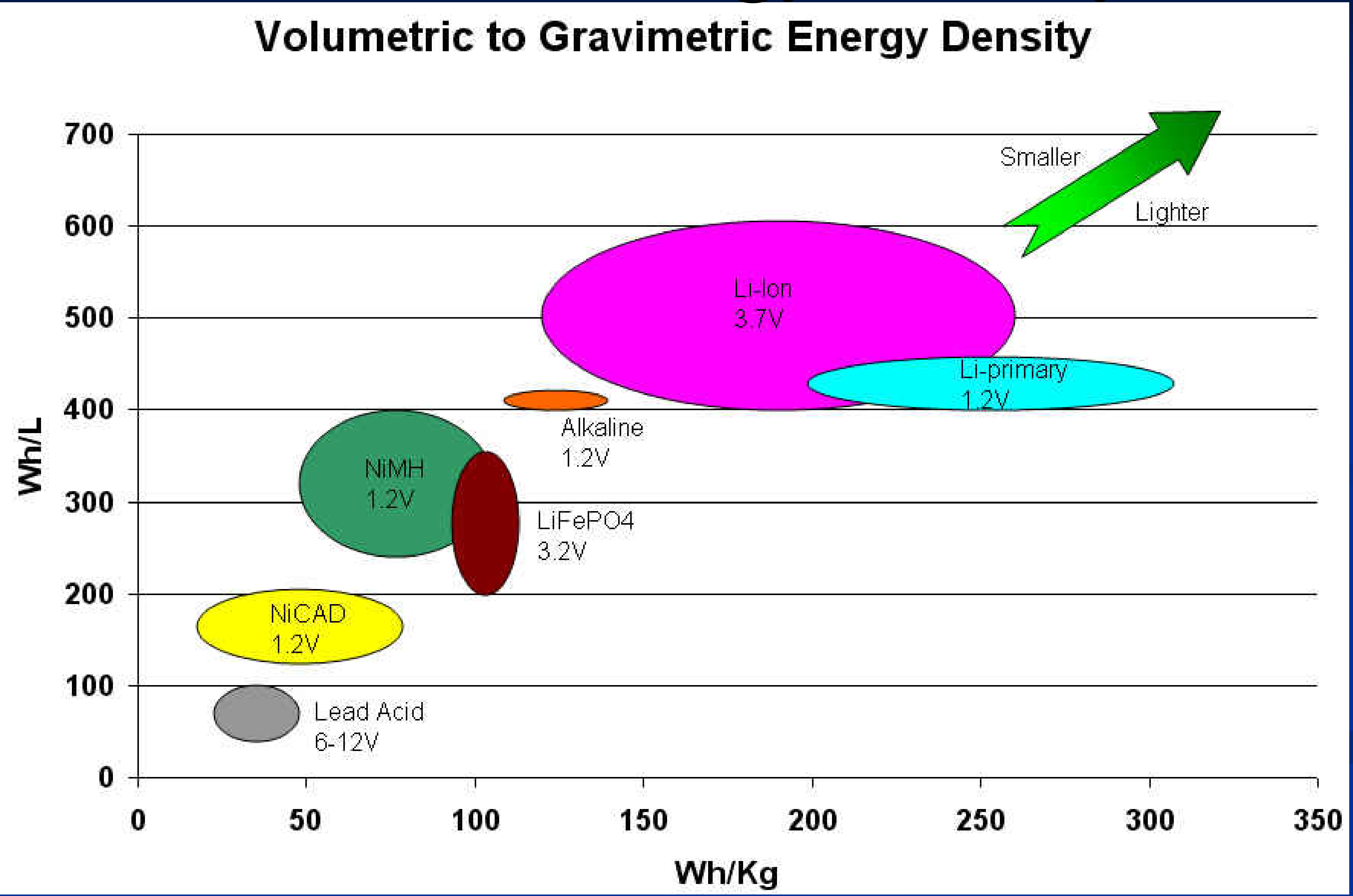
Nickel Cadmium & Nickel Metal Hydride

Lithium Ion

- Capacity & Energy Density
- Charge Characteristics
- Discharge Characteristics incl. Self-Discharge
- Cycle Life
- Safety Considerations

Jim Krause AB4CZ

Relative Energy Density



Cell Characteristics Summary

Battery System	Negative Electrode	Positive Electrode	Electrolyte	Nominal Voltage (V)	Theoretical Specific Energy (Wh/kg)	Practical Specific Energy (Wh/kg)	Practical Energy Density (Wh/L)	Major Issues
Lead-Acid	Pb	PbO_2	H_2SO_4	2	252	35	70	Heavy, Low Cycle Life, Toxic Materials
Nickel Cadmium	Cd	NiOOH	KOH	1.2	244	50	75	Toxic materials, maintenance, cost
Nickel Metal Hydride	H (as MH)	NiOOH	KOH	1.2	278 – 800 (depends on MH)	70	170	Cost
Lithium Ion	Li	Li_xCoO_2	PC or DMC w/ $LiPF_6$	4	766	120	200	Safety Issues, Calendar Life, Cost

Lead-Acid & SLA & AGM

- ~2V / Cell (float at 2.35 – 2.45 V/cell)
- Low cost batteries
- Flooded cells offer high peak current
- Relatively low self-discharge ~ 3% / month
- Fairly tolerant of abuse, easy to charge
- Long life if kept charged
- Variations in charge details, voltage, discharge capabilities of flooded, SLA (VRLA), and AGM
- AGM is best … ~10% self-discharge / year
- Generally, lowest cycle-life count, ~100 full cycles

Lead Acid & SLA

- Charge:
  - Constant Current / Constant Voltage (CCCV)
  - Charge rate should be limited to ~C/5 or lower
    - Car alternators charge deep-discharged batteries too fast
  - Bulk charge occurs during constant current portion
    - Current is selected to match battery characteristics
    - Refer to the data sheet for your battery, or a similar type
  - Voltage is not the same for liquid vs. SLA
    - Voltage mismatch of 5% may HALVE battery life!!!
    - Refer to data sheet for your battery for correct value
  - Trickle charge should be < C/500, i.e. 2mA/Ah
    - Excessive trickle rate > electrolysis, dries out cells

Consult data sheet for your batteries!!

- SLA, Gel Cell, Wet Electrolyte, and AGM all have slightly different charge requirements
- 5% error in float can halve the battery life
- Use Google to find data on your battery, adjust charge characteristics to match your battery
- Example data sheets:
  - Lifeline AGM Batteries Charging Procedure.htm
  - Yuasa Tech Manual.pdf

My Favorite Lead-Acid Charger

- An excellent charge controller is the UC3906
  - 3-State Charge algorithm optimizes charge
    - Constant Current Bulk Charge for rapid recovery
    - Controlled Over-Charge to top off, allows 100% charge
    - Precision trickle charge to maintain battery w/o overcharge
  - Precision voltage reference +/- 1%
  - Temperature compensated to charge at any temp
  - All charge parameters set by 4 resistors & transformer size
  - Optimized for your battery with parts selections
  - Circuit in ARRL Handbook, boards by FAR Circuits
  - Mouser has UC3906s for $5.50
  - QST Advertiser A&A Engineering has kits and info
    - http://www.a-aengineering.com/

UC3906 Charger Circuit

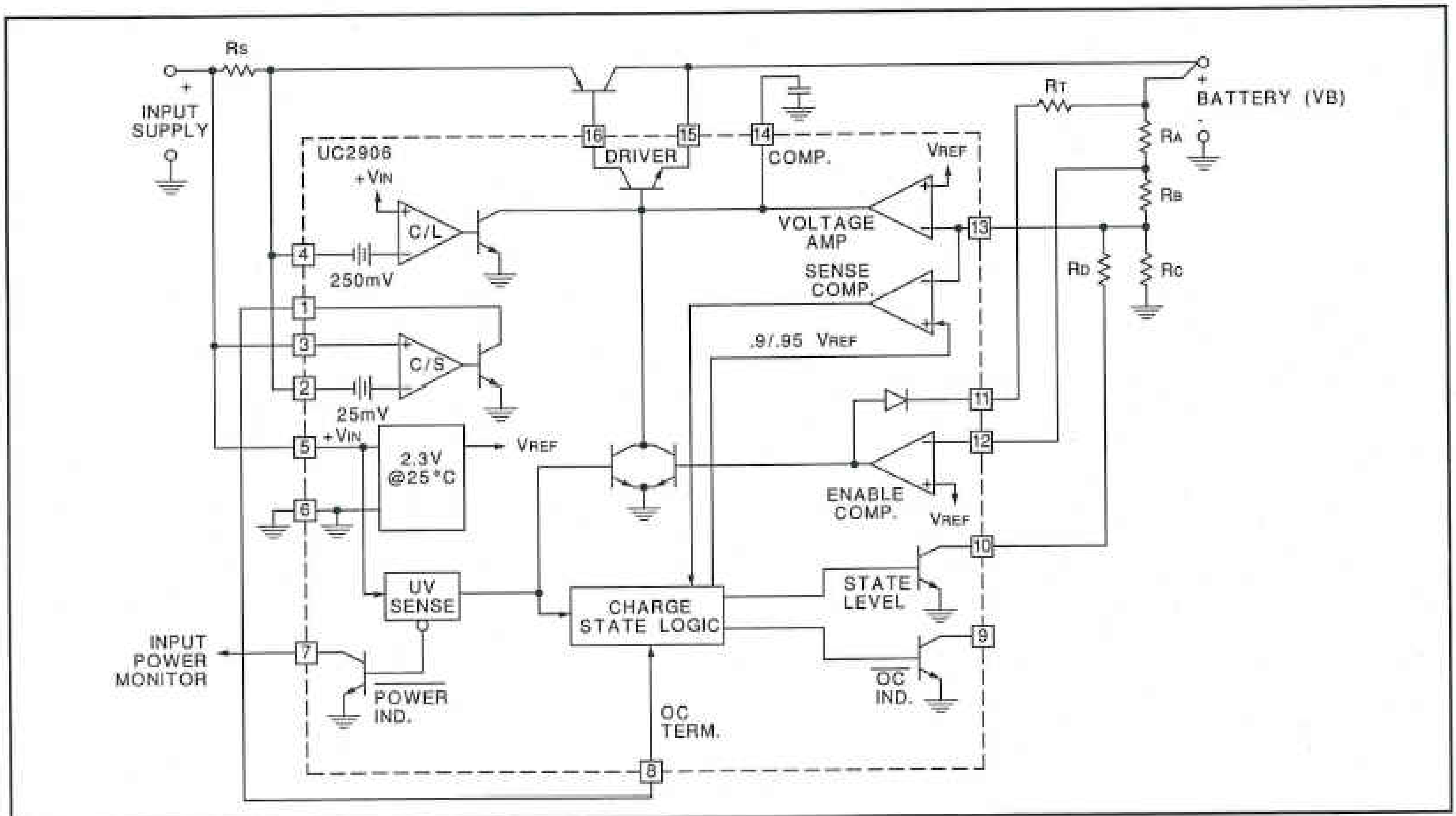


Figure 1. The UC2906 in a dual level float charger.

Jim Krause AB4CZ

Lead Acid Comparisons

- Flooded Lead Acid (liquid electrolyte)
  - Messy, outgas and mist acid, may damage near stuff
  - Most susceptible to vibration, impact, etc
  - Lowest cost per capacity
  - Highest self-discharge of lead acid batteries
  - 80% charge efficiency, i.e 126% charge returned to replace used energy
- SLA or “Gel Cell”
  - Electrolyte gelled with silica, doesn’t spill or leak
  - More robust against damage than liquid electrolyte
  - Most susceptible to over-charge damage
  - 86% charge efficiency, i.e. 116% charge returned to replace used energy
- AGM   Absorbed Glass Mat
  - Fiberglass mat damp with acid electrolyte, can’t spill or leak
  - Most durable against physical damage, vibration, over-charge & discharge, etc.
  - Lowest self-discharge of lead acid batteries
  - Lowest internal impedance
  - Longest cycle life
  - 98% charge efficiency, i.e. 102% charge returned to replace used energy, similar to Li-Ion
  - High charge efficiency means less heat, allows faster recharge rates

Lead Acid & SLA

- Care & Handling
  - DO NOT COMPLETELY DISCHARGE
  - Limit discharge to ~10.5V or higher, recharge soon
  - Store fully charged, top-off monthly
  - If open-circuit voltage drops below 12V, sulfation occurs.
  - Sulfation can be partially reversed with a pulse-type reconditioner. Reconditioning chargers are recommended based on personal experience

Lead Acid State of Charge

- Can approximate SOC (state of charge) by measuring Open-Circuit Voltage at room temp
- Battery must sit idle overnight before measuring
- Battery will sulfate if stored at < 12V

Battery Voltage Reading Using a Voltmeter

State of Charge	Sealed VRLA	CX & YuMicron	Conventional
100%	13.0v	12.7v	12.6v
75%	12.8v	12.5v	12.4v
50%	12.5v	12.2v	12.1v
25%	12.2v	12.0v	11.9v
0%	12.0v or less	11.9v or less	11.8v or less

Deep Cycle vs Starter Batteries

- Deep-Discharge batteries designed for lower peak current but deeper discharge cycles
  - Fewer thick plates give lower peak current but are more durable against erosion due to deep discharge
  - Typically more space for residue at bottom
- Starter batteries designed for high peak current
  - More thin plates give large surface area, high peak current, but more susceptible to damage from over-discharge

Nickel Cadmium

- NiCd –
  - ~1.25 V/Cell
  - Low cost
  - medium capacity
  - Available in packages similar to alkaline cells
  - not environmentally friendly – Cadmium is toxic
  - Good High-Current capability
  - High Self-Discharge (Don't hold charge well)
  - Abuse tolerant, easy to charge
  - Becoming obsolete due to environmental issues and improved capacity of NiMH.
  - Very high cycle life … on order of 1000 cycles

Nickel Metal Hydride

- NiMH –
  - ~1.25V / Cell
  - Higher capacity than NiCd
  - Higher Self-Discharge than NiCd, 30 – 50% per month!*
  - Environmentally friendly – Non toxic metals
  - Available in similar packages to NiCd
  - Good high current capability, but < NiCd
  - Easily damaged by improper charging
  - Replacing NiCd in many applications due to improved capacity as well as environmental considerations.
  - DON'T BUY HIGHEST CAPACITY CELLS! –
    - Less cycle life
    - Increased self-discharge

Judging SOC of Nickel

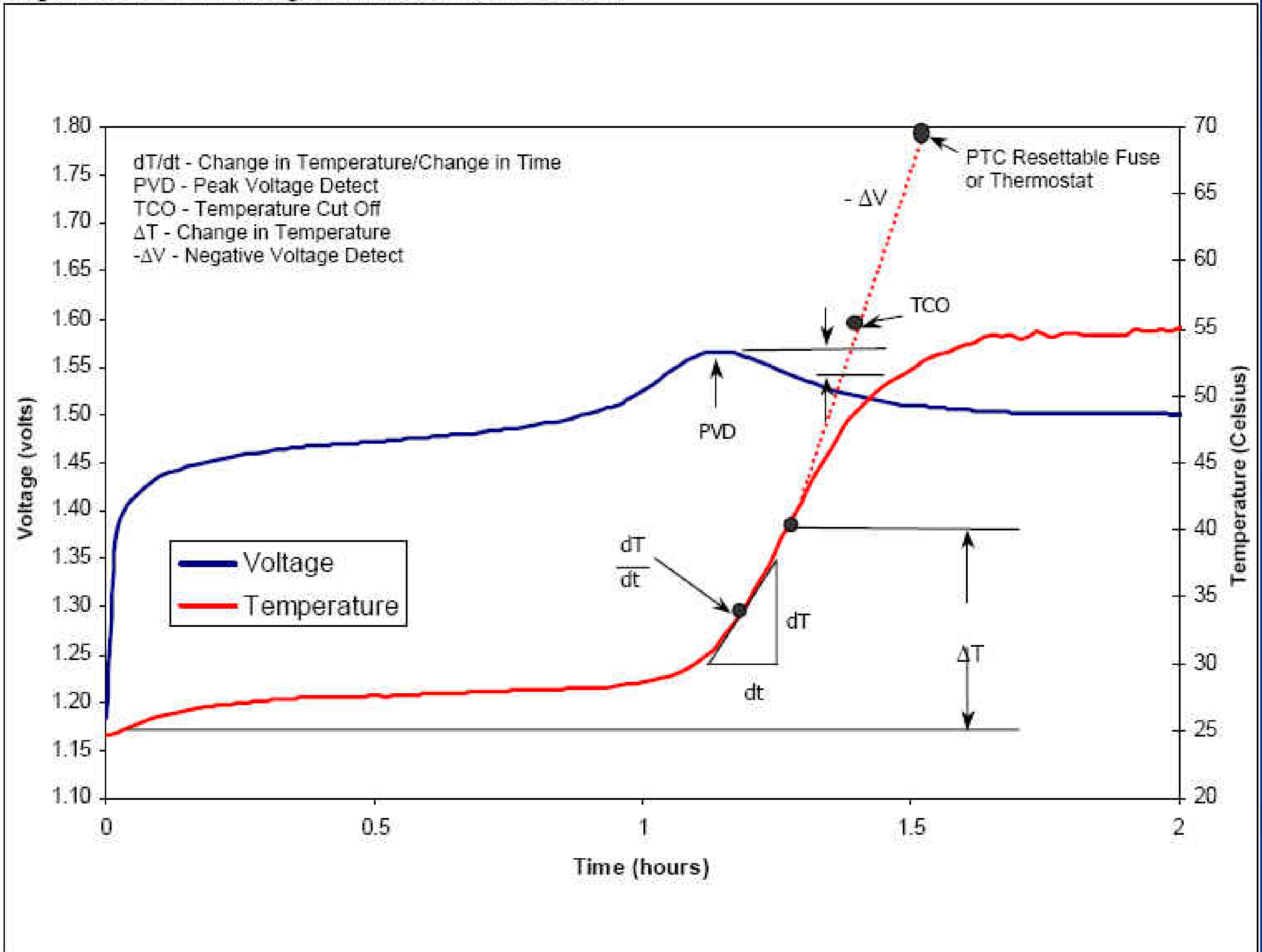
- Can't tell state of charge accurately by voltage
- Very flat discharge curve
  - Results in stable voltage during discharge
  - But, dies very rapidly at the end … No warning!
  - About the only way to know SOC is with "Coulomb Counting" fuel gauge

Charging NiCd & NiMH

- CHARGING
  - Both NiCd and NiMH like constant current charging
  - Cannot terminate by Voltage
  - Terminate by
    - ΔT or $\Delta T/t$ (rate of change of temp rise) (Best)
    - $-\Delta V$ OK with NiCd, not as reliable with NiMH
  - Nickel batteries are about 71% efficient, i.e. replace 140% of energy used
  - DO NOT TREAT NiMh THE SAME AS NiCd!!
    - Do NOT trickle charge NiMH at over C/50
    - Do NOT use "Overnight" chargers (Typically C/10)
    - Use ONLY chargers intended for NiMH
    - BEST to terminate charge by temperature ($\Delta T/t$ or Max T)
    - If NiMH gets over ~55°C, it will be damaged
    - In general, you cannot "drop in" NiMH for NiCD and expect success
  - Store at any state of charge … doesn't seem to matter much, but charge at least once or twice a year

NiMh Charge Termination

Figure 3.8.3 NiMH Charge Termination Nomenclature



NiMh Charge Techniques

Figure 3.8.5 Charge Method Specifications

Charge Method	Charge Current	Charge Termination	Comments
Slow	0.02-0.1C	1. None[1] or Timer	Timer rated at 160%C.
Standard	0.1C	1. Timer	Timer set for 16 hours.
Time	0.1-0.2C	1. Timer, and 2. TCO = 55°C	Timer rated at 160%C @ 0.1C to 120%C @ 0.2C.
Rapid[2]	0.25-0.5C	1. PVD, or dT/dt, or ΔT, and 2. Timer, and 3. TCO = 55°C	PVD = -ΔV of 3-5 mV/cell dT/dt = ~1°C/1 min rise. Timer rated at 140%C @ 0.2C to 120%C @ 0.5C.
Fast[2]	0.5-1.0C	1. PVD, or dT/dt, or ΔT, and 2. Timer, and 3. TCO = 55°C	PVD = -ΔV of 3-5 mV/cell dT/dt = ~1°C/1 min rise. Timer rated at 125%C.
Maintenance	0.002-0.008C	1. None	5-10%C per day at C/128 to C/512 pulse recommended.

[1] Not all batteries can be charged without a termination.
[2] See Rapid/Fast Charging Procedure (Section 3.8.6).

Best Charger for Nickel?

- My Personal Favorite:
  - Maha MH-C9000
    - Charges
    - Discharges
    - Cycles
    - Measures Capacity
    - Not cheap, but you'll love it!   ~$50 - $70
  - Other MAHA chargers also OK, be sure rated for NiMH.
  - MAHA & Powerex are same company

Throw Away your Old NiMH Cells

- ENELOOP (Remember that brand name)
- New NiMH technology from Sanyo / GE offers NiMH cells with dramatically reduced self-discharge
  - 80 – 90% capacity after storage for a year!
  - You can charge them, put them in your HT, and expect your HT to work next month when you need it!
  - TANSTAAFL – Lower capacity than conventional NiMH
  - Not suitable for very high current applications (power tools)
- Also Radio Shack "Pre-Charged" NiMH (May be Sanyo)
- Recently saw ad for Ray-O-Vac pre-charged NiMH
- Key word is "Pre-Charged" … This implies Eneloop type technology

Lithium-Ion

- Highest capacity per volume
- Highest capacity per unit weight
- Lowest self-discharge (~10% - 20% / year)
- High cycle life, ~500 full cycles retaining 80% capacity
- Least tolerant of abuse
- ~3.7V / cell nominal
- Available in Cylindrical and Prismatic packages
- Steel can cells have positive button
- Aluminum can cells have negative button
- Cylindrical cells have CID (Current Interrupt Device) and Polyswitch built in
- Require safety circuit

Li-Ion Charging

- CCCV Charging
  - 4.20V ±1%, current limited to 1C or less
  - Terminate charging by “taper current” <20mA/Ah
    - i.e. for a 1Ah cell, when charged at precisely 4.20V, terminate charging when the current drops to 20mA
  - Approximately 3 Hours to full charge
  - BE AWARE Voltage is very critical. Over voltage can cause cells to “vent with flame”, possibly resulting in injury or fire
  - This is very real … I’ve seen it many times!

Li-Ion Safety Circuits

- ALL commercial Li-Ion batteries include a safety circuit
  - Over-Charge cut-off at ~4.35V (lower on recent)
  - Over-Discharge cut-off at ~2.25V
  - Discharge and Charge current limiting
- Cylindrical cells all have a "CID" Current Interrupt Device that disconnects the cell if pressure builds
- Many cylindrical cells have built-in polyswitch
- Always use a safety circuit with Li-Ion
- If you buy surplus batteries, don't remove the circuit.

Li-Ion Discharge

- Full charge is 4.20 Volts
- Fully discharged at 3.0 Volts
- 3-cells gives a 12.6 – 9.0 Volt discharge cycle
- 4-cells gives a 16.8 – 12 Volt discharge cycle

- Store Li-Ion at ~ 50% charge for best life

Wrap-up

- Lead-Acid
  - + Low Cost, readily available, often surplus or pulls
  - + Often in 12V batteries, useful as-is
  - + Easy to charge, fairly forgiving of abuse
  - + Long life, especially if properly cared for
  - + Relatively low self-discharge, good for standby
  - - Heavy and large for capacity
  - - Lead and sulphuric acid are toxic, corrosive
  - - Will sulphate and die if left uncharged

- NiCD:
  - + In place in many devices; replacement use
  - + Fairly tolerant of abusive charge & discharge
  - + Available in standard alkaline sizes (AA, etc.)
  - + Good low temperature performance
  - + FAST CHARGE capability, fastest of any cell
  - - Cadmium is toxic, banned in Europe
  - - High self-discharge, poor choice for standby

- NiMH
  - + Similar to NiCd, often can drop-in physically
    - (BUT be aware of charging differences)
  - + Higher capacity than NiCd or Lead-Acid
  - + Good low-temperature performance
  - + Non-toxic metals, environmentally friendly
  - - Easily ruined by improper charging
  - - High self-discharge with “normal” cells
  - - Worst choice for occasional use standby devices
  - + BUT new “Eneloop” type cells have good self-discharge, thus may be very good for standby. Time will tell how these new cells hold up

- Li-Ion
  - +Highest capacity per unit weight
  - +Highest capacity per unit volume
  - +Very low self-discharge, good for standby
  - +99% efficient charge/discharge cycles
  - + Non-toxic metals, environmentally friendly
  - - Very sensitive to over-charge and physical damage
  - - Damaged by deep discharge (below 1V)
  - - Require ancillary “safety circuit” to protect cells
  - - Fire or explosion hazard if abused

Q&A

- Q: How should you store NiCd or NiMH battery pack for extended periods of time?
- A: Charge them and freeze them. I've read self-discharge can be reduced to !10%/year if frozen. The batteries must be allowed to reach normal temperature before use.

- Q: How often do you charge/discharge infrequently used NiCd, NiMH or Li-Ion radio battery packs?
- A: For standard NiCd and NiMh, I like to charge them about every 3 – 4 months. I don't like to let them discharge to below 1V and sit for a long time. Actually, NiCd doesn't mind being stored at 0V, but NiMH should not be stored below about .9V.

- Q: In charging, how "Warm" is too warm?
- A: Good Question! Lead Acid and Li-Ion should never get warm during charge. If you're heating up the battery enough to notice, you're charging at too high a rate. Nickel batteries will get warm during normal charge at rates greater than about C/4. With nickel, you use a Constant Current charge regimine …and once the cell is full, that energy is no longer converted to chemical energy, therefore the product of voltage times current that appears across the cell is converted to heat. Nickel cells should not be allowed to get over about 50°C (122°F). If a nickel cell is too hot to hold, it's way too hot and has probably been damaged.!

Q&A

- Q: What is the proper "conditioning" for new batteries of each type?
- A: Generally, all batteries want to be fully charged before initial use. Lead Acid requires nothing more. Nickel and Li-Ion batteries will not deliver full capacity on the first cycle, and may require up to 3 charge / discharge cycles to deliver full capacity. You can do this prior to first use, or just charge them and use them. Remember, NiCd likes to be fully discharged prior to re-charge. Otherwise, no special “break-in” is required.

- Q: For each type of battery, what are proper "storage' maintenance procedures, e.g if you put an FT-817 on the shelf for a month or two because one is not traveling?
- A: Charge lead-acid or nickel batteries every 3-4 months. If handy for the nickel batteries, discharge them prior to recharging. For Li-Ion, store them at 50% charge. No top-off should be necessary for more than a year.

Q&A

- Q: Is it true you should never let an Sealed Lead Acid (SLA) go below 10.5 volts in discharge? What is the effect if we do?
- A: Generally, I use 10 Volts, but depends on current. At high currents, the battery may dip to 10V but will recover to a higher voltage when the load is removed. Very low current discharges are the most damaging, because they truly deplete the charge and no recovery occurs. The battery should recover to 12V or greater after load is removed. If it doesn't recover to 12V, the battery is over-discharged.

- Q: Can I just leave an SLA on float at 13.8 volts until I need to use it? OK, how about 14.2 volts?
- A: 13.8V OK, 14.2 will be too high for float. Refer to the specific data sheet for the battery, because differences in chemistry require slightly different voltages. REMEMBER, a difference of only 5% in voltage (0.7V) can result in reducing life by half. Data sheets are readily available on the WEB.

- Q: What kind of charger should I use on NiCad or NiMH batteries/cells? What if I charge my NiMH batteries on a charger that says for NiiCd?
- A: I like Maha chargers and have had good luck with them. A good NiCd charger may ruin NiMH. They're not the same! Voltage depression is less with NiMH, hence a NiCd charger may not detect full charge and will over-charge them. Over-charge is the most common reason nickel batteries fail.

- Q: How can I tell if a single NiCad or NiMH cell is shot? I have some that don't seem to hold their charge too well but being in a string in my Antenna Analyzer, it's hard to tell which ones are "weak".
- A: If you can access the individual cells, measure voltage across each cell as the battery approaches full discharge. The weak cells will drop voltage first, and may even reverse polarity during discharge. If they've reversed, they're toast. Use 'em for ballast. Try cycling weak cells in your Maha MH-C9000,.

- Q: I have a string of NiMH cells I put together (soldered) to yield 13.2 volts, how should I charge these?
- A: Never solder directly to cells. Buy cells with tabs. I can weld tabs at work (in reasonable numbers) Well, I don't really like charging cells in series, but you're kinda stuck. You can build a NiMh charger using an available chip, or you can use a commercial charger such as the Triton charger that will adapt to a large number of cells in series. With the Triton, use the Temperature sense adapter to get reliable charge termination.

- Q: Is there a way to "restore" batteries after they appear to be weak?
- A: Lead-acid, use a pulse de-sulfater. For Nickel, cycle 3 or more times using a cycling charger or cycle manually. No remedy for Lithium

- Q: Of those little 4 cell (or 2 cell) chargers, is there a way to tell which are better than others.
- A: Read reviews in the digital camera forums. I've found these to be the best source of information regarding these chargers. Some of these guys apparently have too little to do and spend all their time comparing chargers. I'm a geek, but even I don't do thiis!
- http://www.steves-digicams.com/nimh_batteries.html#chargers

- Q: Can you recommend a charger that will do 4 or more cells - NiCad or NiMH - that won't break my billfold?
- A: Maha MH-C9000, Maha C204W, LaCrosse BC-900. Go to the Steve's Digicams site or others for recommendations.

Some good reading about batteries

- Storage recommendations:
  - www.powerstream.com/storage.htm`
- Charging Lead-Acid
  - www.batteryuniversity.com/partone-13.htm
- General battery stuff ….LOTS of it:
  - www.batteryuniversity.com
- Good reviews of NiMH chargers & cells:
  - www.steves-digicams.com/nimh_batteries.html#chargers
- UC3906 Charger Kits: A&A Engineering
  - www.a-aengineering.com
- Comparison of lead-acid battery types, good info regarding AGM
  - http://www.advancedpowerproducts.com/marinecomps.php