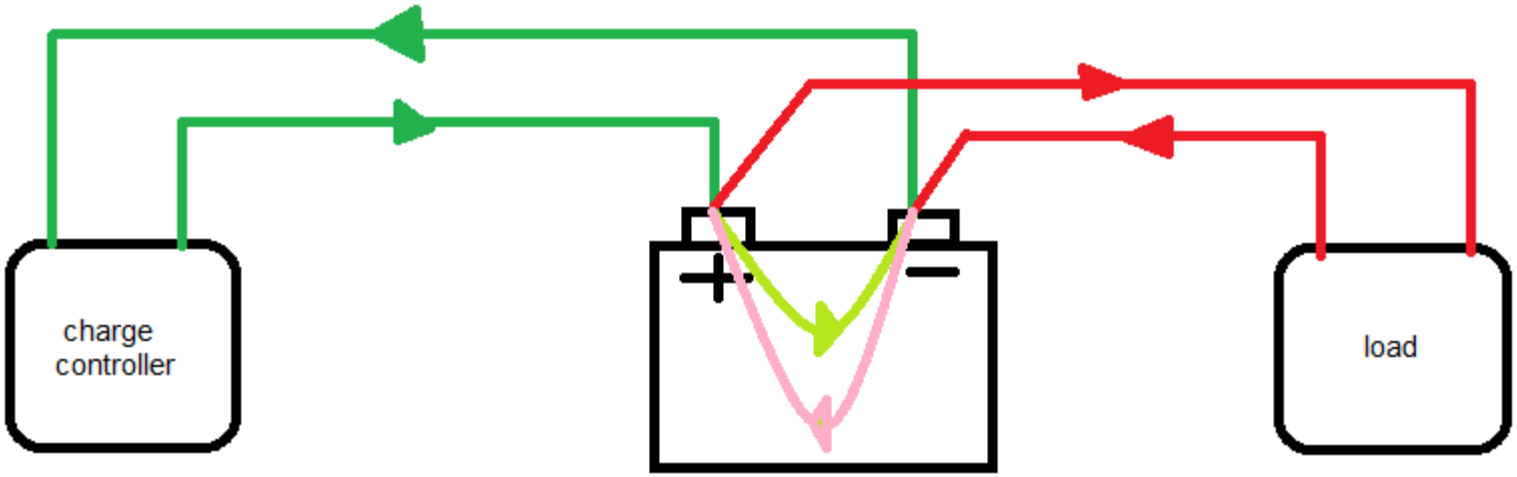
"Charge & Discharge"



Ed Erny - NZ1Q

August 2017

WMARC Mt Washington Valley, NH **SPARC** St Petersburg, FL

Battery types today

- ***Primary Batteries*** **(disposable)**
  - Leclanché Cells
  - Alkaline Cells
  - Mercury Oxide Cells
  - Zinc/Air Cells
  - Aluminum/Air Cells
  - Lithium Cells
  - Lithium Iron Primary
  - Magnesium-Copper Chloride Reserve
- ***Secondary Batteries*** **(rechargeable)**
  - Lead–Acid Cells
  - Nickel/Hydrogen Cells
  - Nickel/Cadmium Cells
  - Nickel/Metal Hydride Cells
  - Sodium/Sulfur Cells
  - Nickel/Sodium Cells
  - Lithium ion Cells
  - Lithium Iron Phosphate
  - Manganese-Titanium (Lithium) Cells
  - Rechargeable Alkaline Manganese Cells
  - Nickel Zinc Cells
  - Iron Nickel Cells
  - Iron Air Cells
  - Iron Silver Cells
  - Redox (Liquid Electrode) Cells

Popular Rechargeable Batteries

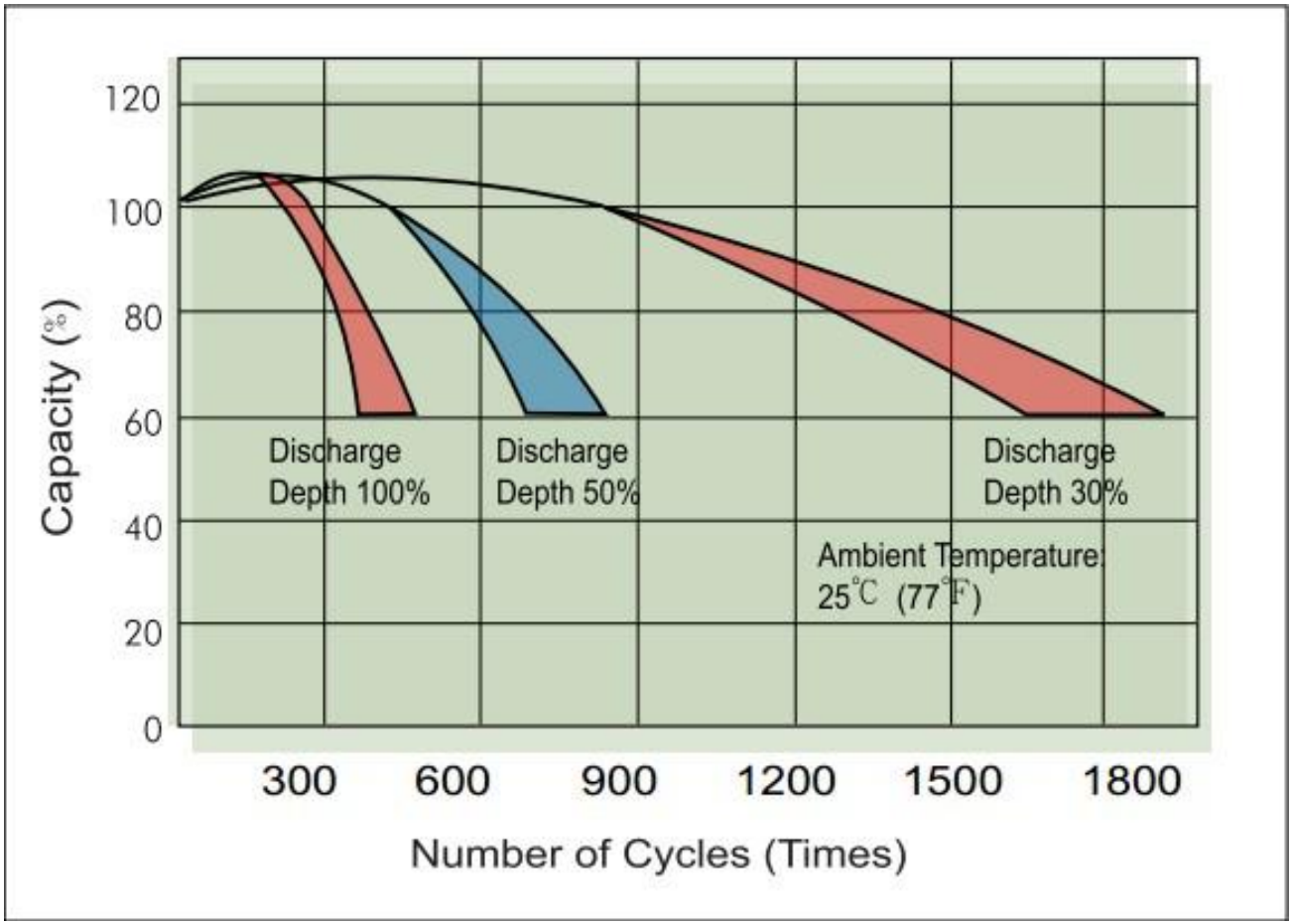
- Lead Acid storage batteries (VRLA*)
  - Flooded Lead Acid
  - Gel Cell
  - Absorbed Glass Matt –AGM
- Li based & Ni based
  - Nickel Cadmium (NiCd)
  - Nickel Metal Hydride (NiMH)
  - Lithium ion
    - Lithium Cobalt ion (LiCoFe) (a.k.a. Li-ion)
    - Lithium Iron Phosphate (LiFePo4)

* **VRLA** – Valve Regulated Lead Acid (a.k.a. Sealed or maintenance free)

Lead Acid Depth of Discharge vs. Battery Life

Battery Life depends on Depth of Discharge (DoD)

Flooded Lead Acid deep cycle batteries are built to use only ~50% of their rated capacity (C) to achieve the cycle rating (life).



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Lead Acid Discharge Rate

What is the capacity? Capacity is Amperes x hours (Ah) or C.

Ah (amp x hours) tells us: **100Ah = 100 Amps for 1 hr = 1.0C**

The rating of a 100Ah flooded Lead-Acid battery is defined as 5 Amps discharge over 20 hours or 0.05C.

2.0 C = 200A for 0.5 hr
1.0 C = 100A for 1.0 hr
0.5 C = 50A for 2 hrs
0.1 C = 10A for 10 hrs
0.05 C = 5A for 20 hrs

20 hour discharge gives the max rated capacity and full number of cycles.

Flooded lead acid battery cycles are always rated over a 20 hr discharge.

**

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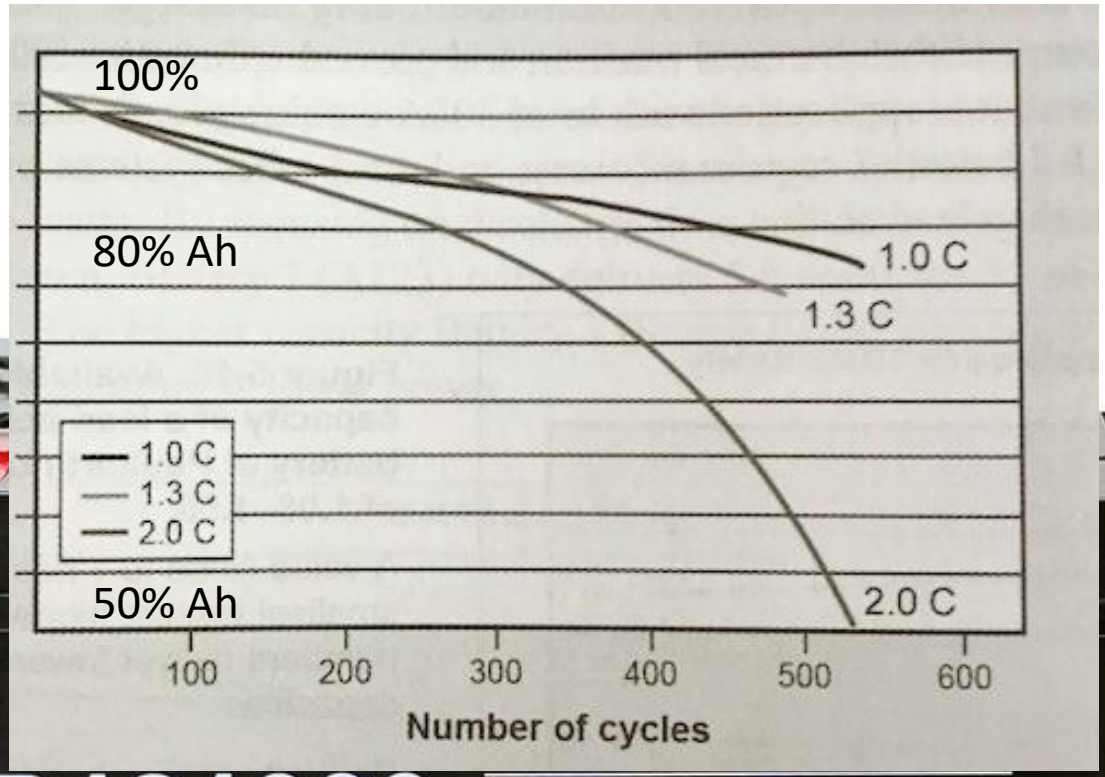
Flooded lead acid battery cycles are always rated over a 20 hr discharge.

Battery Life (cycles) depends on how fast it is discharged.



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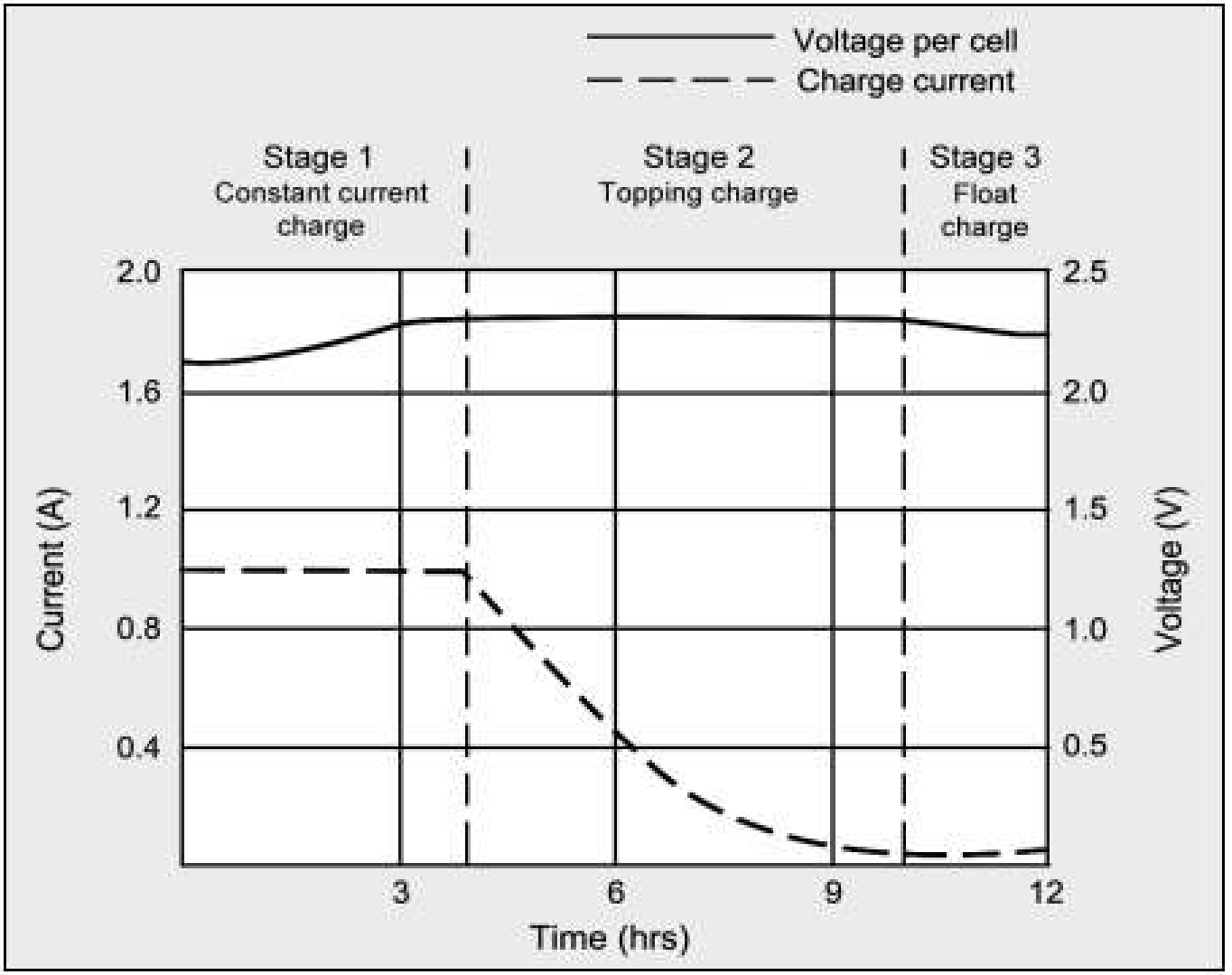
Charging Lead Acid Batteries

How much charge current to use?
Some batteries can be charged at 1.0C, others such as flooded should only be charged at 0.05C to 0.10C (Ah rating).



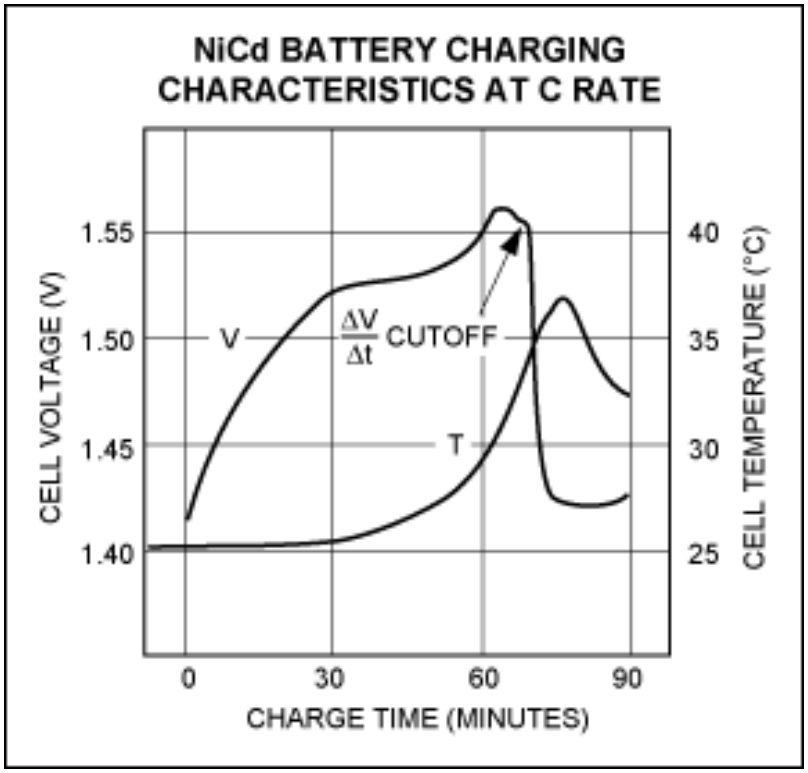
Stage 1: Voltage rises at constant current to V-peak.

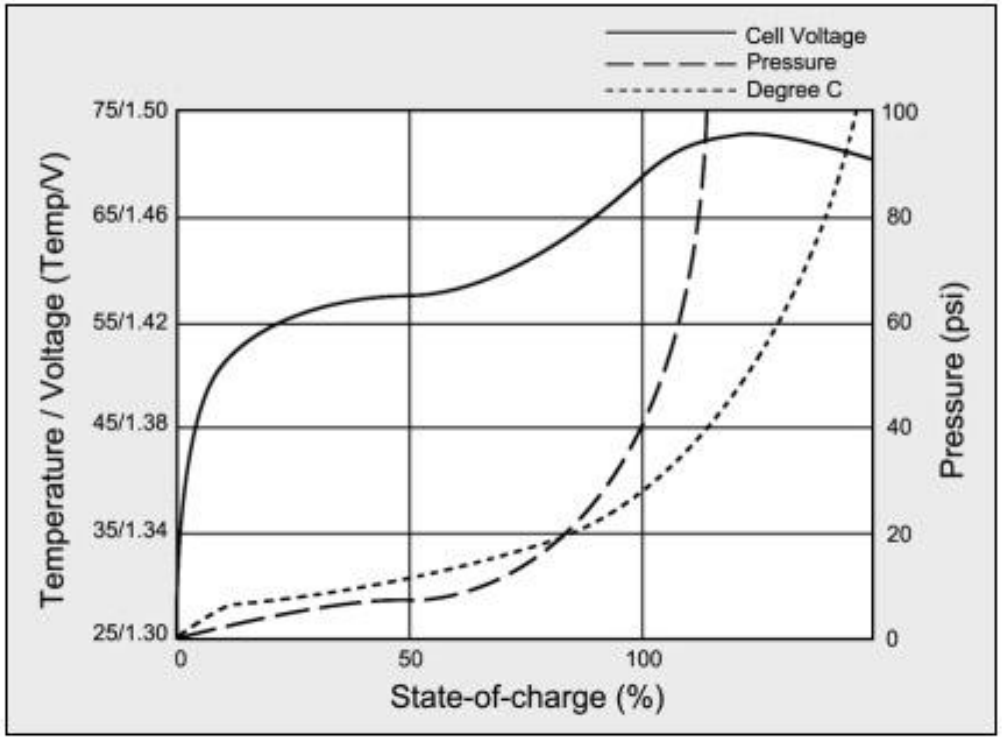
Stage 2: Current drops; full charge is reached when current levels off

Stage 3: Voltage is lowered to float charge level

NiCd & NiMH charging

High rates preferred (~1.0C)

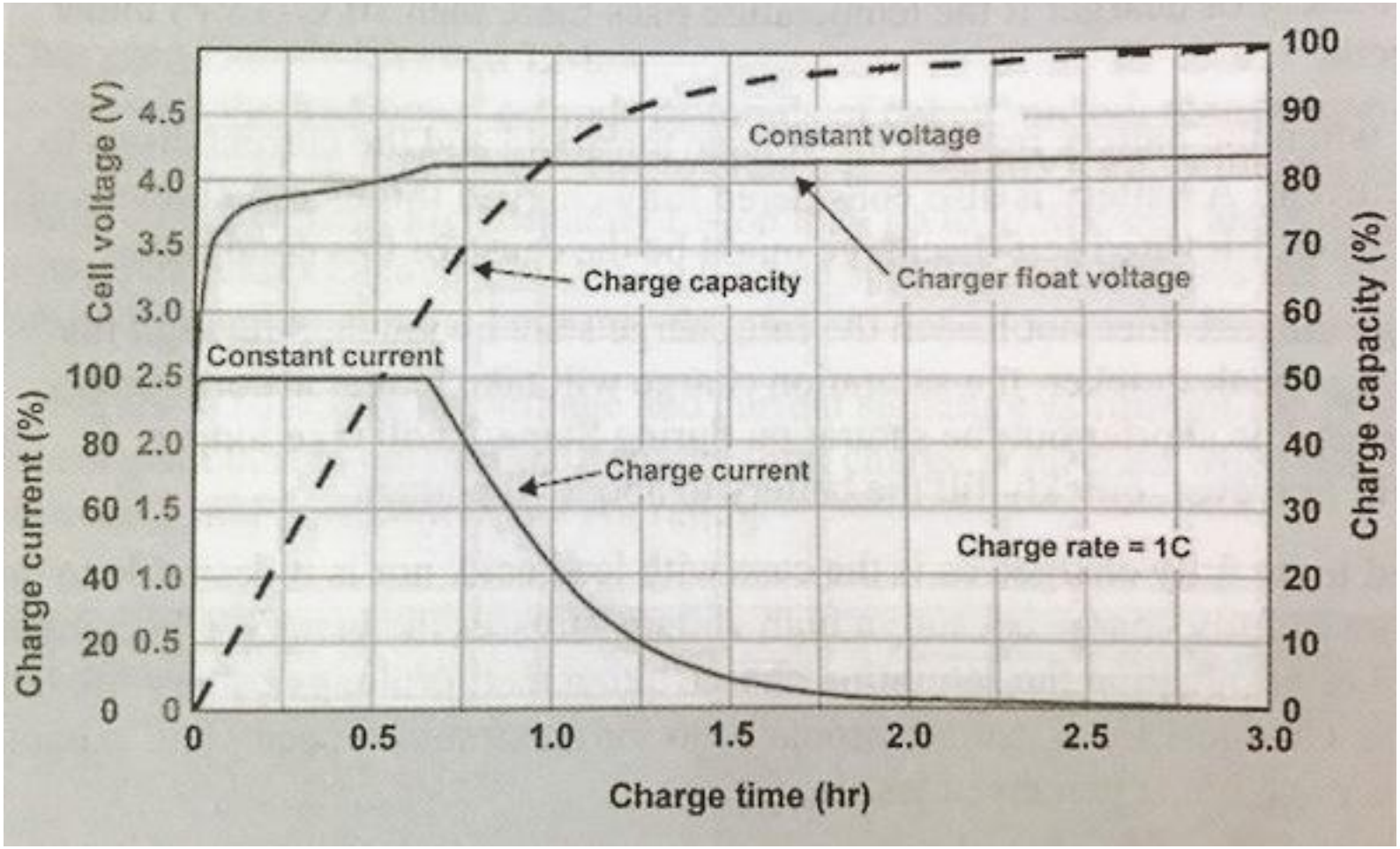




Where charging Ni based batteries gets into trouble

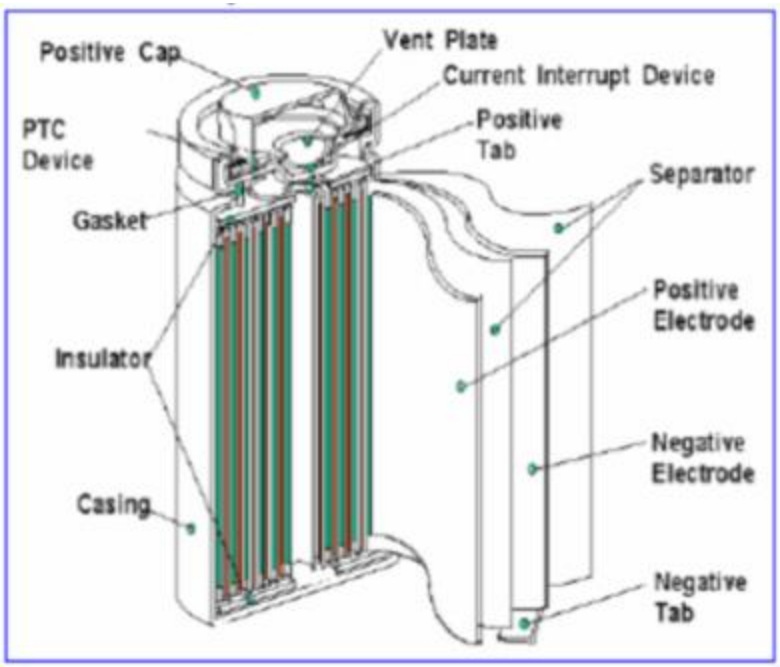
Repeatedly reinserting a handheld with a Ni-based battery back in its charger after a short transmission, re-initiates a charge cycle and reheating of the battery to around 122 deg F.

Li-ion Charging



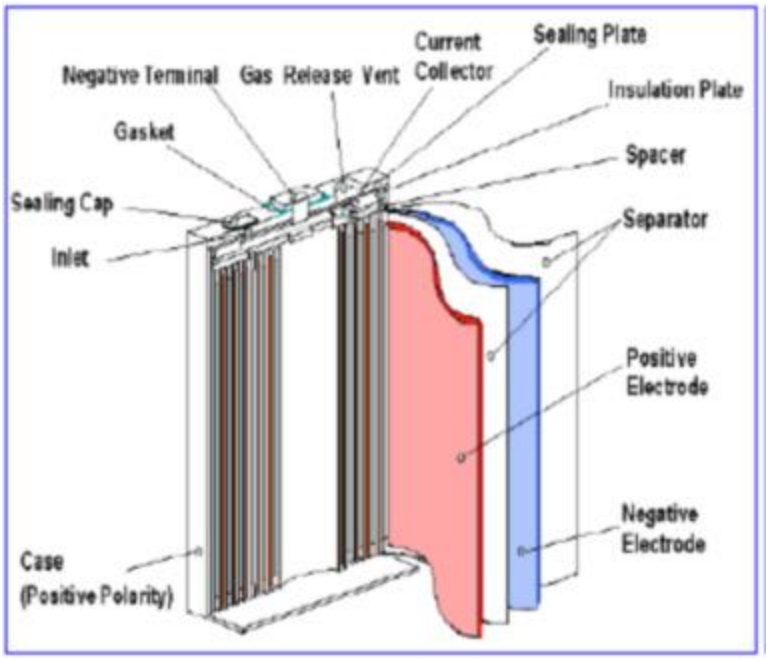
For example, charging at 0.8 to 1C :
an 1800 mAh battery could be charged at 1500mA to 1800mA

Li-ion



Hard case cylindrical or prismatic: these cells generally have an Aluminum can with a laser-welded or crimped cover. They contains liquid electrolyte. Lithium in a solvent.

Li Polymer



Soft or pouch cells: these cells use a thin aluminized plastic bag. In general, they contains electrolyte in a polymer, reason why they are often called “lithium-ion polymer”.

Best Practices	**Lead Acid** (flooded, AGM)	**Nickel Based** (NiCd & NiMH)	**Lithium** (Li-ion, polymer)
How to care for a new battery	Comes fully charged. Float charge or top off every few weeks.	Charge 14-16h.	Apply a topping charge before use.
Can a battery be damaged with incorrect use?	Yes, do not store partially charged, keep fully charged.	NiCd is robust and will give best performance in mid life.	Keep partially charged during storage. LiFePO4 can be stored full.
Do I need to apply a full charge before use?	**Yes, partial charge causes sulfation. Always apply a full charge after use.**	**Partial charge is fine. Deep cycle NiCd to prevent memory.**	**Partial charge is better than a full charge for long life.**
Should all the energy be used up before recharging.	No, deep discharge wears down the battery. Charge often. No memory.	Apply scheduled full discharges only to prevent memory every 1-3 months.	Very deep discharge wears the battery down. No memory.
How to calibrate a smart battery fuel gauge.	Not applicable.	Apply discharge/charge cycle when the “fuel gauge” becomes inaccurate. Repeat every 1-3 months.	

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Best Practices cont'd	**Lead Acid** (flooded, AGM)	**Nickel Based** (NiCd & NiMH)	**Lithium-ion** (Li-ion, polymer)
Can I charge while the device is on.	Seldom a problem. Avoid if possible.	Parasitic loads can alter full-charge detection and overcharge the battery.	
Should the battery be remove from charger when full?	**No, charger switches to float charge mode.**	**Remove after a few days in charger, 16hrs min charge.**	**Not necessary, charging turns off if BMS is used.**
How to store batteries.	Keep cells above 2.1v (12.6v). Charge every few months?	Store in cool place, can be stored fully charged.	Store in cool place, store partially charged (~70%).
Does the battery heat up on charge?	Lukewarm toward the end of charge.	Warm but will cool after full charge.	Must stay cool or only slightly warm.
How to charge when very cold	Slow charge (0.1C) between 32-113 deg F Fast charge (0.5-1C) between 41-113 deg F		Do not charge below freezing.
Charging when hot	Lower float 3mV/cell /deg C above 25 deg C	Battery will not fully charge when hot.	Do not charge above 122 deg F
What to know about chargers	Float at 13.5-13.8 volts. Use 3 stage.	Should include temperature sensing	Must stay cool, no trickle charge, BMS.

**

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agm

AGM – Absorbed Glass Matt (lead acid)

- **Advantages**
  - Spill-proof (glass matt technology)
  - High specific power (low internal resistance)
  - Up to 5 times faster charge than flooded Lead-Acid
  - Better cycle life than flooded Lead-Acid, cycle to 80% DoD compared to 50% for Lead-Acid.
  - Water (electrolyte) retention (oxygen and hydrogen recombine to produce water)
  - Vibration resistance due to tight layered construction
  - Stands up well to cold temperature
  - Less prone to sulfation if not regularly topper off, stores longer, lower self-discharge
  - Has less electrolyte and lead than the flooded version

- **Limitations**
  - Higher manufacturing cost than flooded , but cheaper than GEL
  - Use correct charger to avoid overcharge (gassing)
  - Must be stored in charged condition, but less critical than flooded

$LiFePO_4$ (LFP) - Advantages

- LiFePO4 batteries have built-in battery management system (BMS) that internally balances cells and protects from over-charge, over-discharge and short circuiting.
- Dependable and reliable without the possibility of lithium fires.
- 50% to 70% lighter than a traditional SLA (sealed lead acid) battery.
- Allows use of >90% of the rated capacity (Ah), whereas a flooded lead acid battery only allows use of 50% of the rated capacity to achieve cycle life.
- Service life of 2000+ charge cycles at 80% discharge, with 7-10+ years shelf life, which far exceeds the service life of many other batteries.
- Can be charged at 2 - 2.5 C (Ah rating). 0.3 to 0.5C is preferred.
- More constant discharge voltage (3.2 V/cell, 12.8 V bat).
- Used for starting or deep cycle.
- No electrolyte to spill or corrode.

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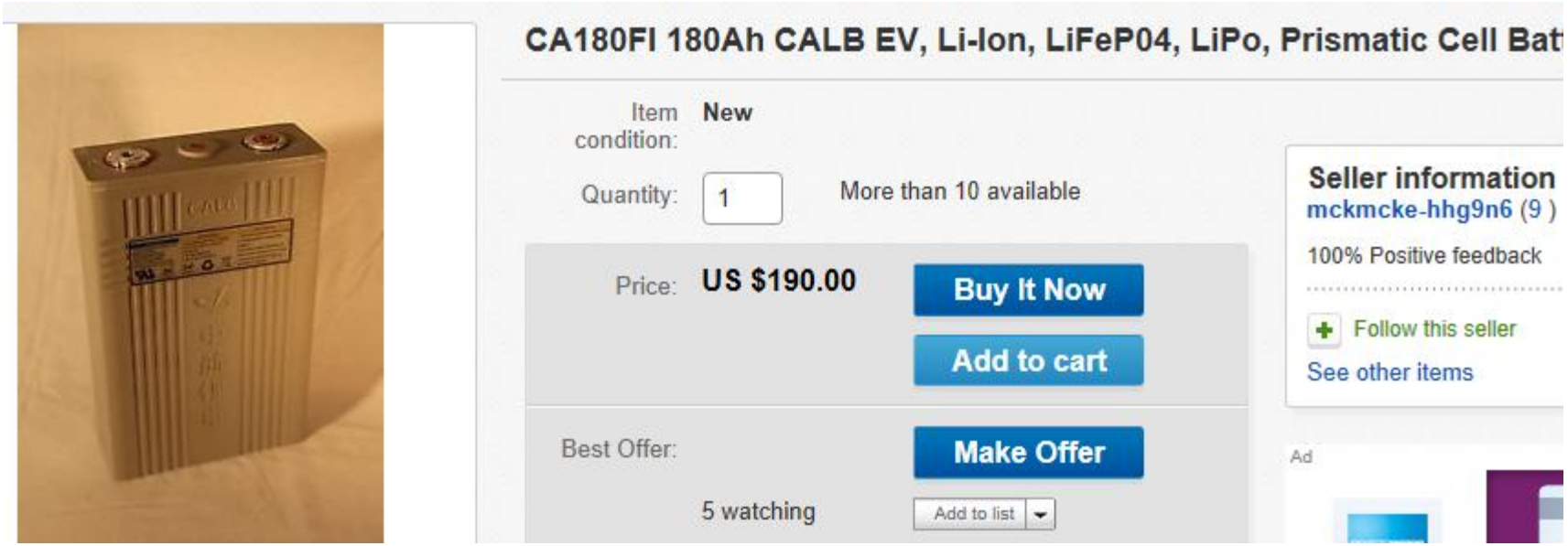
LiFePO4 (LFP) – a new technology

- LFP has made its way into power tools, starting batteries and deep cycle storage.



LiFePO4 (LFP) – a new technology

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LiFePO4 12V 24-35ah **Battery** for BMW R100GS, PD, R, RS, RT…

$224.95 List price $249.95

Save **$25.00**

Reduced Price

Show only Mighty Max Battery items

ML-LI24R is a 12V 24-35(Ah) 500 Cold Cranking Amps (CCA) Lithium Iron Phosphate (**LiFePO4**) **Battery**
Case Dimensions: 6.50 inches x 3.40 inches x 5.12 inches; Polarity: Negative on the Lef

LiFePO4 (LFP) – a new technology

- LFP has made its way into power tools, starting batteries and deep cycle storage.

Tenergy AA 14500 Size 3.2V 400mAh **LiFePO4** Rechargeable…

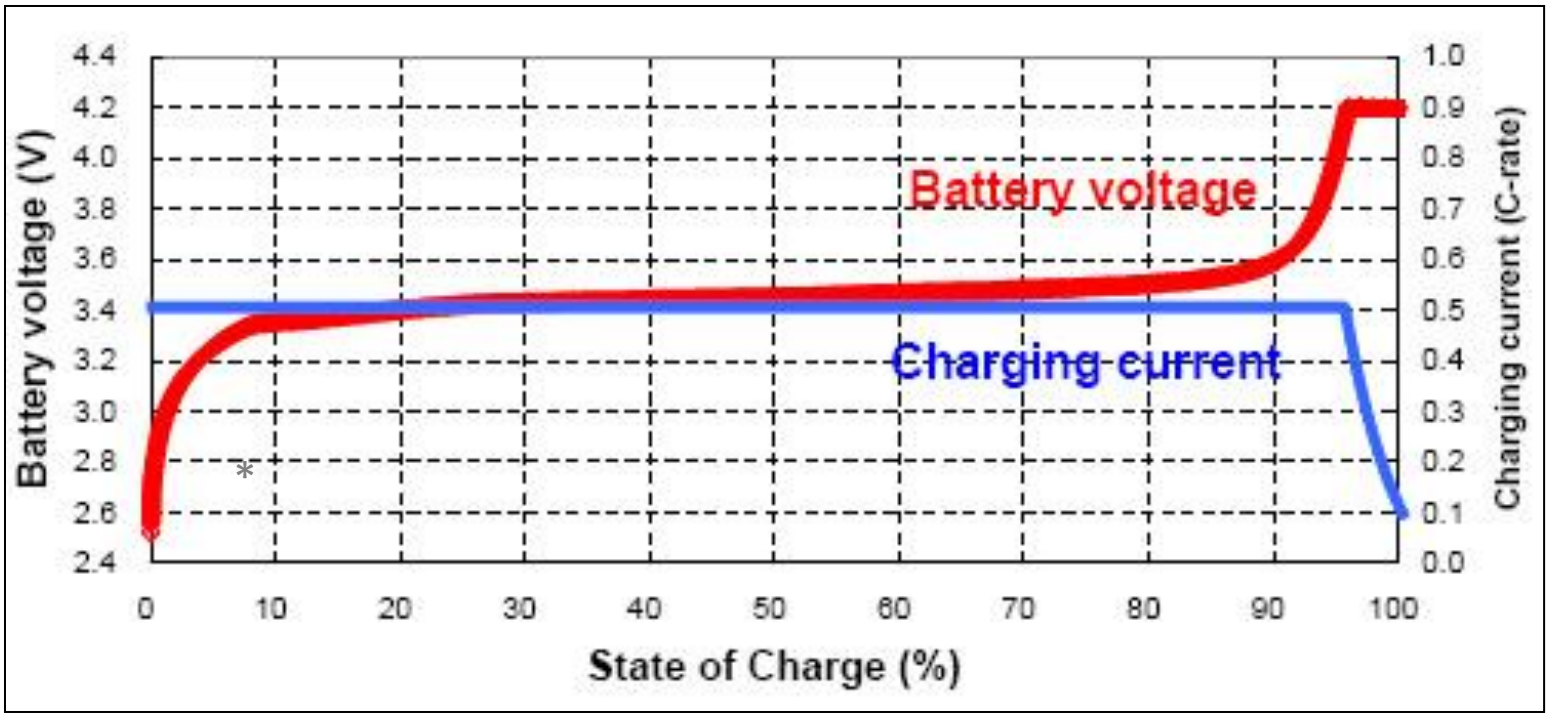
$9.99

★★★★★ (1)

Popular for solar applications like solar garden lights;
Direct replacement for 14500 3.2V **batteries;**
High energy density & high performance;
Dimensions: 14mm x 50mm (D x

$LiFePO_4$

Charge rate is much higher than flooded Lead Acid.
1.0 – 2.0C.
Batteries have built-in BMS.



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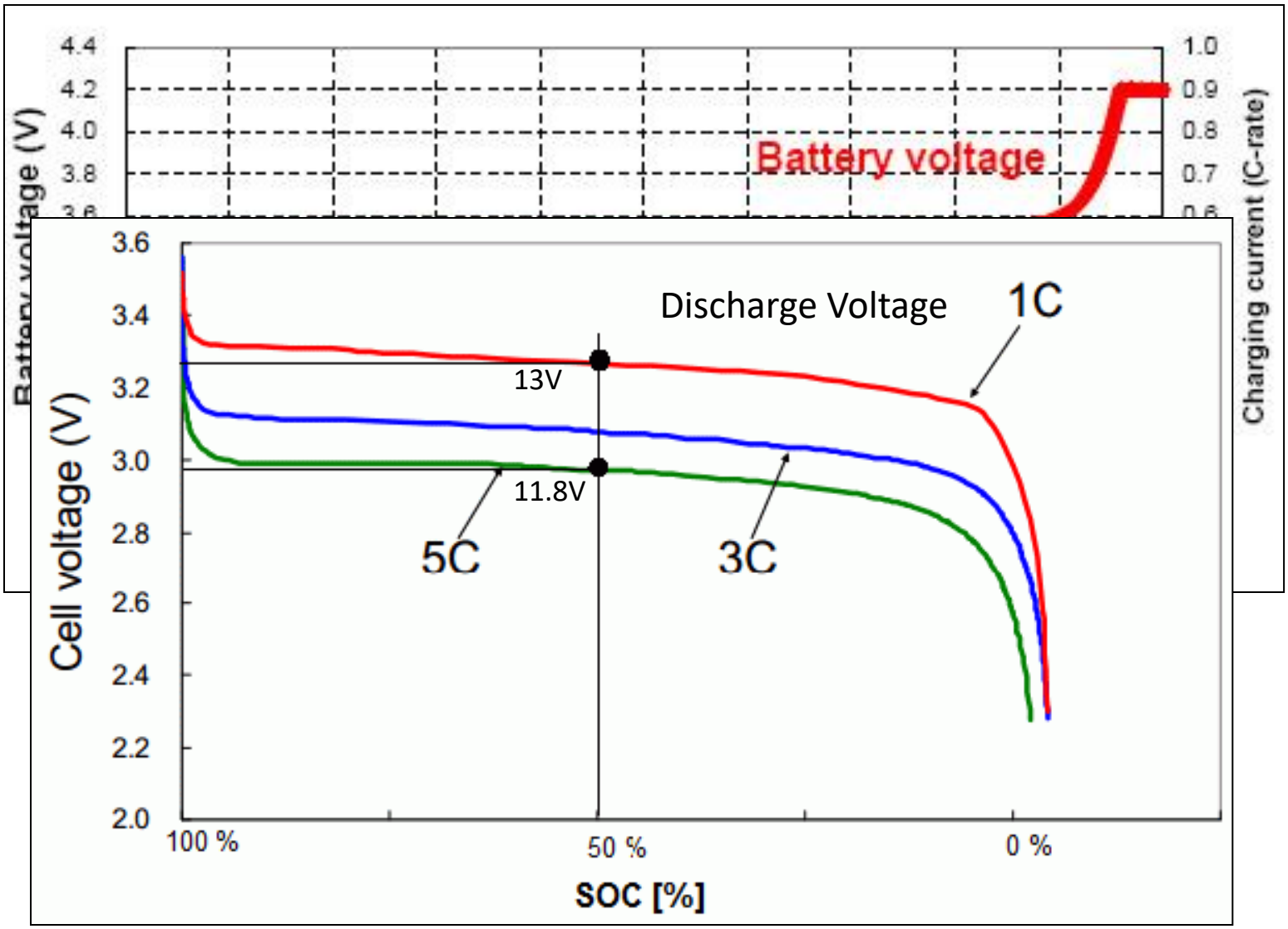
$LiFePO_4$

Charge rate is much higher than flooded Lead Acid. 1.0 – 2.0C. Batteries have built-in BMS.

Discharge: Holds voltage very well similar to Ni based cells.

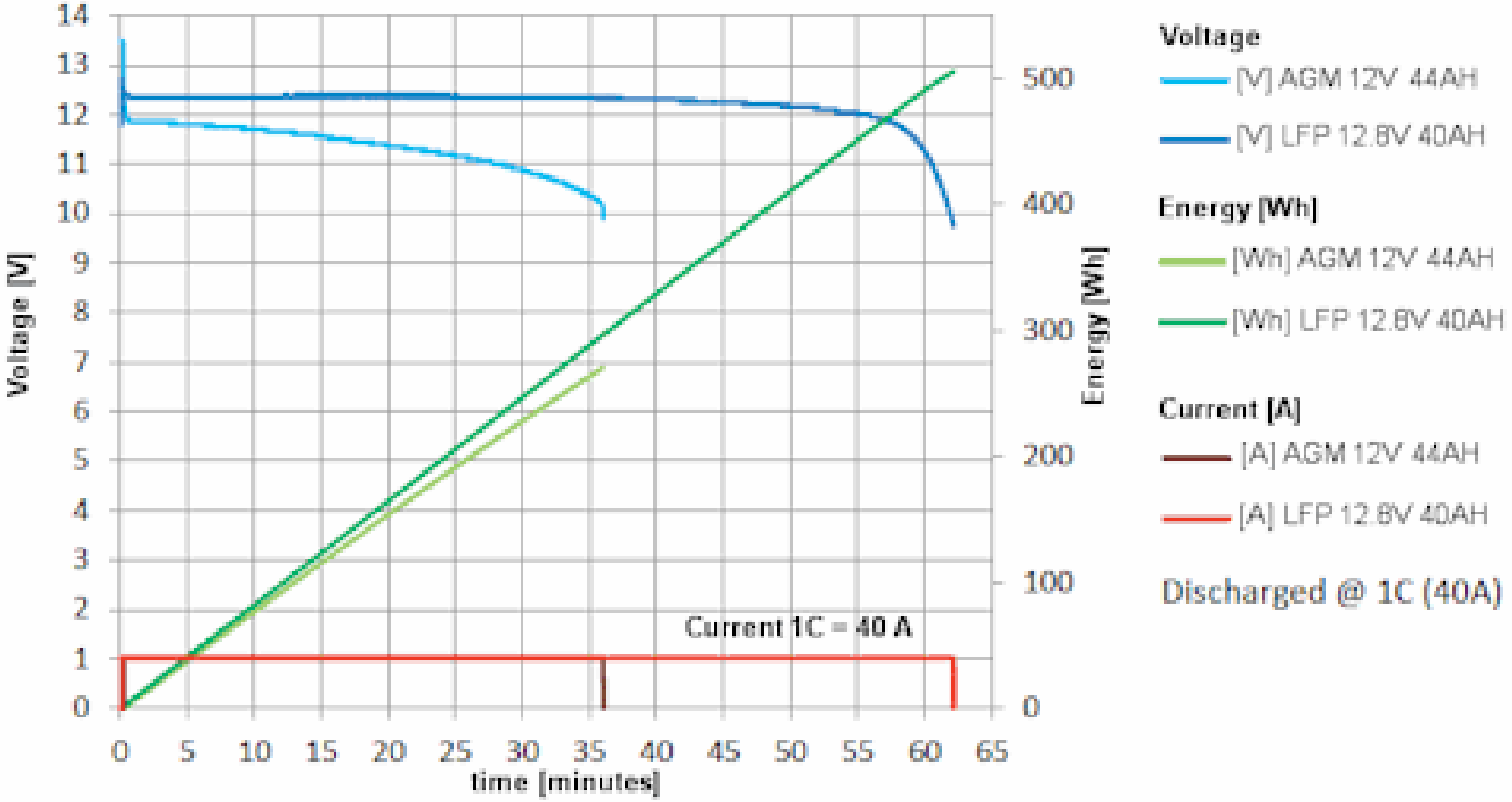
Battery voltage is typically 12.5 to 13.6.

Nearly all the capacity is usable.

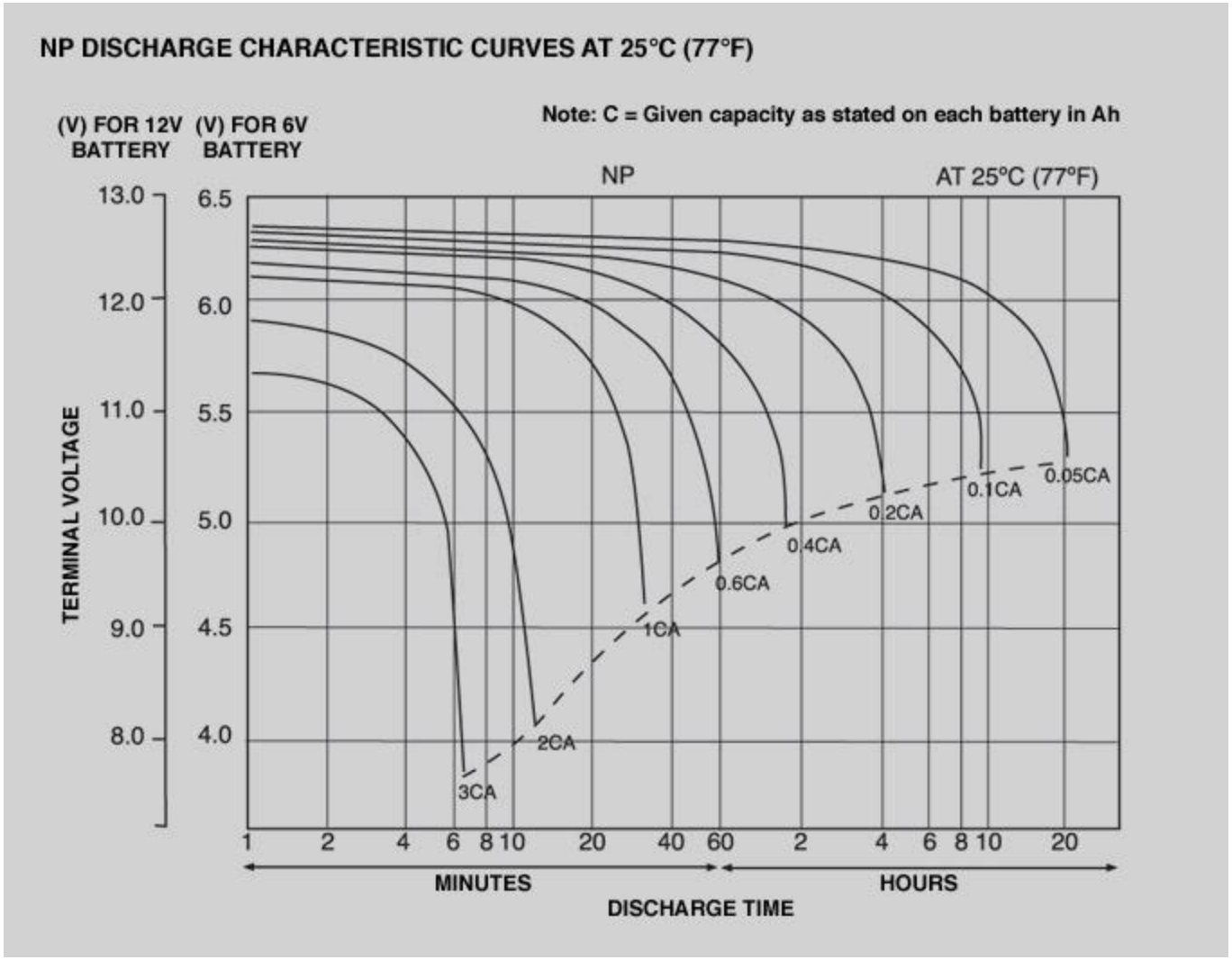


Comparing AGM 44AH and LFP 40AH

Lead-Acid battery AGM 12-44Ah VERSUS LiFePO4 12.8V-40Ah



Lead Acid Battery Discharge



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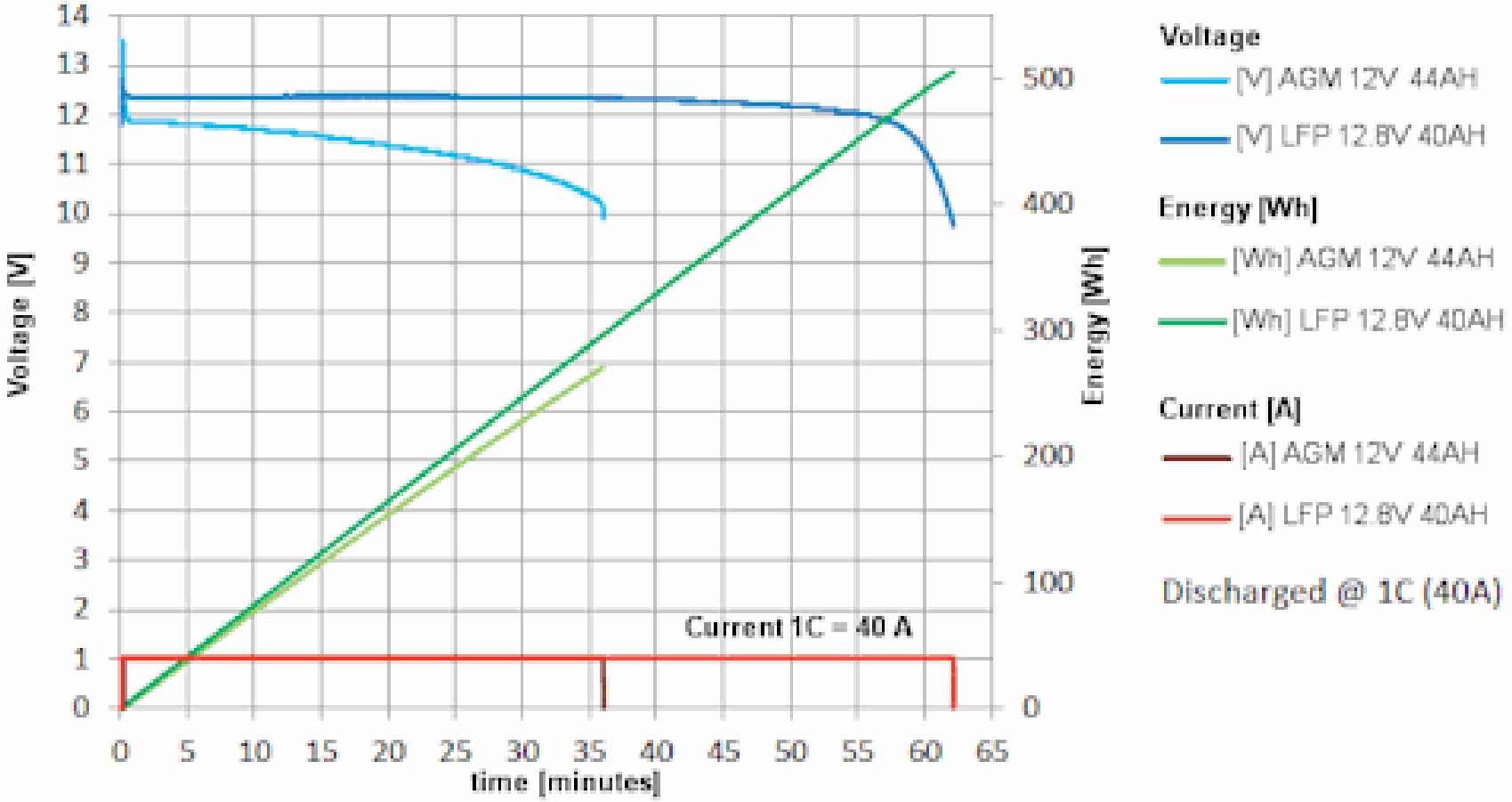

The LFP will yield nearly twice the energy of the AGM for the same battery rating because of the inherent limitations of lead acid as shown in the previous slide.

Quick Comparison Table

Type cell, [12V bat]	Lead Acid - flooded	- AGM	NiCd / NiMH	Li-ion, LiPo	LiFePO4
Working V/c [12V Bat]	1.8-2.1 V/cell [10.8-12.6V]		1.2V/cell	3.0-4.2V/cell	3.0 - 3.3 [12.0-13.6]
Discharge, lowest voltage allowed	1.75V. Lower than that and damage occurs. [~10]		High discharge rate of 1.0C	1.0C rate max, cutoff 2.5V	2.5V [10.0], some say 2.0V before damage.
Power vs. Energy storage	Star bat = hi power. Deep cycle = more energy	Similar with lower internal resistance than flooded.	Hi power and energy		Low internal resistance, hi power and hi energy
Capacity, (energy density/Vol)	**60-110Wh/Liter**		**NiCd: 50-150 NiMH: 140-200Wh/L**	**150-200Wh/L**	**220 Wh/Liter (3x Lead acid by weight)**
Typical cost	~ $1/Ah	~ $2/Ah	~ $8/Ah, cells less	~ $12/Ah	~ $2/Ah

*

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Quick Comparison Table, cont'd

Type cell, [12V bat]	**Lead Acid** - flooded	- AGM	**NiCd / NiMH**	**Li-ion, LiPo**	**LiFePO4**
Charging	14-16 hrs at 0.05 to 0.1 C, use float.	Can charge faster and can be stored without float for months	Fast constant current bulk charge 1.0C, trickle charge at 0.05C for a day.	0.7-1.0C 3hr typical. Constant voltage to 4.20V/cell; no trickle charge;	Fast charge, 2.0C to 3.6V [14.4V]
Safety	Liquid acid, out gases H_2 and O_2	Non liquid, any position, little out gassing if any	Any position, good for portable use.	Li-poly has thermal fuse, non-poly runaway at 300degF	Chemically and thermally stable.
Cycle life to 80% capacity	**50%DoD Start: <120, Deep: 400-500**	**50%DoD Start: >300, Deep: 500 - 1300**	**100%DoD >2000. Common 300-400**	**70%DoD 500-1000**	**80% DoD 2000 – 7000**

dd

Do's and Don'ts to prolong life

Battery Care	**Lead acid:** flooded, AGM	**Nickel based:** NiCd, NiMH	**Lithium based:** Li-ion, Li-polymer
Best way to Charge	**Apply saturated charge to prevent sulfation; can remain on charge with correct float voltage.**	**Avoid getting too hot on charge. Do not leave battery in charger for more than a few days. NiCd subject to memory**	**Partial and random charge is fine; does not need full charge; lower charge preferred; keep battery cool.**
Charge methods	Constant current to 2.40-2.45/cell, float at 2.25-2.30V/cell. Battery should stay cool; no fast charge possible. Charge time 14-16 hrs.	Fast charge preferred. Constant current and float charge at 0.05C. Slow charge = 14hr Rapid charge = 3hr Fast charge = 1 hr	Constant current to 4.20V/cell; no trickle charge; battery can stay in charger. Rapid charge = 3hr Fast charge = 1h
Discharge	Can endure high peak currents. Avoid full discharges. Charge after each use.	Do not over-discharge on a heavy load; cell reversal causes short. Avoid full discharges.	Apply some charge after a full discharge to keep the protection circuit alive. Store at 60-70% charge.
BMS	Not applicable	Not applicable	Required for Li-ion, LiPo and LiFePO4

Do's and Don'ts to prolong life, cont'd

Battery Care	Lead acid: flooded, AGM	Nickel based: NiCd, NiMH	Lithium based: Li-ion, Li-polymer
How to prolong battery life.	**Limit deep cycling; do not deep cycle starter battery. Apply full saturation charge. Avoid heat. Keep charged.**	**To prevent memory, discharge packs in regular use to 1V/cell every 1-3 months (mainly NiCd).**	**Keep cool; operate in mid SoC of 20% to 80%. Prevent ultra fast charging and high loads (mostly Li-ion)**
Storage	Keep cells at >2.05V. Apply topping charge every 6 months to prevent sulfation.	Store in cool place; NiCd stores for 5 years; re-charge before use. Can be stored at 0V.	Store at 40% charge in cool place (40% SoC reads 3.75-3.80V/cell). Do not go below 2.0V/cell.
Disposal (Note local regulations)	Toxic. Do not dispose. Electrolyte is corrosive. Profitable to recycle.	NiCd: Do not dispose. NiMH: may be disposed in low volume.	Low toxicity. Can be disposed of in low volume. Best to recycle.

What AA battery is best for use in cold WX?

Type	Zinc –Carbon	Alkaline	RAM	Li-FeS_2	Li-ion	NiCd	NiMH	NiZn
IEC name	R6	LR6	LR6	FR6	?	KR6	HR6	ZR6
ANSI/NEDA name	15D	15A	15A	15LF	14500	1.2K2	1.2H2	?
Capacity under 50 mA constant drain	400–1700 mAh	1800 –2600 mAh	1800 –2600 mAh	2700 –3400 mAh	600-800 mAh	600 –1000 mAh	600 –2850 mAh	1500 –1800 mAh
Nominal voltage	1.5 V	1.5 V	1.5 V	1.5 V	3.6-3.7 V	1.2 V	1.2 V	1.6-1.65 V
Max. energy at nominal voltage and 50 mA drain	2.55 Wh	3.90 Wh	3.90 Wh	5.10 Wh	2.88-2.96 Wh	1.20 Wh	3.42 Wh	2.97 Wh
Rechargeable	No	Some	Yes	No[8]	Yes	Yes	Yes	Yes

cb

Info from “The Energizer Bunny”
(a.k.a. The Energizer Technical Specification Dept.)

- Energizer said their AA Alkaline:
  - “Has Superior cold Temp performance”
  - Types:
    - Economy – Remote control, radio, clock
    - Standard – Lighting, toys, games
    - Premium – Dig camera, photo flash, tape players

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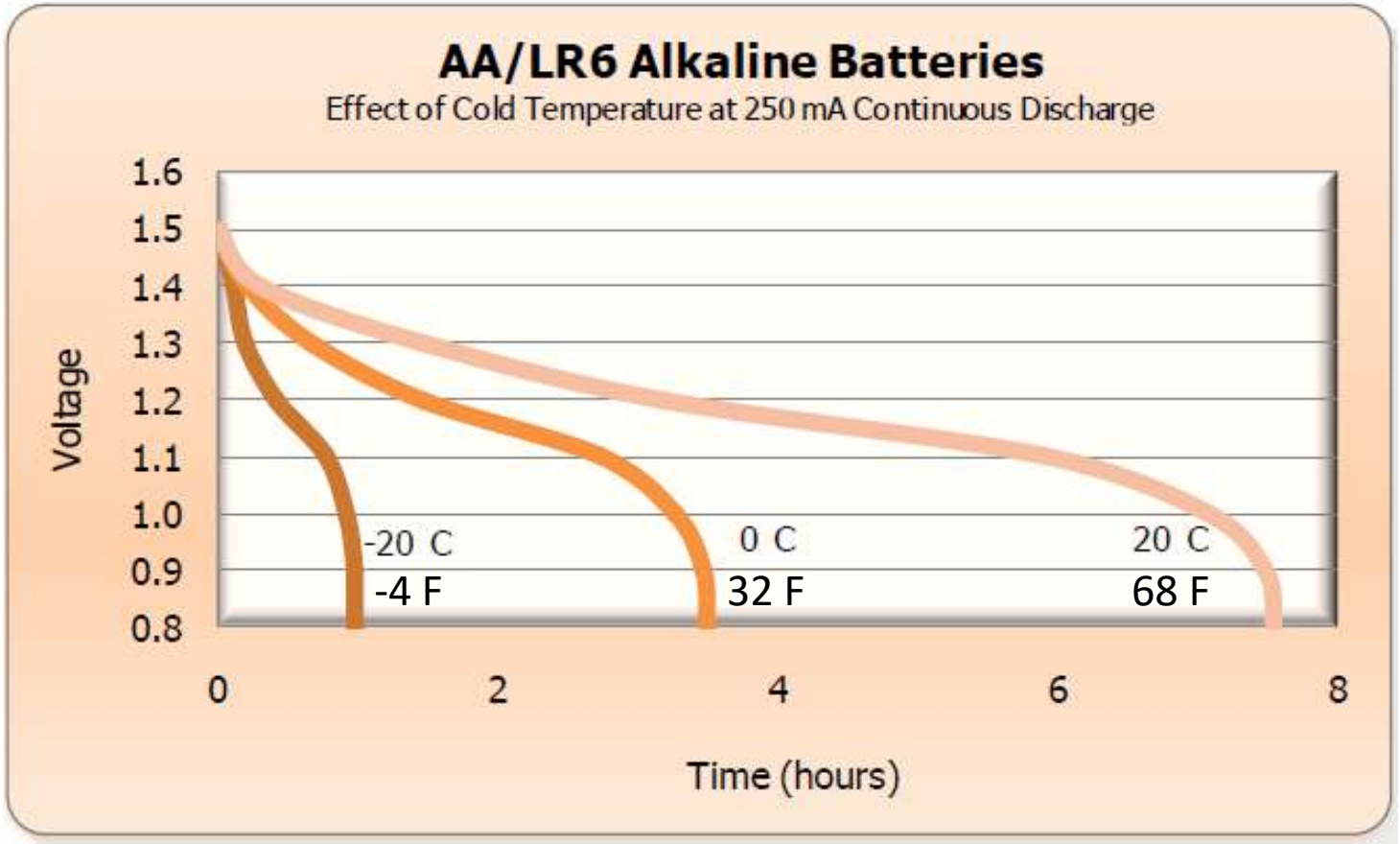

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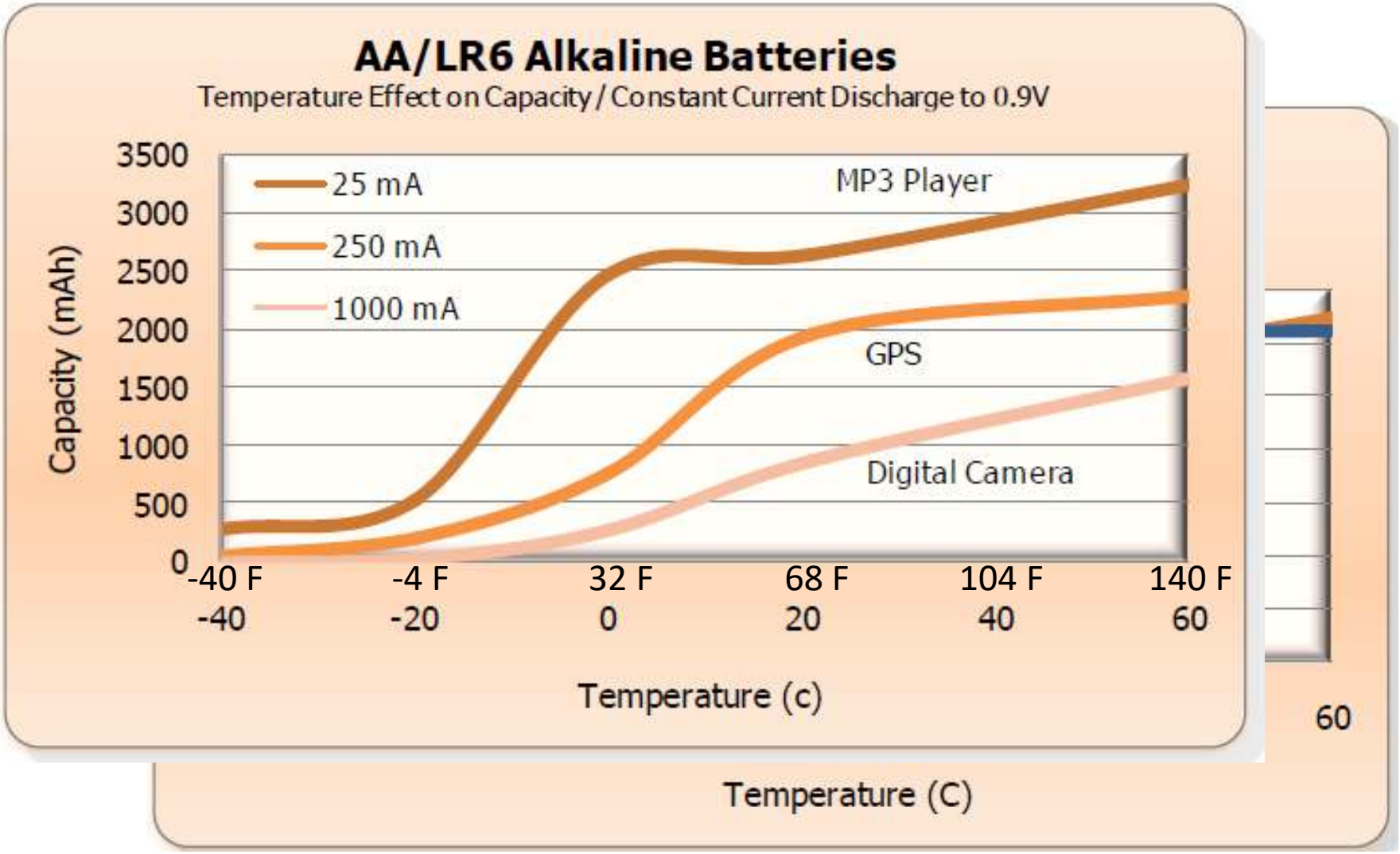
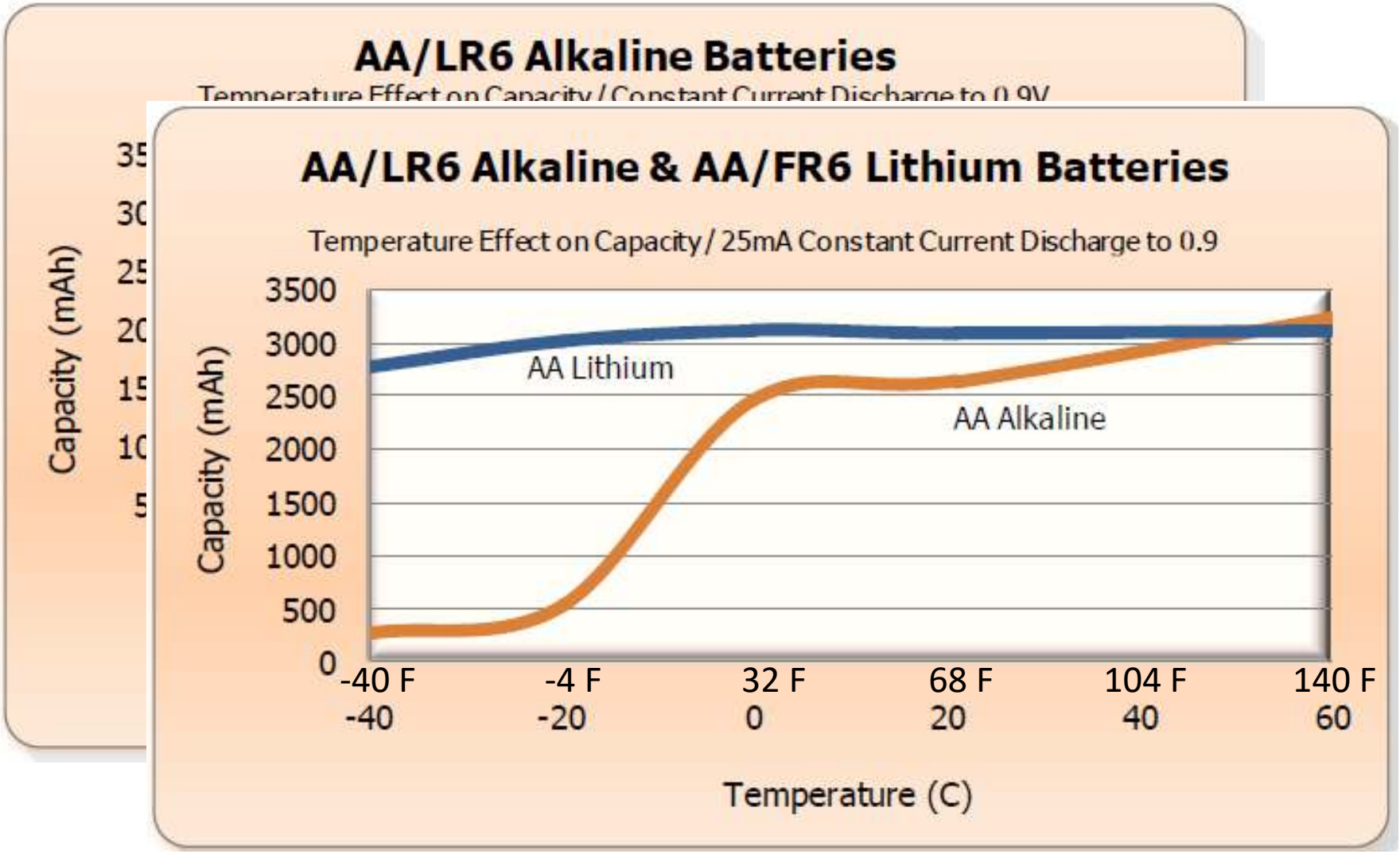
AA - Alkaline Performance at Temperature

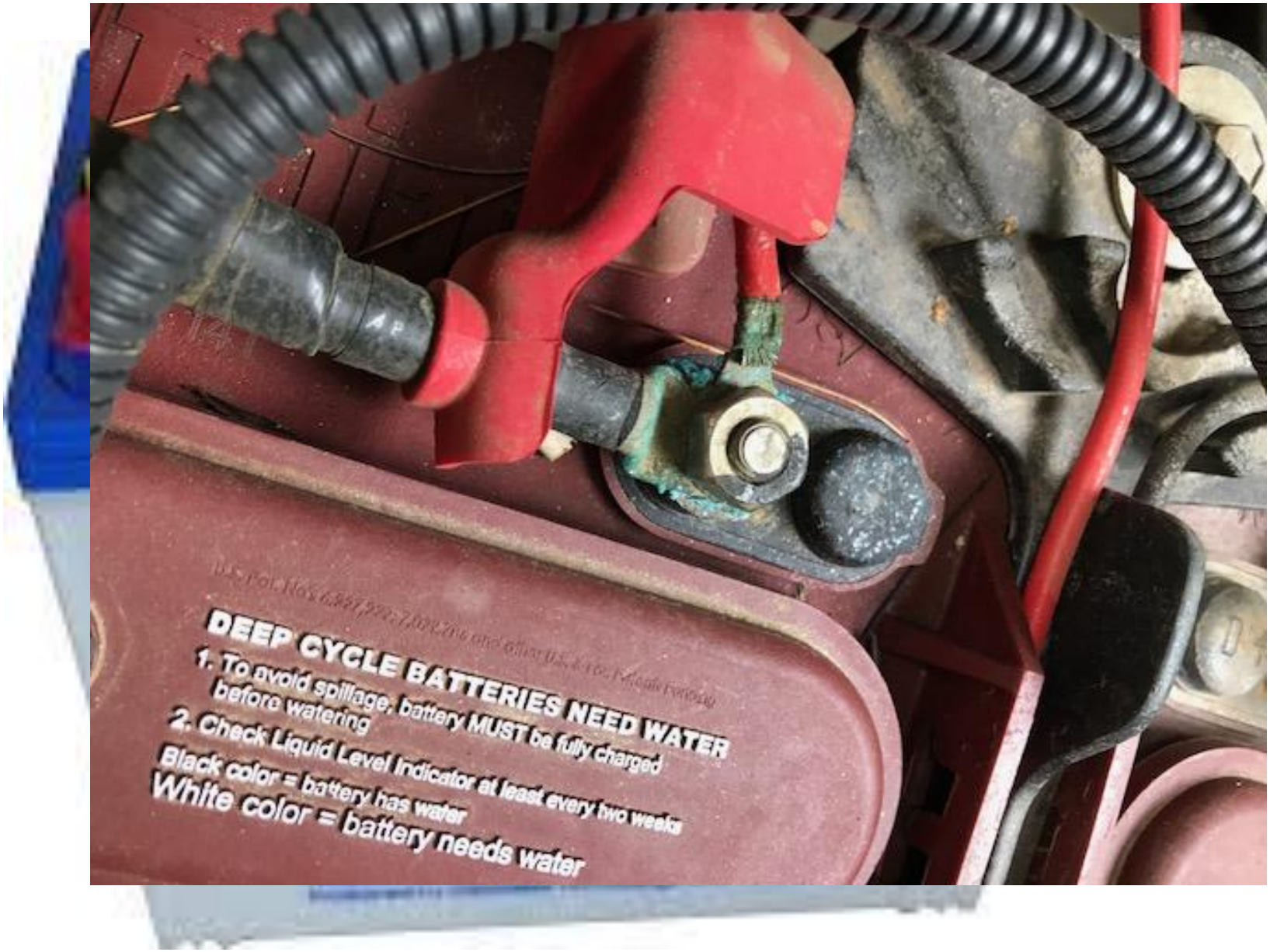


AA - Alkaline Performance at Temperature



* pic

pb


DEEP CYCLE BATTERIES NEED WATER
1. To avoid spillage, battery MUST be fully charged before watering
2. Check Liquid Level Indicator at least every two weeks
Black color = battery has water
White color = battery needs water

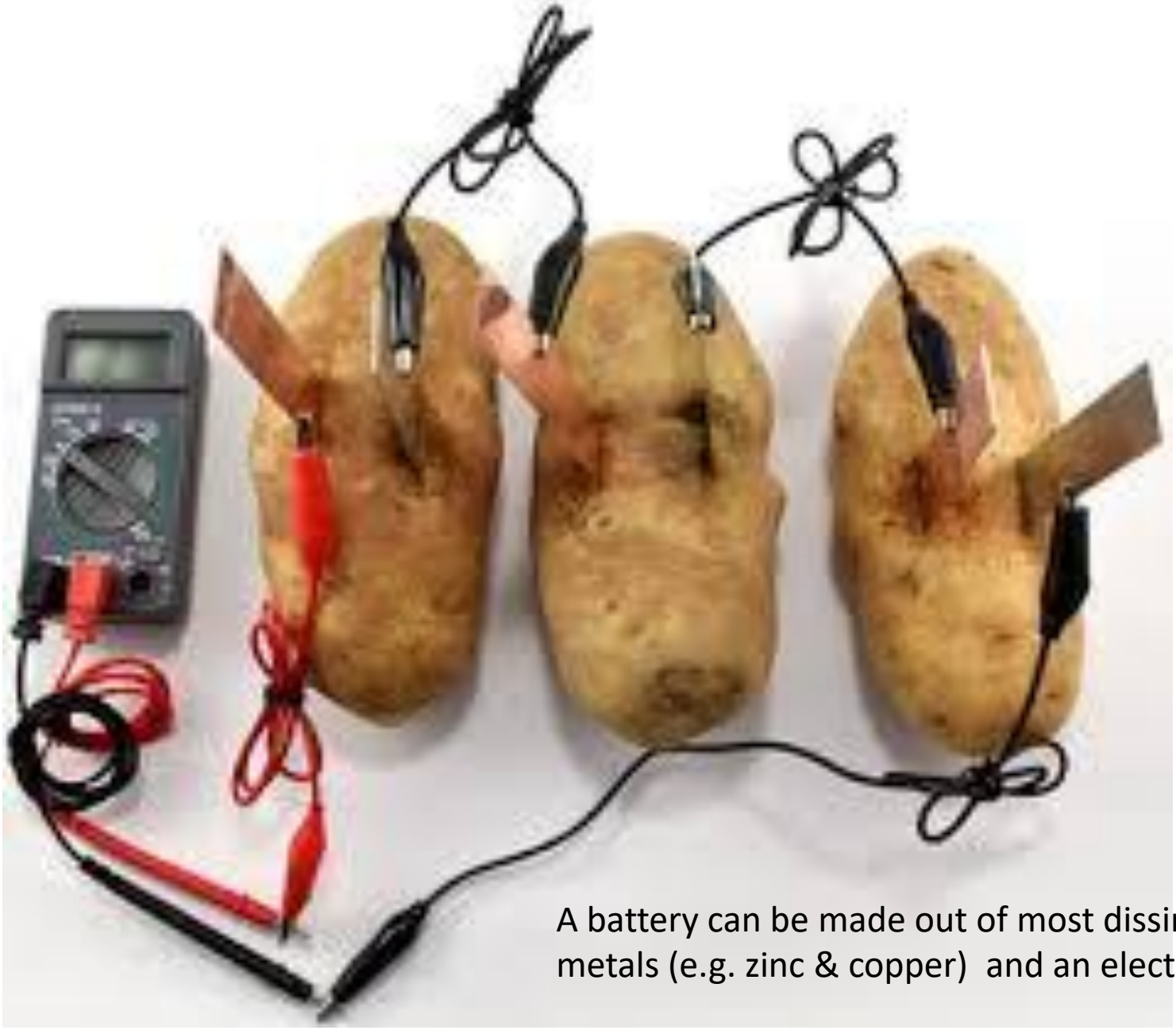
pb


Black color = battery has water
White color = battery needs water

pb

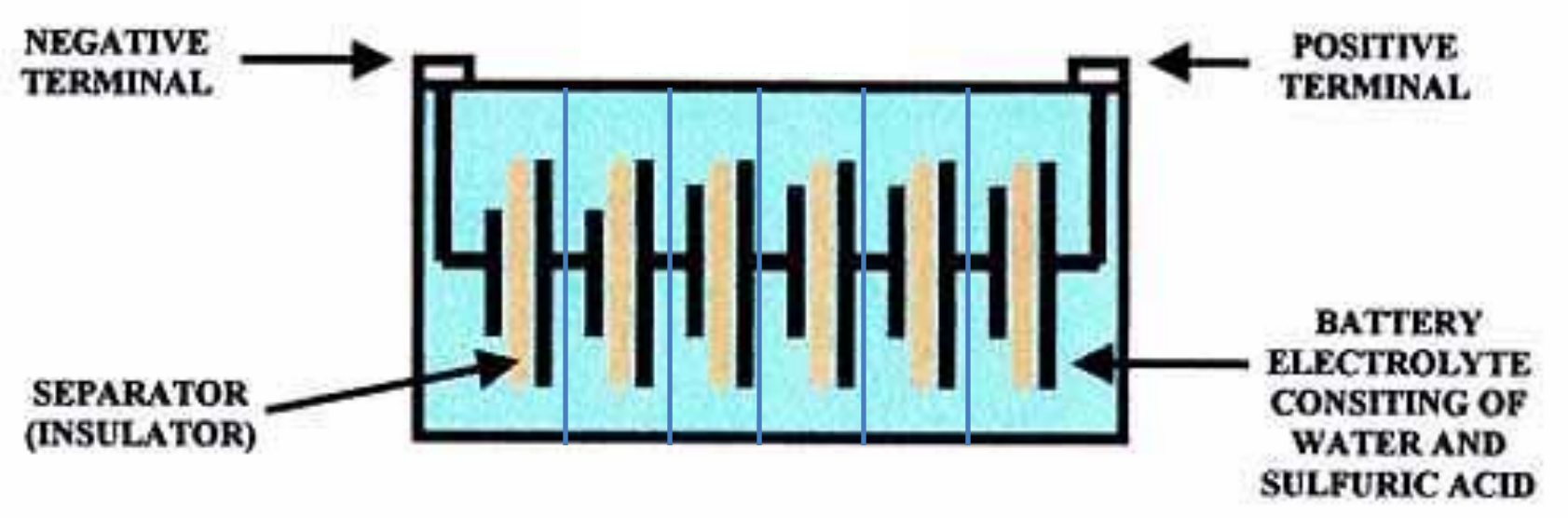
pb

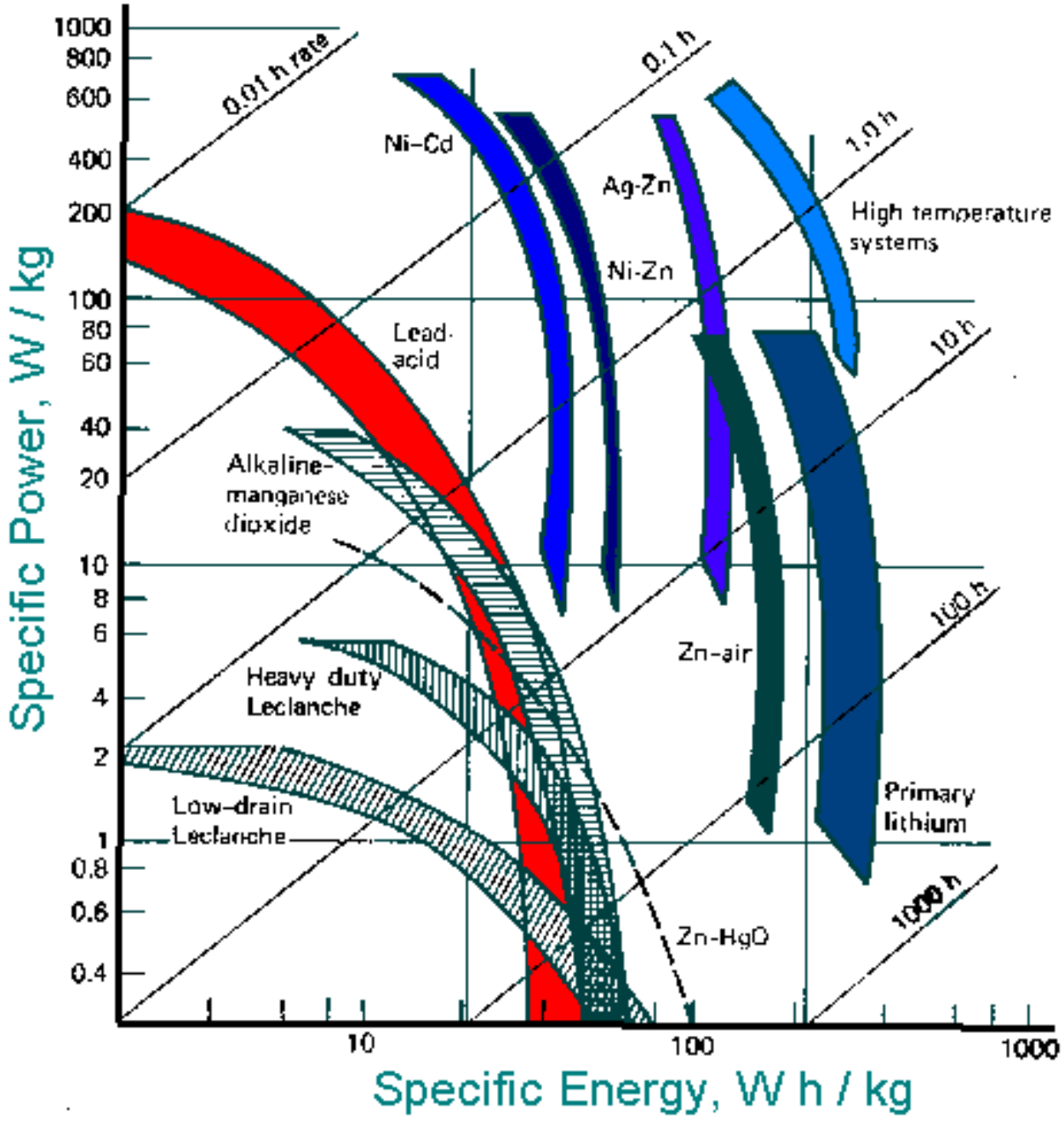
pb

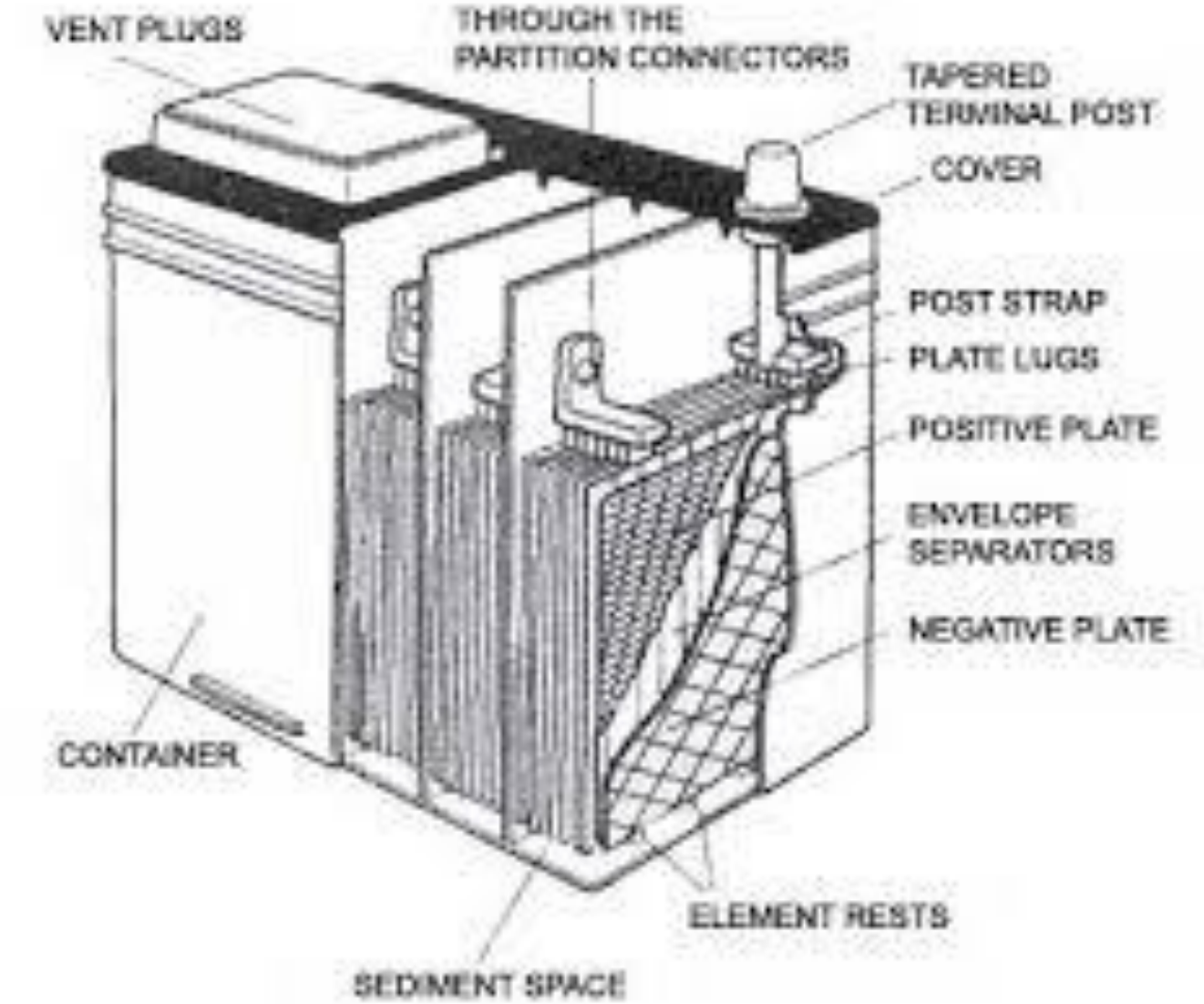


A battery can be made out of most dissimilar metals (e.g. zinc & copper) and an electrolyte.

Extra Material Follows


NEGATIVE TERMINAL
POSITIVE TERMINAL
SEPARATOR (INSULATOR)
BATTERY ELECTROLYTE CONSITING OF WATER AND SULFURIC ACID


Specific Power, W / kg
1000
800
600
400
200
100
80
60
40
20
10
8
6
4
2
1
0.8
0.6
0.4
0.01 h rate
0.1 h
1.0 h
10 h
100 h
1000 h
Ni-Cd
Ag-Zn
Ni-Zn
High temperature systems
Lead-acid
Alkaline-manganese dioxide
Heavy duty Leclanche
Low-drain Leclanche
Zn-air
Primary lithium
Zn-HgO
10
100
1000
Specific Energy, W h / kg


VENT PLUGS
THROUGH THE PARTITION CONNECTORS
TAPERED TERMINAL POST
COVER
POST STRAP
PLATE LUGS
POSITIVE PLATE
ENVELOPE SEPARATORS
NEGATIVE PLATE
CONTAINER
ELEMENT RESTS
SEDIMENT SPACE

Voltage table for cyclic use charging. The higher voltages (above the gassing voltage) should only be used on flooded batteries that can have the water replaced:

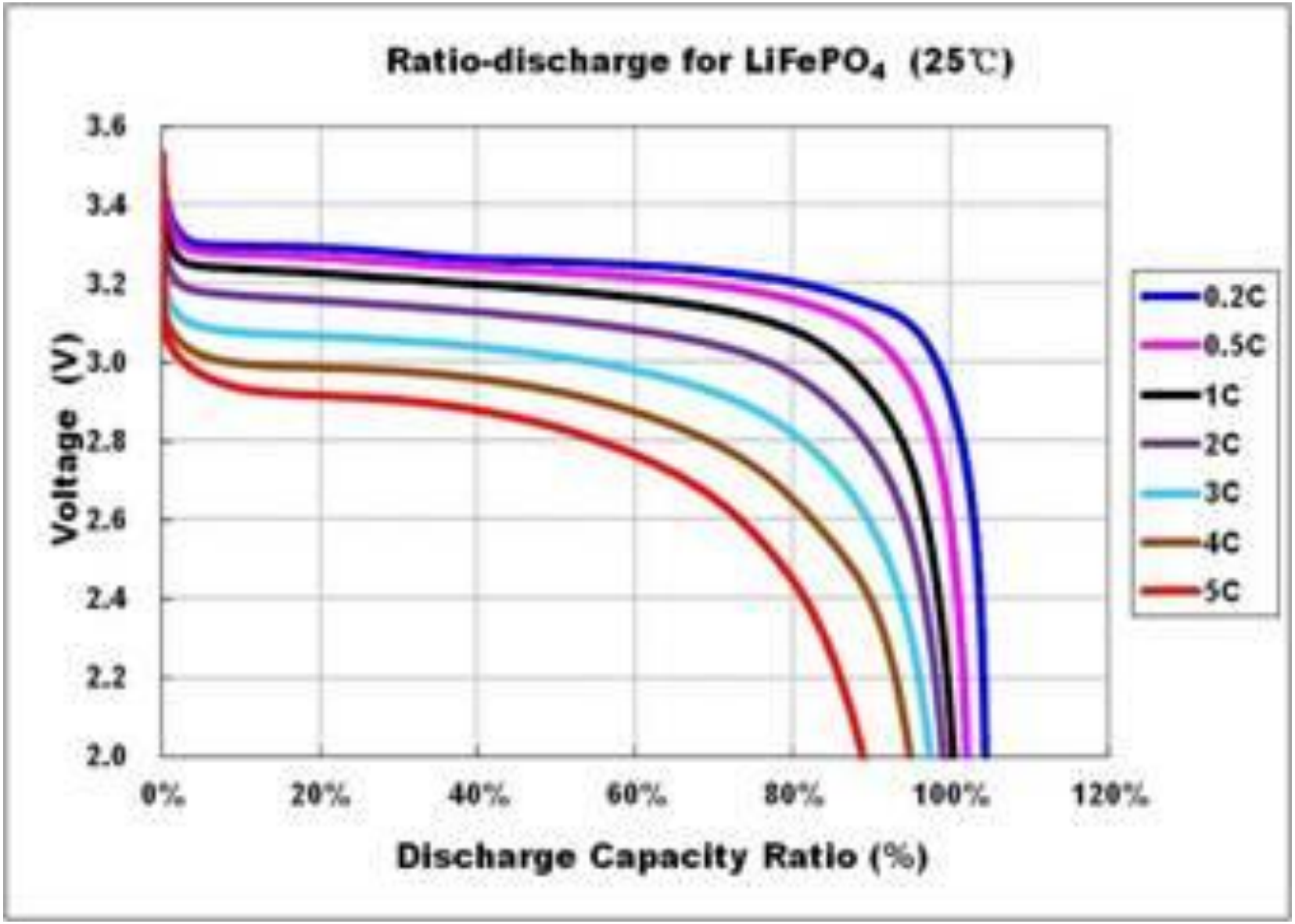
Battery Temperature	Charge Voltage per cell	Charge Voltage for a 12 Volt battery	Gassing Voltage per cell	Gassing Voltage for a 12V battery
-20 °C *	2.67 to 2.76	16.02 to 16.56	2.97	17.82
-10 °C *	2.61 to 2.70	15.66 to 16.2	2.65	15.9
0 ° C *	2.55 to 2.65	15.3 to 15.9	2.54	15.24
10 °C	2.49 to 2.59	14.94 to 15.54	2.47	14.82
20 °C	2.43 to 2.53	14.58 to 15.18	2.415	14.49
25 °C	2.40 to 2.50	14.40 to 15.00	2.39	14.34
30 °C	2.37 to 2.47	14.22 to 14.82	2.365	14.19
40 °C	2.31 to 2.41	13.86 to 14.46	2.33	13.98
50 °C	2.25 to 2.35	13.5 to 14.10	2.30	13.8

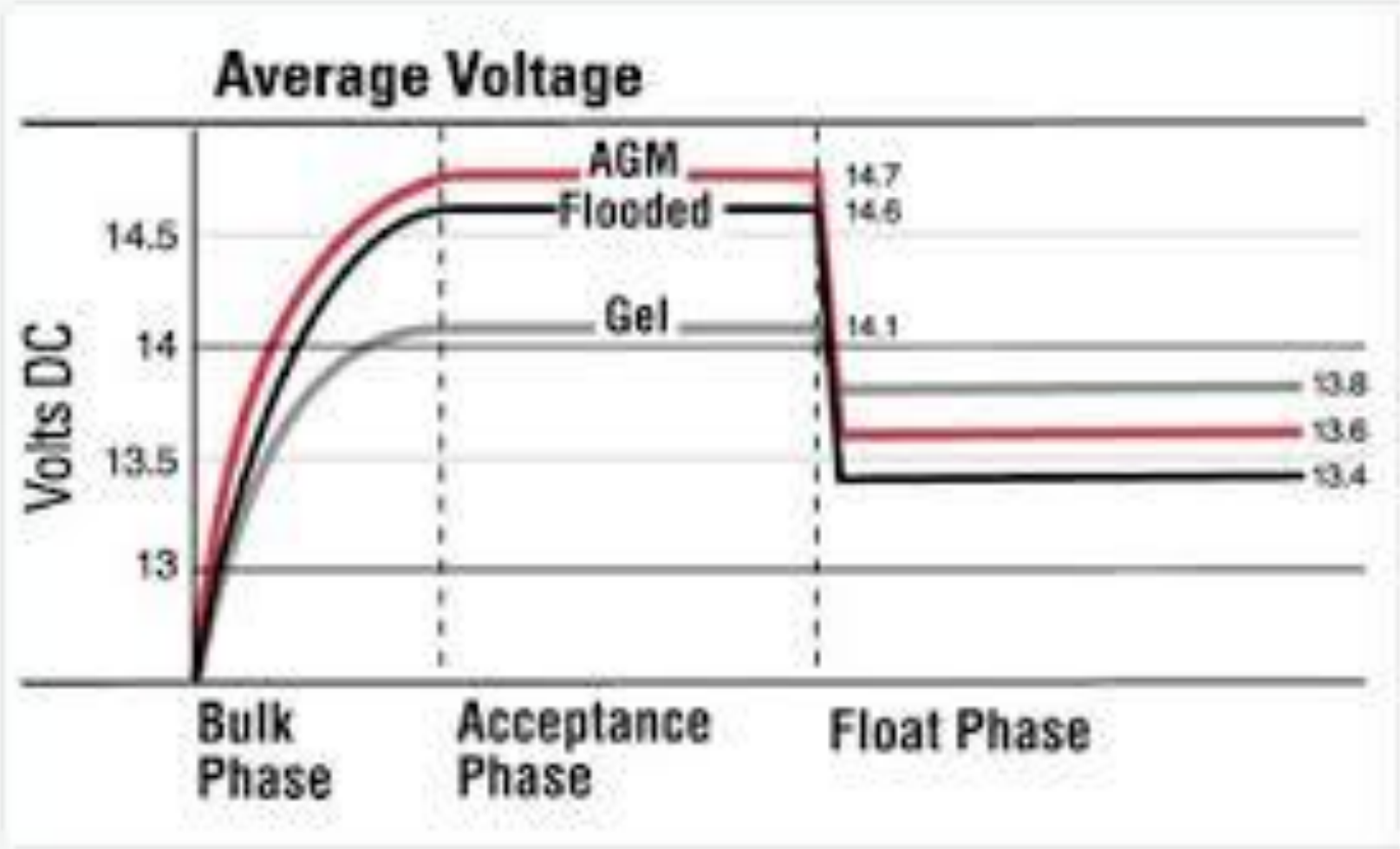
Voltage table for standby use charging:

Battery Temperature	Charge Voltage per cell	Charge Voltage for 12V Battery	Gassing voltage
-30 °C *	2.44	14.6	
-20 °C *	2.34 to 2.38	14.04 to 14.28	2.97
-10 °C *	2.32 to 2.37	13.92 to 14.22	2.65
0 °C	2.30 to 2.35	13.8 to 14.1	2.54
10 °C	2.28 to 2.33	13.68 to 13.98	2.47
20 °C	2.26 to 2.31	13.56 to 13.86	2.415
25 °C	2.25 to 2.30	13.5 to 13.8	2.39
30 °C	2.24 to 2.29	13.44 to 13.74	2.365
40 °C	2.22 to 2.27	13.32 to 13.62	2.33
50 °C	2.20 to 2.25	13.2 to 13.5	2.30

RC - Reserve Capacity

- European starter batteries are rated in Ah
- North America uses Reserve Capacity (RC)
- RC reflects the discharge time in minutes that a battery will discharge at a 25A rate to 10.5V.
- Conversion to AH is (RC/2)+16, or approx RC/1.9
- Ah rating is for 20 hour discharge (0.05C)


Ratio-discharge for LiFePO4 (25℃)
Voltage (V)
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
0%
20%
40%
60%
80%
100%
120%
Discharge Capacity Ratio (%)
0.2C
0.5C
1C
2C
3C
4C
5C

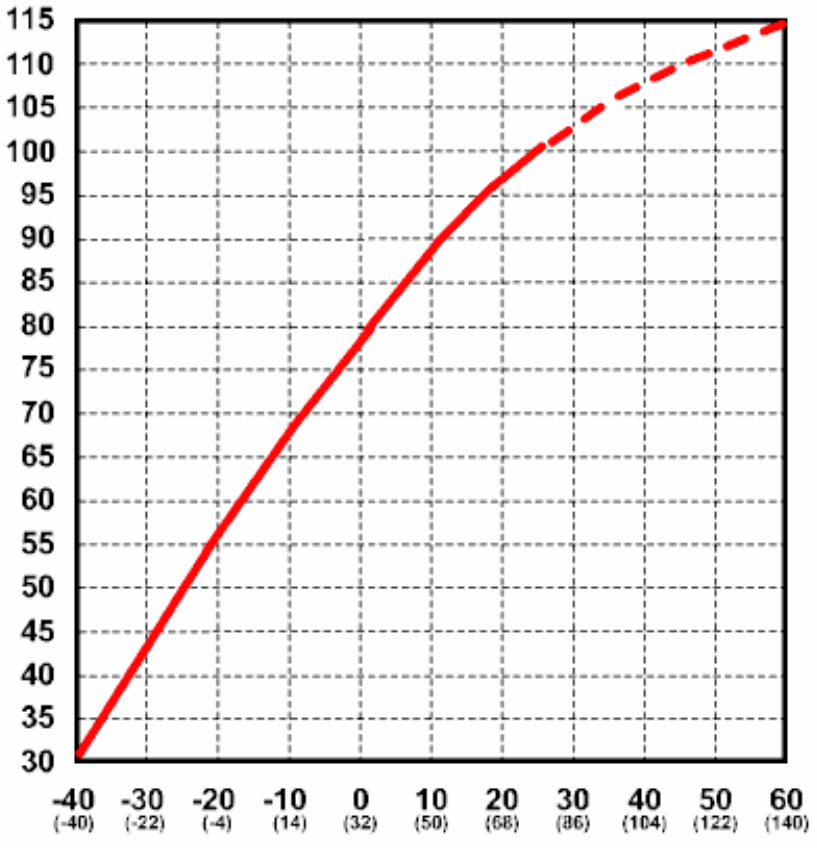

Average Voltage
Volts DC
14.5
14
13.5
13
AGM
Flooded
Gel
14.7
14.6
14.1
13.8
13.6
13.4
Bulk Phase
Acceptance Phase
Float Phase

Lead Acid Size Codes

U1	34 to 40 Amp hours	12 volts
Group 24	70-85 Amp hours	12 volts
Group 27	85-105 Amp hours	12 volts
Group 31	95-125 Amp hours	12 volts
4-D	180-215 Amp hours	12 volts
8-D	225-255 Amp hours	12 volts
Golf Cart & T-105	180 to 225 Amp hours	6 volts
L-16, L16HC etc.	340 to 415 Amp hours	6 volts

Lead Acid Capacity vs. Temp

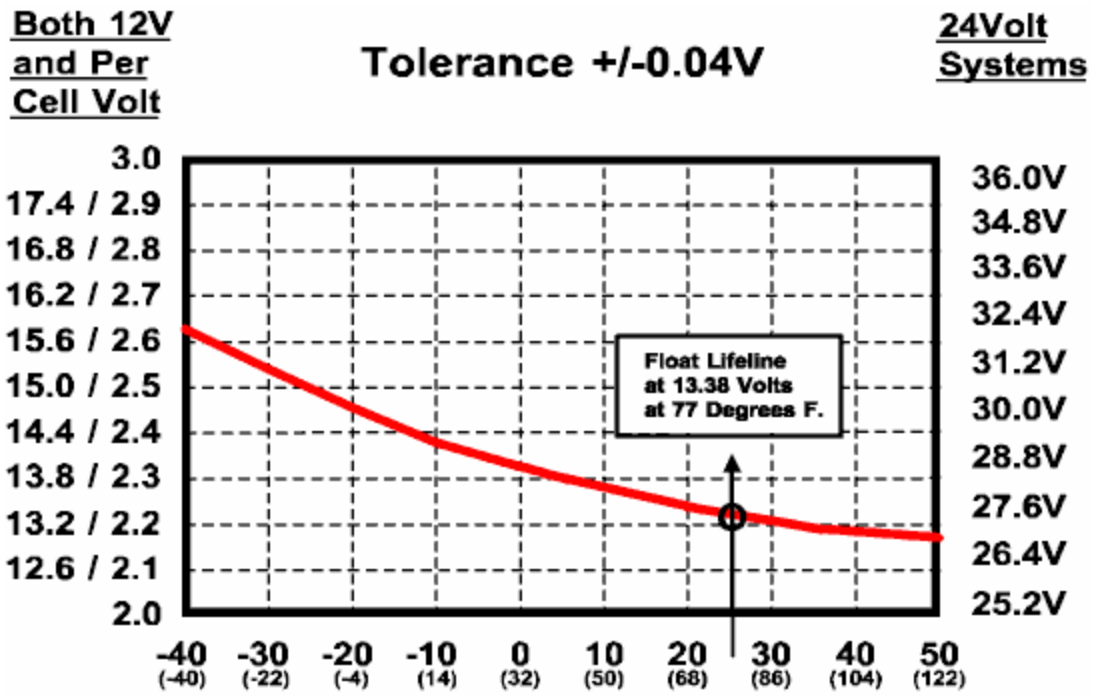
- Even though battery capacity at high temperatures is higher, battery *life* is shortened. Battery capacity is reduced by 50% at -22 degrees F - but battery LIFE increases by about 60%. Battery life is reduced at higher temperatures - for every 15 degrees F over 77, battery life is cut in half. This holds true for ANY type of Lead-Acid battery, whether sealed, gelled, AGM, industrial or whatever. This is actually not as bad as it seems, as the battery will tend to average out the good and bad times.



Lead Acid Charge Voltage vs. Temp

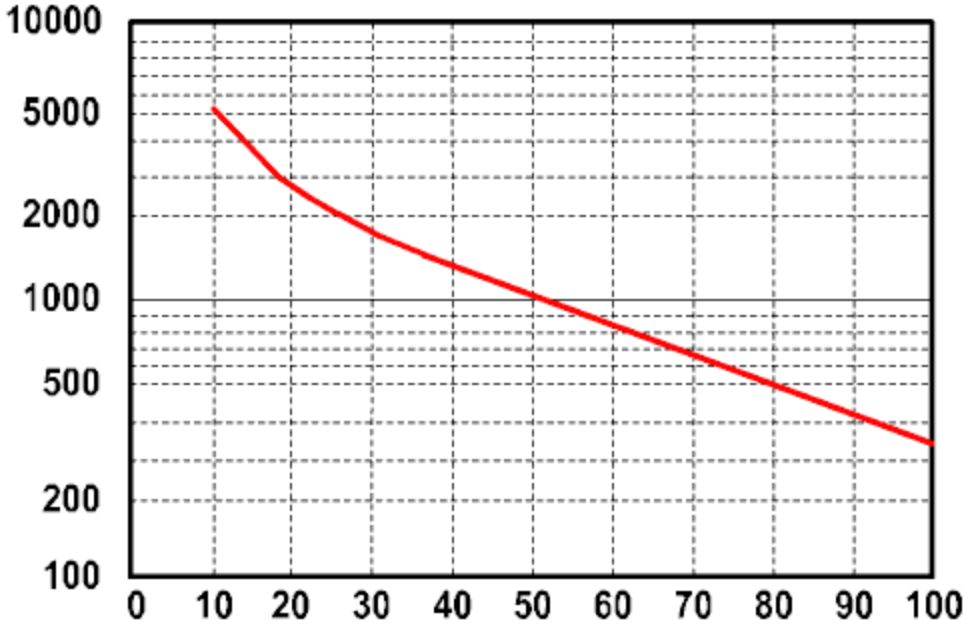
Battery charging **voltage** also changes with temperature. It will vary from about 2.74 volts per cell (16.4 volts) at -40 C to 2.3 volts per cell (13.8 volts) at 50 C.

This is why you should have temperature compensation on your charger or charge control if your batteries are outside and/or subject to wide temperature variations. Some charge controls have temperature compensation built in (such as Morningstar) - this works fine if the controller is subject to the same temperatures as the batteries.



Lead Acid DoD vs. Cycle Life

Battery life is directly related to how **deep** the battery is cycled each time. If a battery is discharged to 50% every day, it will last about twice as long as if it is cycled to 80% DOD. If cycled only 10% DOD, it will last about 5 times as long as one cycled to 50%. Obviously, there are some practical limitations on this - you don't usually want to have a 5 ton pile of batteries sitting there just to reduce the DOD.



The most practical number to use is 50% DOD on a regular basis. This does NOT mean you cannot go to 80% once in a while. It's just that when designing a system when you have some idea of the loads, you should figure on an **average** DOD of around 50% for the best storage vs cost factor.

Lead Acid

Typical no-load voltages vs state of charge

(Figured at 10.5 volts = fully discharged, and 77 degrees F).

VPC is the volts per individual cell - if you measure more than a .2 volt difference between each cell, you need to equalize, or your batteries are going bad, or they may be sulfated.

These voltages are for batteries that have been at rest for 3 hours or more. Batteries that are being charged will be higher - the voltages while under charge will not tell you anything, you have to let the battery sit for a while.

For longest life, batteries should stay in the green zone. Occasional dips into the yellow are not harmful, but continual discharges to those levels will shorten battery life considerably.

State of Charge	12 Volt battery	Volts per Cell
100%	12.7	2.12
90%	12.5	2.08
80%	12.42	2.07
70%	12.32	2.05
60%	12.20	2.03
50%	12.06	2.01
40%	11.9	1.98
30%	11.75	1.96
20%	11.58	1.93
10%	**11.31**	**1.89**
0	**10.5**	**1.75**

Lead Acid Deep Cycling

These are some typical (minimum - maximum) expectations for batteries **if used in deep cycle service**. There are so many variables, such as depth of discharge, maintenance, temperature, how often and how deep cycled, etc. that it is almost impossible to give a fixed number.

- Starting: 3-12 months
- Marine: 1-6 years
- Golf cart: 2-7 years
- AGM deep cycle: 4-8 years
- Gelled deep cycle: 2-5 years
- Deep cycle (L-16 type etc): 4-8 years
- Rolls-Surrette premium deep cycle: 7-15 years
- Industrial deep cycle (Crown and Rolls 4KS series): 10-20+ years.
- Telephone (float): 2-20 years. These are usually special purpose "float service", but often appear on the surplus market as "deep cycle". They can vary considerably, depending on age, usage, care, and type.
- NiFe (alkaline): 5-35 years
- NiCad: 1-20 years