

BATTERIES for RC

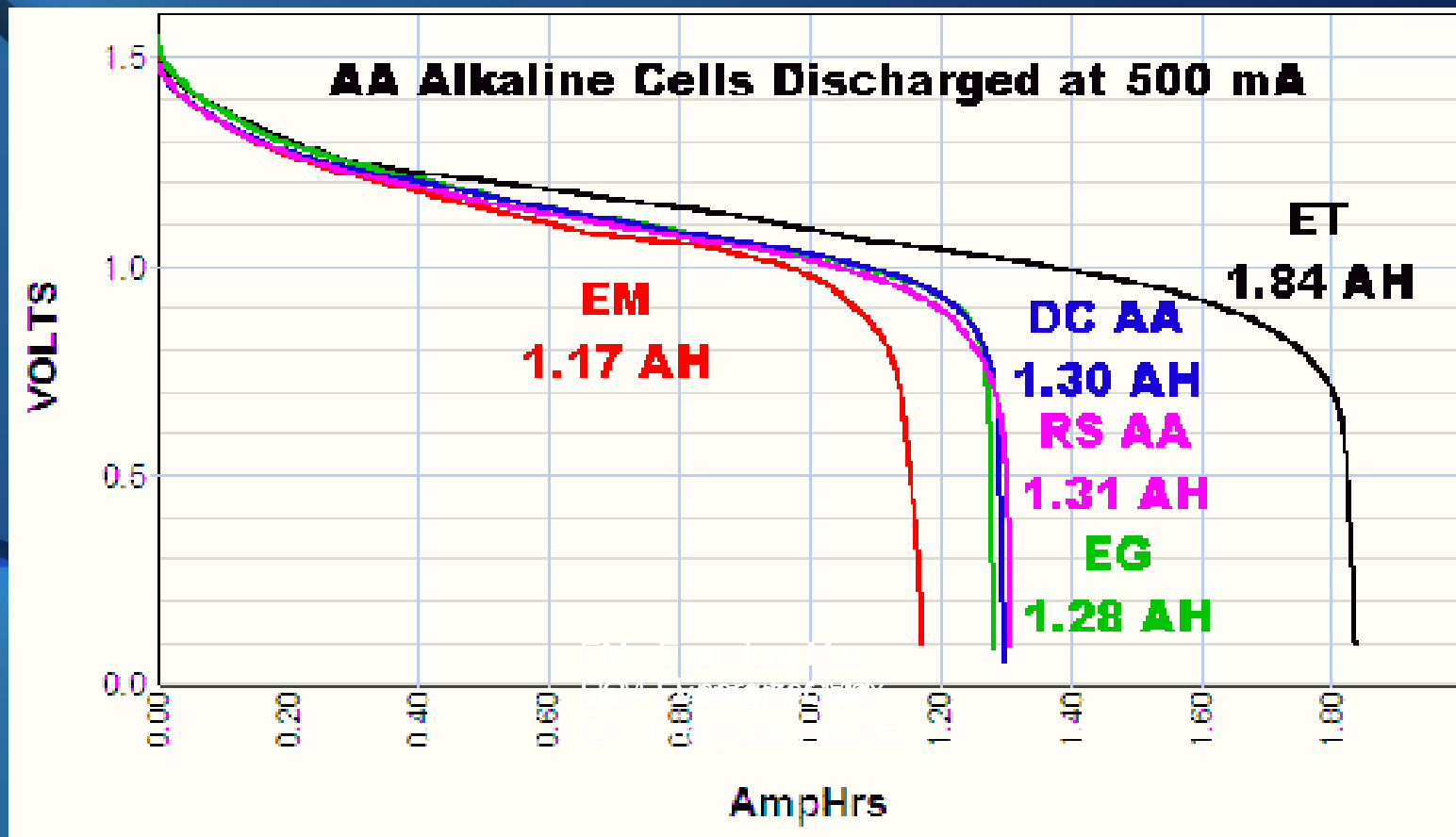
Performance, Care and Feeding

Information:
Slides:

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Bill Kuhlman

The background is a deep blue with several large, overlapping, wavy shapes in lighter and darker shades of blue, creating a sense of movement and depth. The word "Alkaline" is centered in a white, sans-serif font.

Alkaline



EM - Energizer Max

DC - Duracell Coppertop

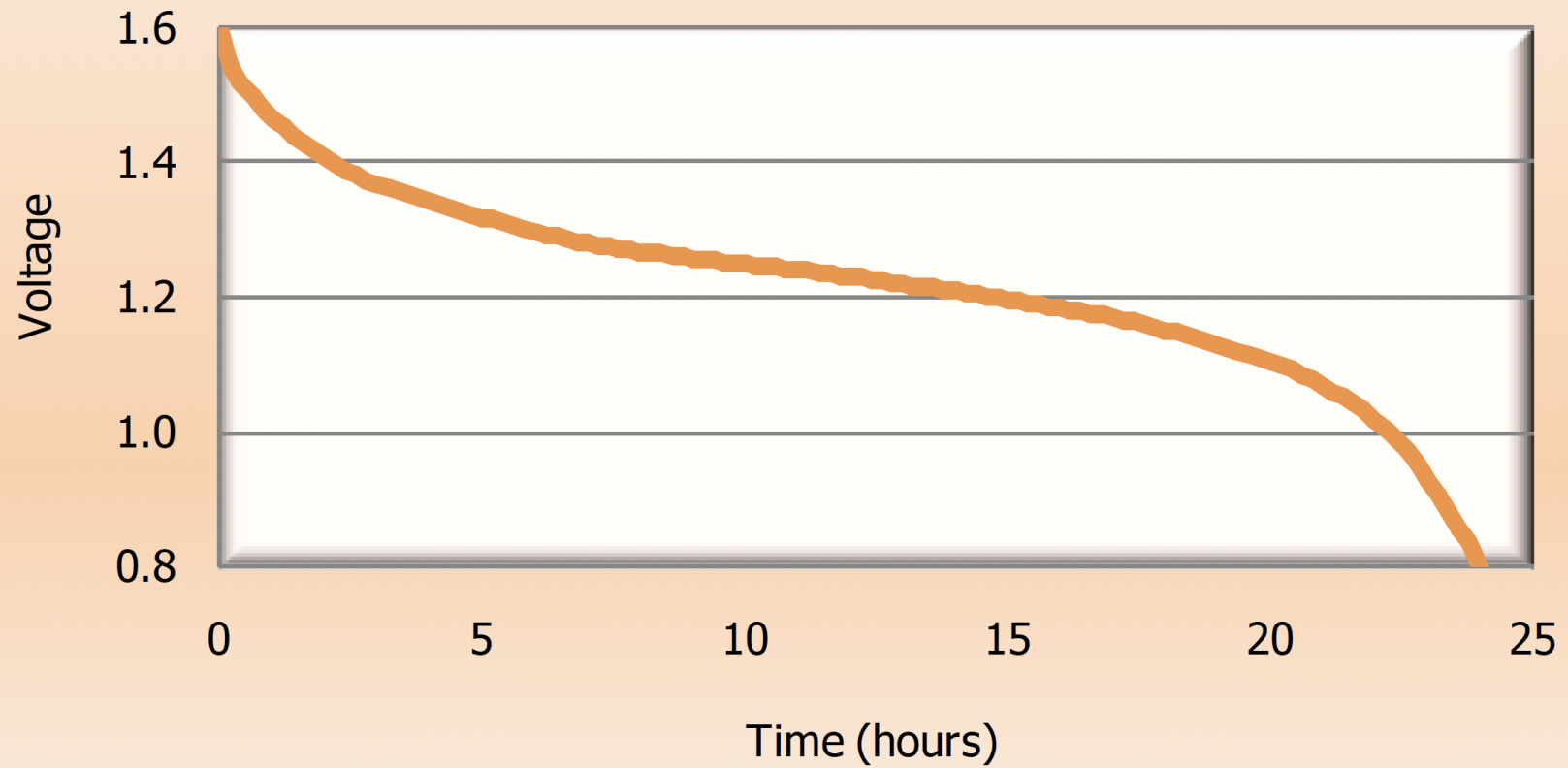
RS - Radio Shack

EG - Eveready Gold

ET - Energizer Titanium

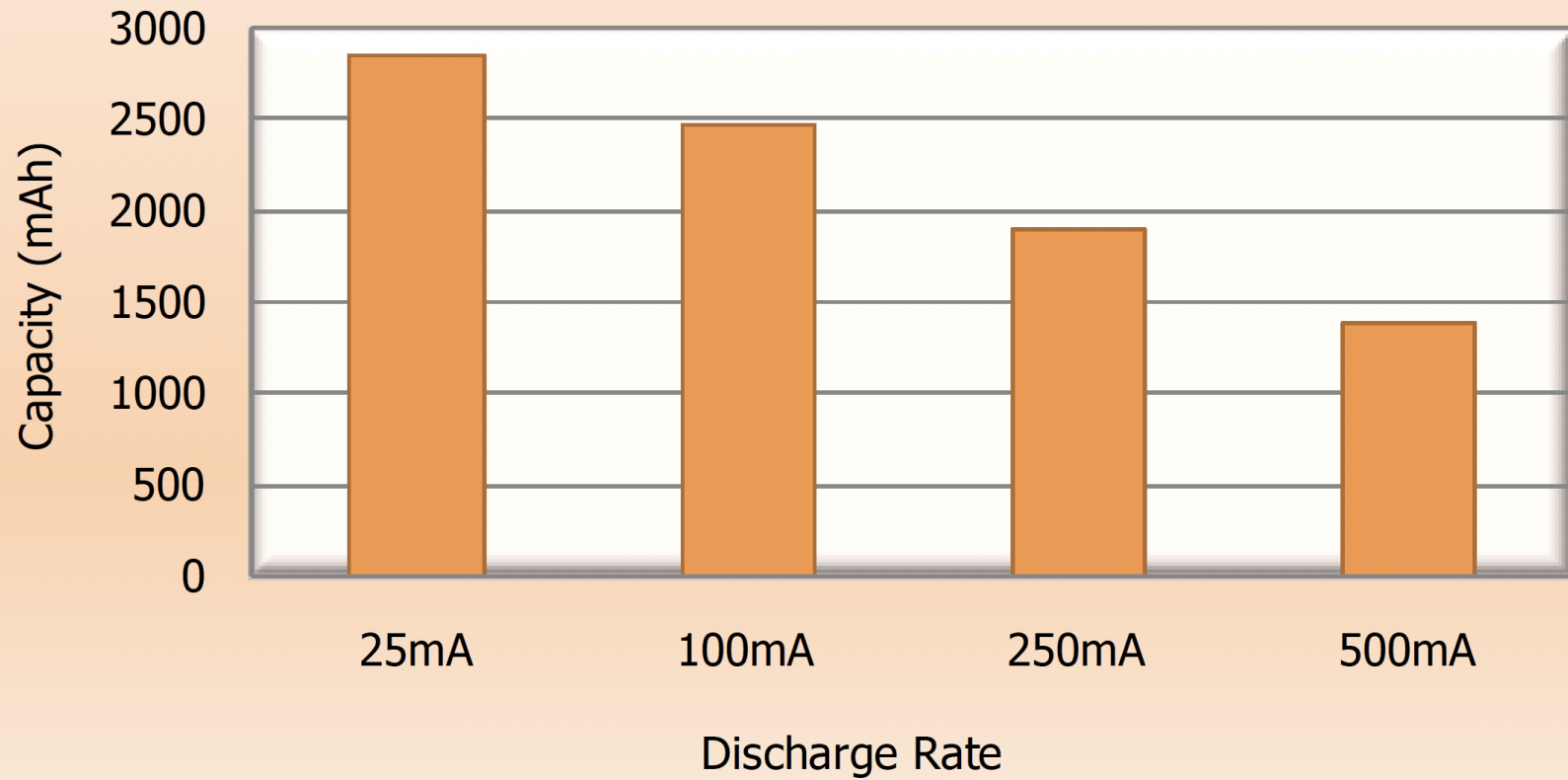
AA/LR6 Alkaline Batteries

100mA Constant Current Discharge at 21C



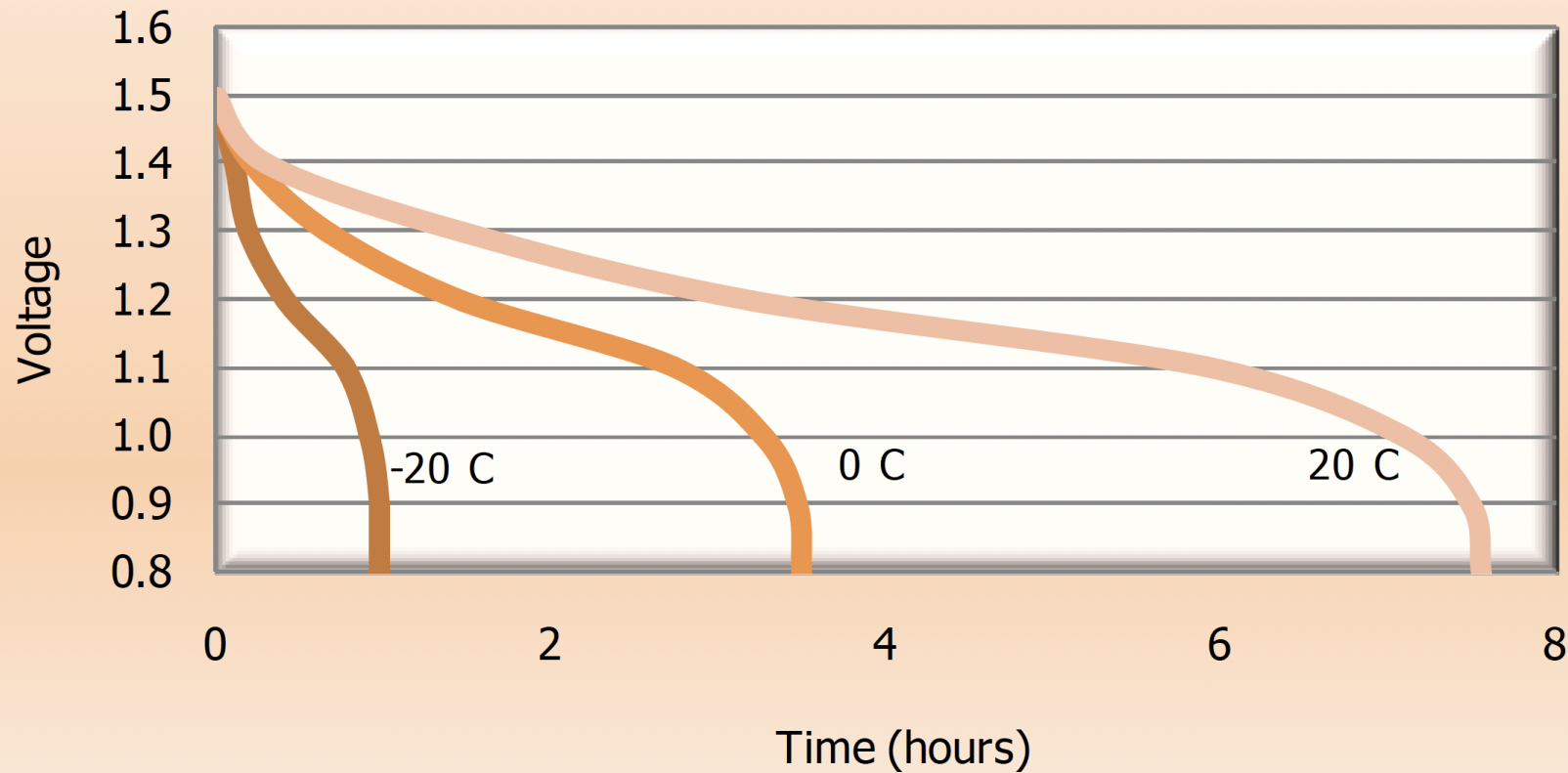
AA/LR6 Alkaline Batteries

Capacity (mAh) at 21C to 0.8 Volts



AA/LR6 Alkaline Batteries

Effect of Cold Temperature at 250 mA Continuous Discharge

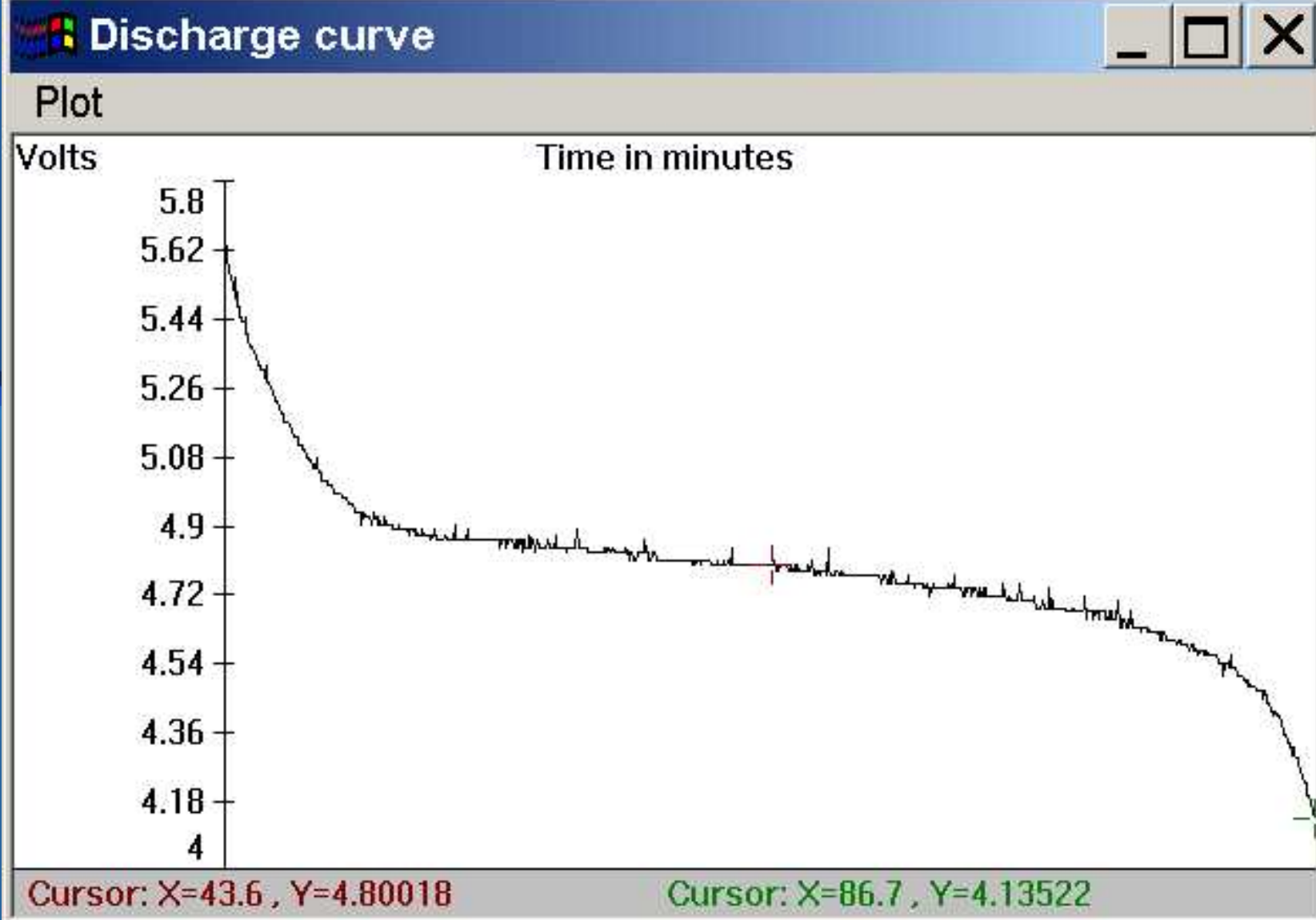


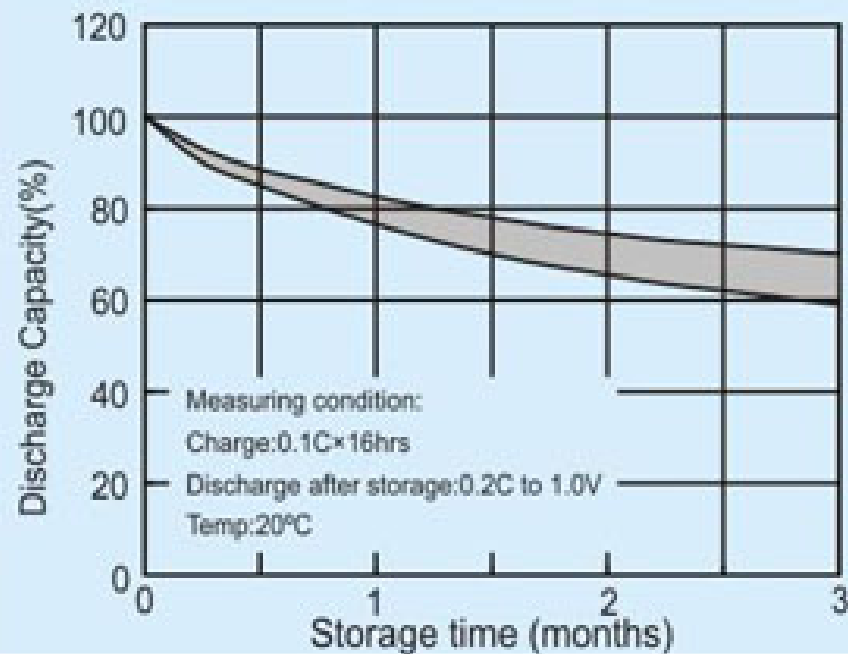
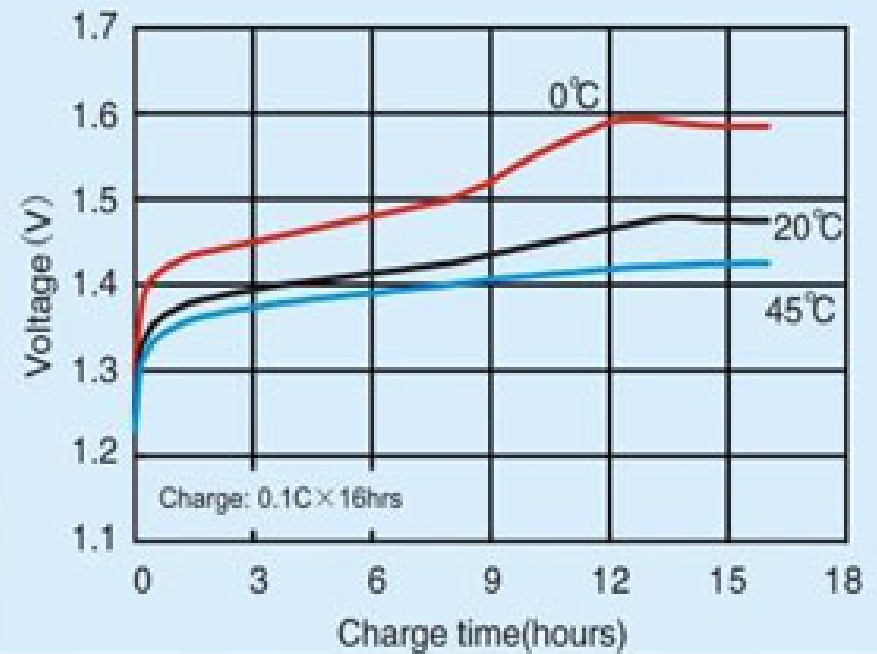
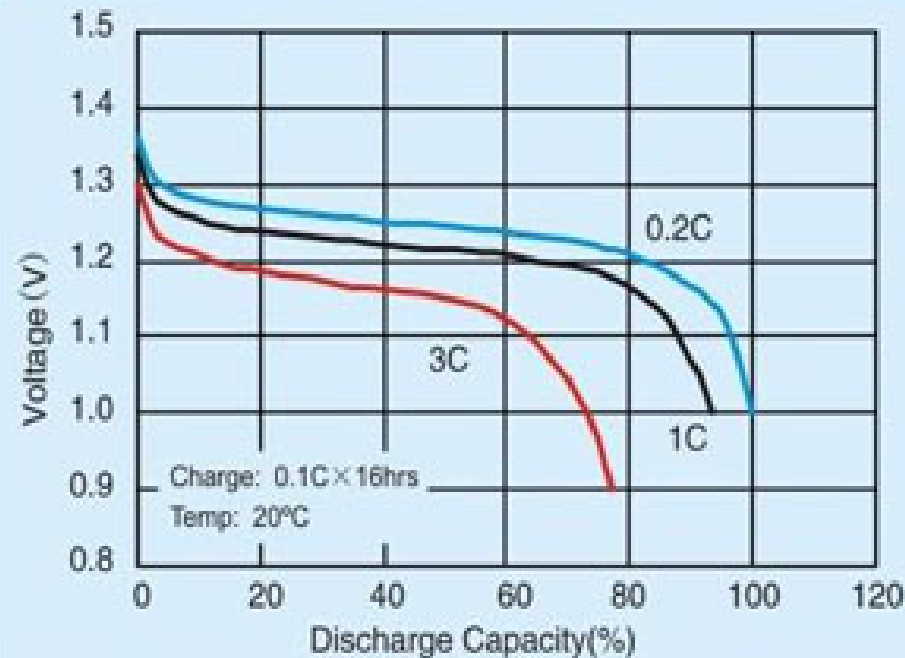
Current Drain Rate	Typical AA (MN1500) Usable Capacity	Typical AAA (MN2400) Usable Capacity
Low Drain (<i>e.g., 25 mA to 50 mA</i>)	~2,500 to 2,850 mAh	~1,000 to 1,150 mAh
Moderate Drain (<i>e.g., 100 mA to 250 mA</i>)	~1,800 to 2,200 mAh	~700 to 900 mAh
High Drain (<i>e.g., 500 mA to 1000 mA+</i>)	~1,000 to 1,500 mAh	~400 to 600 mAh

Alkaline Battery Characteristics

- Relatively flat discharge curve under low load until near end, then rapid voltage drop.
- Internal resistance is stable, minimal change.
- Risk of leakage of over-discharged.
- Not suitable for high C-rates.

Nickel Cadmium (NiCd)





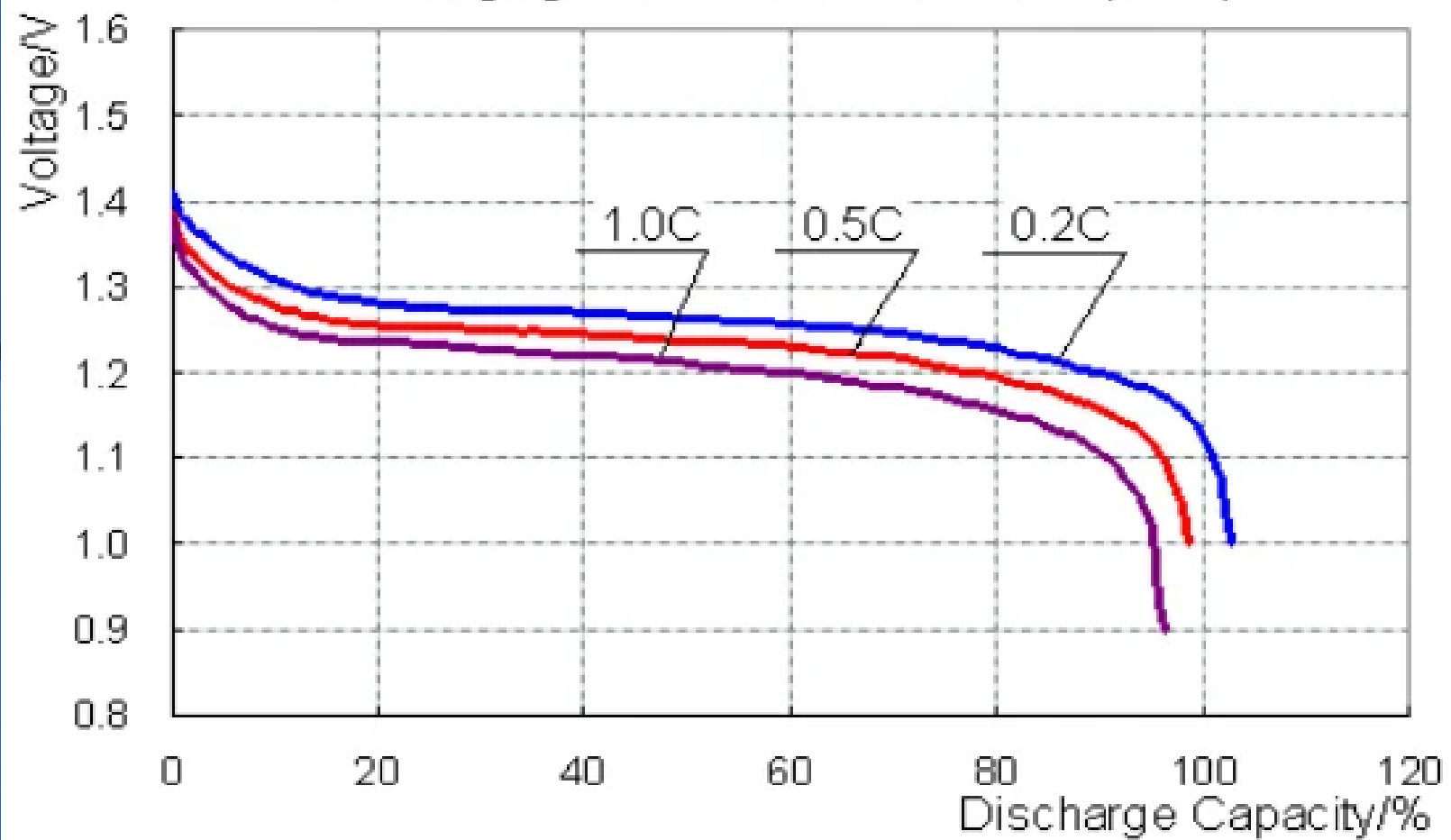
- Flatter discharge curve than alkaline
- Capacity reduced with higher load
- Always charge at $1/10C$!
- Cell V with full charge (12-16 hours) depends on charge temperature
- Be aware of self-discharge

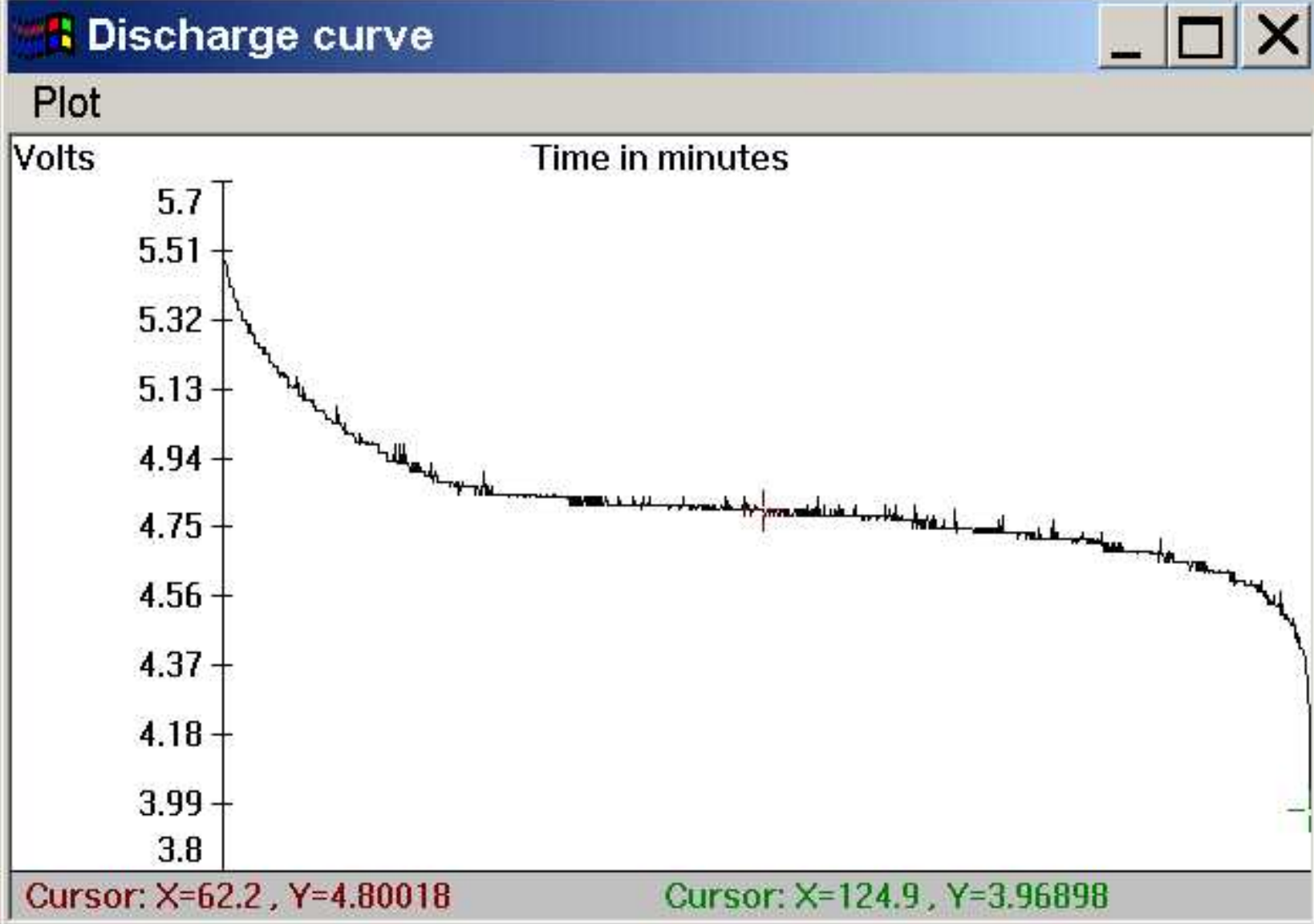
NiCd Battery Characteristics

- Gradual drop in discharge curve with a slight flat region.
- Can recover voltage with rest.
- Charge curve shows a sharp rise to peak, then tapering off.
- Chargers detect peak peak voltage (1.4V/cell)
- Internal resistance increases with cycles (memory effect).
- Risk of thermal runaway if overcharged; can vent gas.

Nickel Metal Hydride (NiMH)

Discharging Curves at Various Rates(20°C)

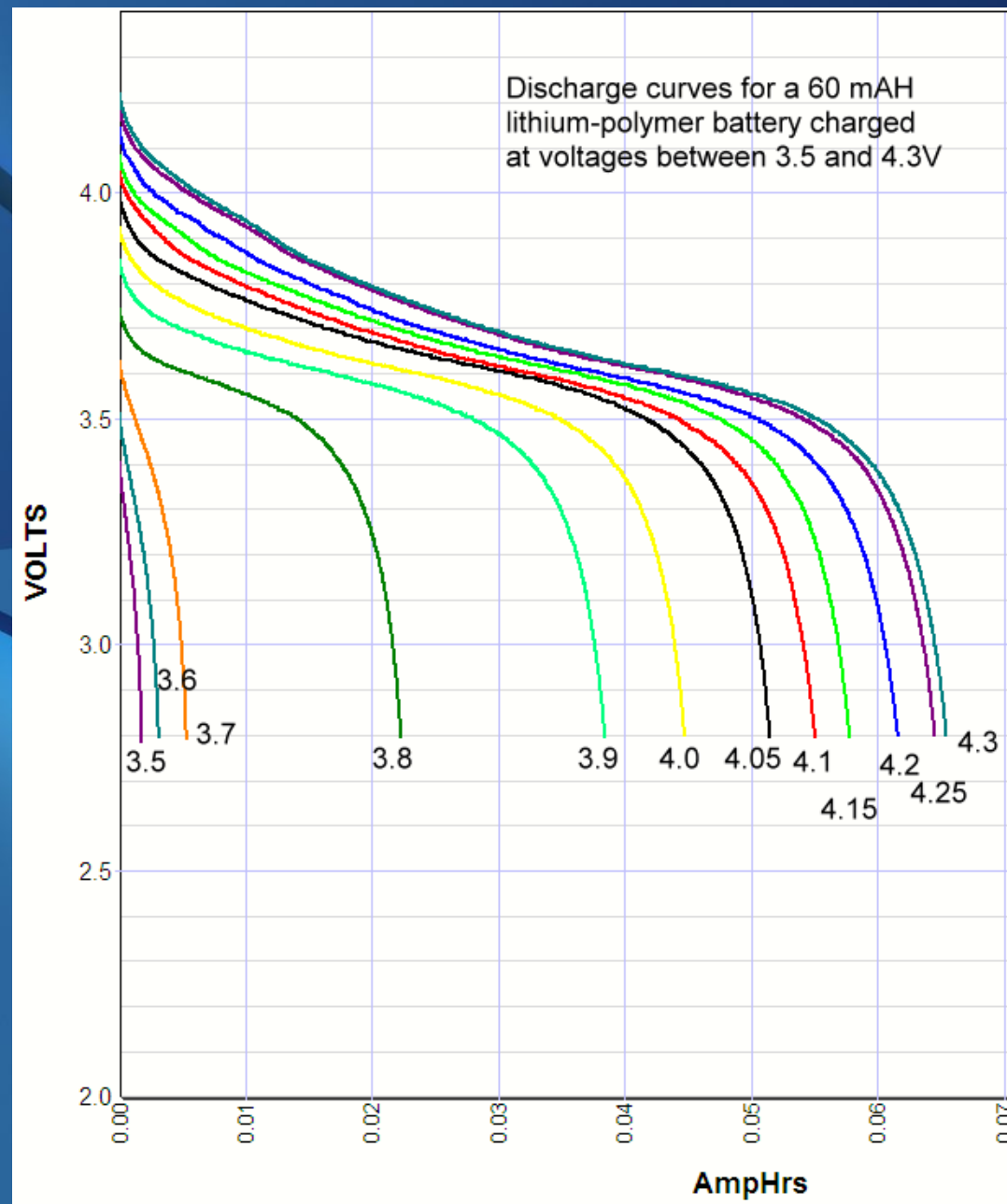




NiMH Battery Characteristics

- Gradual drop in discharge curve with a longer flat region than NiCd.
- Charge curve shows a sharp rise to peak, then tapering off, similar to NiCd but at lower peak voltage.
- Charger detects peak voltage (1.45V/cell).
- Internal resistance increases with cycles, but less severe than NiCd.
- Can heat up under high C discharge; risk of venting.

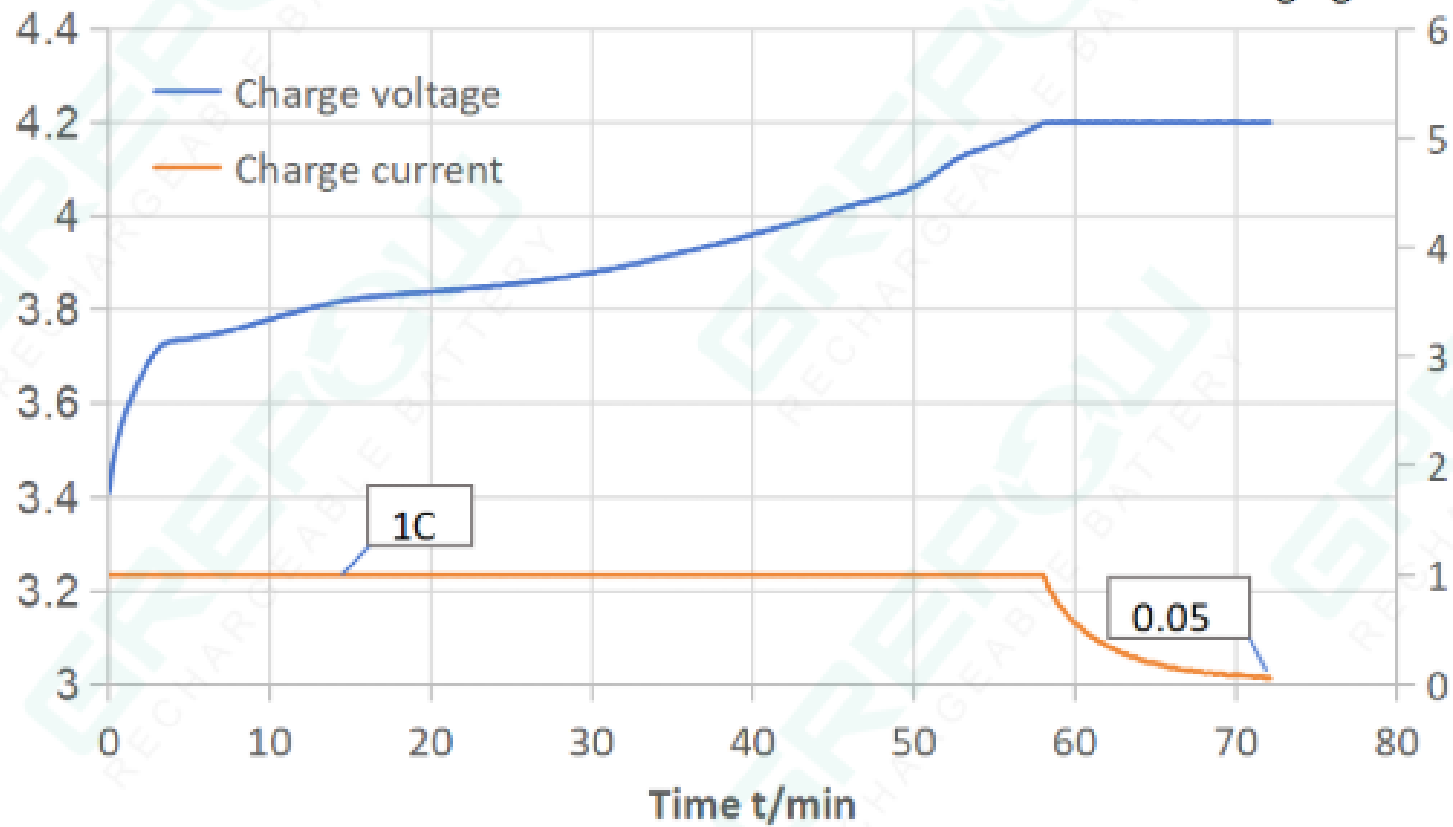
Lithium
(LiPo)



CCCV 1C / 4.2V / $I_{\min}$ 0.05C(RT)

Voltage(V)

Charging



LiPo Battery Characteristics

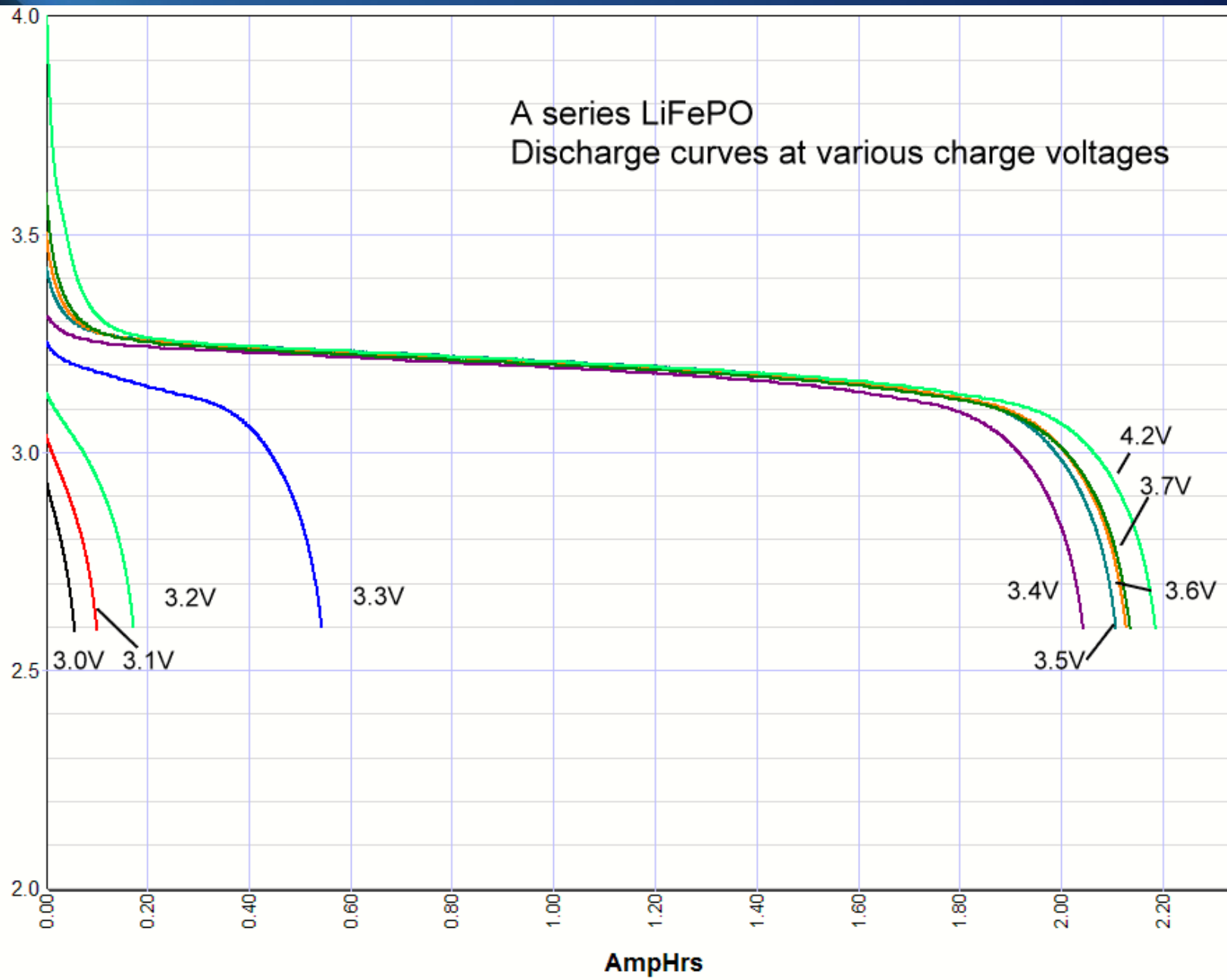
- Sharp drop after initial voltage plateau; can recharge cut-off voltage quickly.
- Charge curve shows a rapid rise to peak, then a sharp decrease.
- Charger detects peak voltage (4.2V/cell).
- Internal resistance is generally stable, but can increase with cycles.
- Fire hazard if punctured or overcharged; must be monitored for swelling.

Lithium

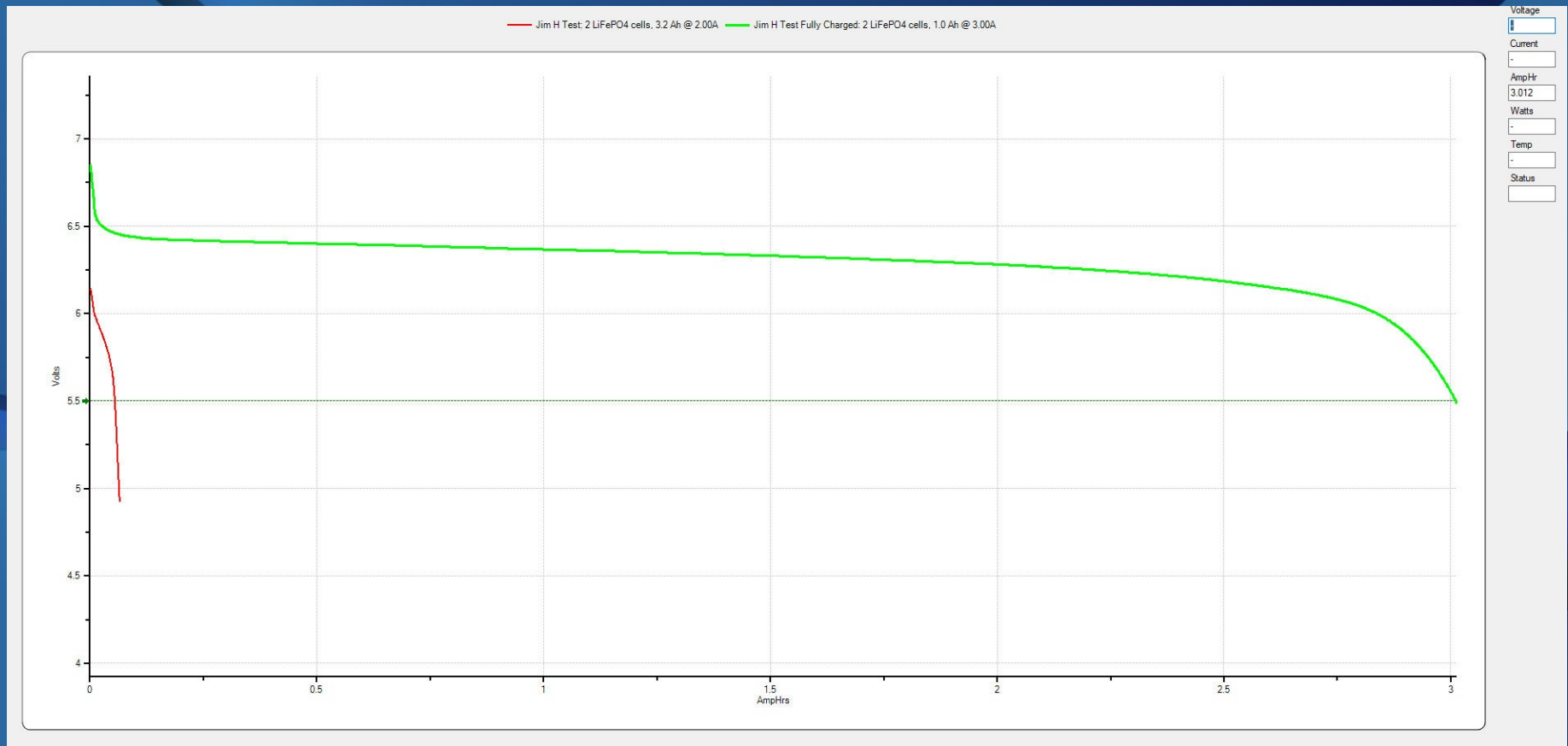
$\text{LiFePO}_4/\text{LiFe}$

A series LiFePO₄
Discharge curves at various charge voltages

VOLTS

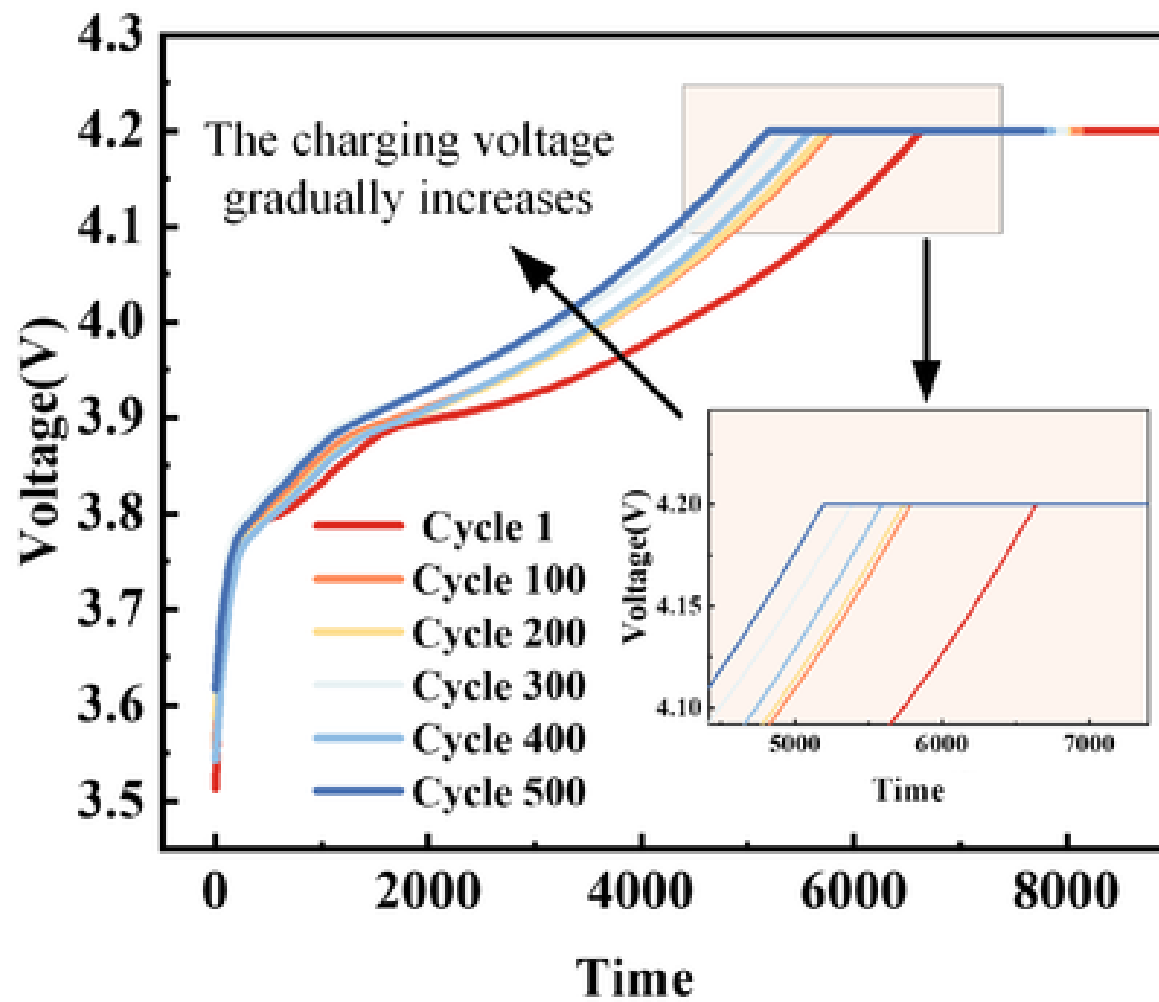


AmpHrs



- Discharge curve for a 3200mAh 2S, 6.12V at start, 2.0A load.
- Discharge curve for a 3200mAh 2S, 6.85V (fully charged) at start, 3.0A load.

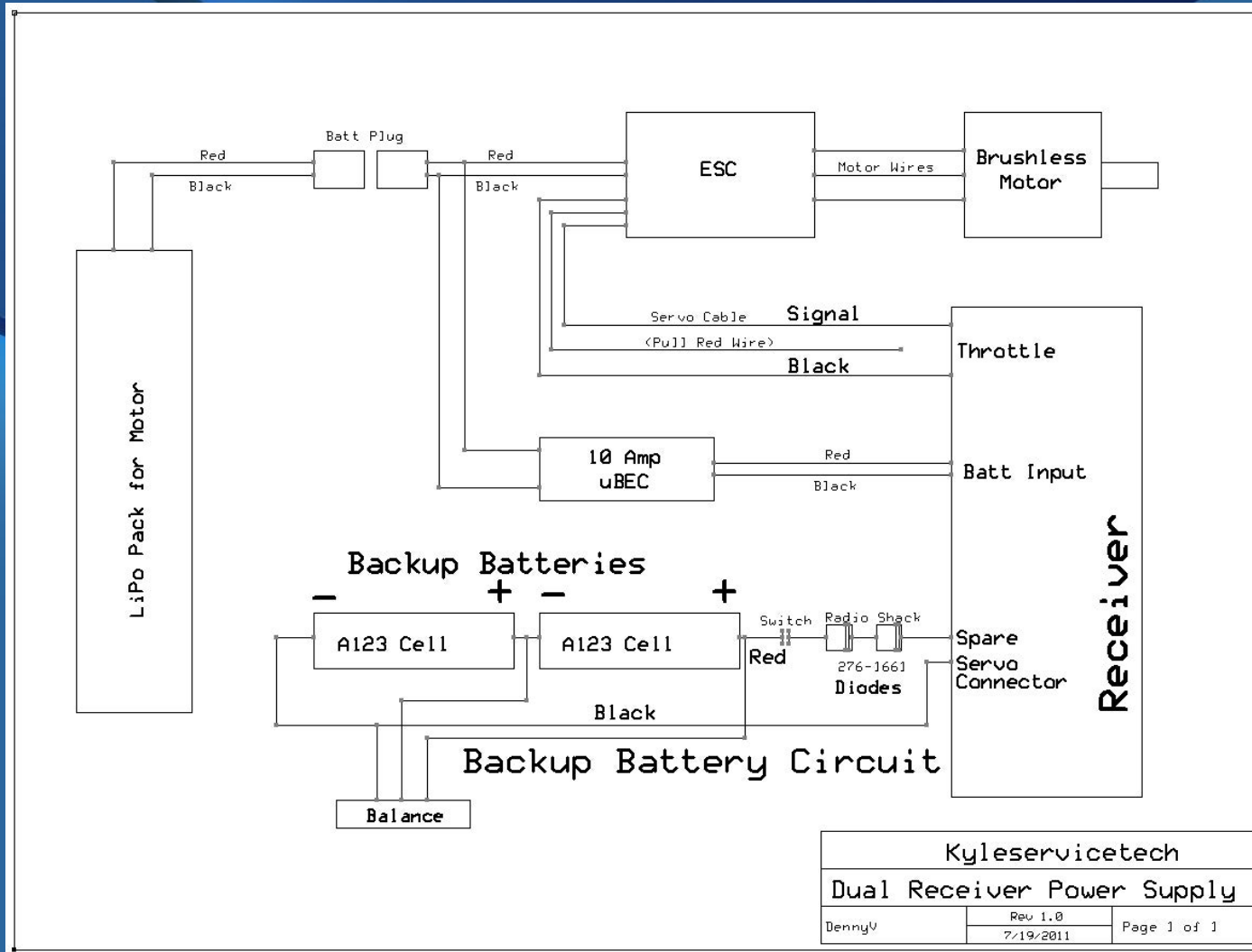
Western Mountain CBA battery analyzer



LiFe Cell Data

Cell designation	Diameter × Length	Typical capacity	Typical weight
10440	10 × 44 mm	300–350 mAh	~10 g
14500 (AA size)	14 × 50 mm	500–700 mAh	~18–22 g
18650	18 × 65 mm	1.1–1.8 Ah	~35–42 g
26650	26 × 65 mm	2.3–3.5 Ah	~80–95 g
32700	32 × 70 mm	5–7 Ah	~140–150 g

Dual Battery Circuit



LiFe Battery Characteristics

- Flat discharge curve; maintains voltage better under load.
- Charge curve is similar to LiPo, but with lower peak voltage.
- Charger detects peak voltage (3.6V/cell).
- Internal resistance is extremely stable, with minimal changes over cycles.
- Safer than LiPo. Can handle high C-rates better than LiPo, but still risks overheating.

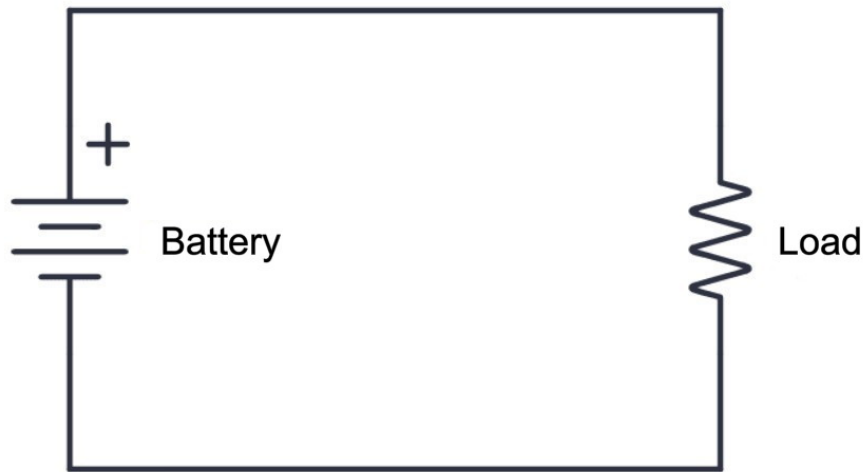
General Characteristics

- Alkaline cells are used in low-drain applications and are not rechargeable.
- NiCd cells are robust and can deliver high discharge rates. Suffer from memory effect, reducing effective capacity.
- NiMH offer higher capacity than NiCd with less memory effect. No cadmium, so environment-friendly.
- LiPo have high energy density with light weight, so popular. Requires careful handling due to fire hazard.
- A123/LiFe are known for both safety and stability. Can handle high discharge rates and have a long cycle life.

All rechargeable battery types require dedicated chargers.

The Importance of Battery Internal Resistance

Sources of Resistance



Internal Resistance
(battery ONLY)

Load:

- Receiver
- Servo(s)
- Telemetry transmitter
- ESC
- Powerplant(s)/Motor(s)

E, I, R, IR and P

E = voltage drop across the pack or cell [V]

I = the current in the circuit = V/R [Amps]

R = Resistance, the degree to which a conductor opposes an electric current through that conductor [Ω]

IR = Internal Resistance, the resistance of the battery alone [$m\Omega$]

P = Power loss in the form of heat generated in the pack. [W]

Ohms Law: $E_{\text{voltage}} = I_{\text{current}} \times R_{\text{resistance}}$

$$P_{\text{watts}} = I^2 \times IR$$

$$P_{\text{watts}} = V^2_{\text{voltage drop}} / IR$$

$$P_{\text{watts}} = I \times V_{\text{voltage drop}}$$

Using $P_{\text{watts}} = I^2 \times IR$

Example 1:

3S1P 850mAh high C battery, 50A at 12.6V

$IR = 10\text{m}\Omega/\text{cell} = 30\text{m}\Omega$ total IR

$$P = 50^2 \times 0.03 = 2500 \times 0.03$$

= 75W heat energy

Using $P_{\text{watts}} = I^2 \times IR$

Example 2:

3S1P 850mAh high C battery, 50A at 12.6V

$IR = 20\text{m}\Omega/\text{cell} = 60\text{m}\Omega$ total IR

$$P = 50^2 \times 0.06 = 2500 \times 0.06$$

= 150W heat energy

Using $E_{\text{voltage drop}} = I_{\text{current}} \times IR$

Example 3:

3S1P 850mAh high C battery, 50A at 12.6V

$IR = 10\text{m}\Omega/\text{cell} = 30\text{m}\Omega$ total IR

$E = 50\text{A} \times 0.03\Omega = 1.5\text{V}$

$12.6\text{V} - 1.5\text{V} = 11.1\text{V}$ @ 50A load

$12.6\text{V} \times 50\text{A} = 630\text{W}$, and $11.1\text{V} \times 50\text{A} = 550\text{W}$

But motor will now draw 38A , and $11.1\text{V} \times 38\text{A} = 421\text{W}$

Warning: Cell voltage is now down to 3.7V!

Using $E_{\text{voltage drop}} = I_{\text{current}} \times IR$

Example 4:

3S1P 850mAh high C battery, 50A at 12.6V

$IR = 20\text{m}\Omega/\text{cell} = 60\text{m}\Omega$ total IR

$E = 50\text{A} \times 0.06\Omega = 3.0\text{V}$

$12.6\text{V} - 3.0\text{V} = 9.6\text{V}$ @ 50A load

$12.6\text{V} \times 50\text{A} = 630\text{W}$, and $9.6\text{V} \times 50\text{A} = 480\text{W}$

But motor will now draw 28A , and $9.6\text{V} \times 28\text{A} = 269\text{W}$

Warning: Cell voltage is now down to 3.2V!

The Importance of Balancing

- Cell with higher IR will discharge and charge faster than other cells
 - High IR cell may go to 0.0V or enter a negative charge state
 - Longer charge time for entire pack
-
- Charger balance cycle attempts to bring all cells to same V level

Calculating Max Discharge Rate

Example 5:

3S1P high C battery, 4.2V/cell, cutoff set at 3.0V/cell

Voltage drop = 1.2V/cell, 3.6V for 3-cell pack

Using $E_{\text{voltage drop}} = I_{\text{current}} \times IR$

$$3.6V = I \times IR$$

Where I = max A with V drop of 3.6V

$$I = 3.6V/IR$$

If $IR = 0.03\Omega$ then $I = 3.6V/0.03\Omega = 120A$

This is not practical!

Calculating Max Discharge Rate

Example 6:

3S1P high C battery, 4.2V/cell, cutoff set at 3.6V/cell

Voltage drop = 0.6V/cell, 1.8V for 3-cell pack

Using $E_{\text{voltage drop}} = I_{\text{current}} \times IR$

$$1.8V = I \times IR$$

Where I = max A with V drop of 1.8V

$$I = 1.8V/IR$$

If $IR = 0.03\Omega$ then $I = 1.8V/0.03\Omega = 60A$

Breaking in New Packs

- Cycling a new pack lowers the Internal Resistance
 - Charge at 1C or less
-

Example 7

Battery pack had an initial IR = $17\text{m}\Omega/\text{cell}$

After 8 charge/discharge cycles IR = $7\text{m}\Omega/\text{cell}$

Battery Care and Feeding

	LiFe/Li-Ion	LiPo
Maximum Temperature	176°F/80°C - 5 to 10°F after flight	140°F/60°C - 5 to 10°F after flight
Under Load Cut-off Voltage	2.5V/cell	3.7V/cell
Maximum Charge Voltage	3.6V	4.2V/cell (4.35V/cell for HV LiPo)
Charge Voltage for Longer Life	3.6V for LiFe 4.1V/cell for 4.2V Li-Ion	4.1V/cell (4.25V/cell for HV LiPo)
Ideal Charge Rate	1C or less, 0.5C ideal Never 2C if above 72°F/22°C	1C or less, 0.5C ideal Never 2C if above 72°F/22°C
Storage Temperature	72°F/22°C 40-60°F/4-15°C ideal	72°F/22°C 40-60°F/4-15°C ideal
Use direct spot-welded connections when making up packs.		

Special Case

Ampac JP40 & JP50

Lithium Nickel Manganese Cobalt Chemistry

	JP40 Li-Ion	JP50 Li-Ion
Cell Type	21700 cylindrical lithium-ion rechargeable cell	21700 cylindrical lithium-ion rechargeable cell
Chemistry	Lithium Nickel Manganese Cobalt (NMC)	Lithium Nickel Manganese Cobalt (NMC)
Capacity	4000mAh	5000mAh
Nominal Voltage	3.7V	3.58V
Charge Cut-off Voltage	4.2V	4.2V
Discharge Cut-off Voltage	2.5V	2.5V
Max Continuous Discharge	45A	40A
Max Pulse Discharge	140A (5 sec.)	180A (5 sec.)
Dimensions	21.31mm × 70.42mm	21.35mm x 70.45mm
Weight	70g / 3S = ~235g*	72g / 3S = ~235g*

* A 4000mAh LiPo pack is in the 400gm range