Rechargeable battery types

- Nickel Cadmium (NiCd)
  - long cycle life, high load current and economical
- Nickel-Metal Hydride (NiMH)
  - higher energy density than NiCd at the expense of reduced cycle life and lower load current
- Lead Acid
  - cheap, easily rechargeable and capable of high current pulses, but heavy
- Lithium Ion (Li-ion) and Lithium Ion Polymer (Li-on polymer)
  - high energy density making them very compact, but low load current, expensive and difficult to charge

Characteristics of rechargeable batteries[1]

	NiCd	NiMH	Lead Acid	Li-ion	Li-ion polymer
Gravimetric Energy Density (Wh/kg)	45-80	60-120	30-50	110-160	100-130
Internal Resistance (in mΩ) (includes peripheral circuits)	100 to 200[1] 6V pack	200 to 300[1] 6V pack	<100[1] 12V pack	150 to 250[1] 7.2V pack	200 to 300[1] 7.2V pack
Cycle Life (to 80% of initial capacity)	1500[2]	300 to 500[2,3]	200 to 300[2]	500 to 1000[3]	300 to 500
Fast Charge Time	1h typical	2-4h	8-16h	2-4h	2-4h
Overcharge Tolerance	moderate	low	high	very low	low
Self-discharge / Month (room temperature)	20%[4]	30%[4]	5%	10%[5]	~10%[5]
Cell Voltage (nominal)	1.25V[6]	1.25V[6]	2V	3.6V	3.6V
Load Current - peak - best result	20C 1C	5C 0.5C or lower	5C[7] 0.2C	>2C 1C or lower	>2C 1C or lower
Operating Temperature[8] (discharge only)	-40 to 60°C	-20 to 60°C	-20 to 60°C	-20 to 60°C	0 to 60°C
Maintenance Requirement	30 to 60 days	60 to 90 days	3 to 6 months[9]	not req.	not req.
Typical Battery Cost[10] (US$, reference only)	$50 (7.2V)	$60 (7.2V)	$25 (6V)	$100 (7.2V)	$100 (7.2V)
Cost per Cycle (US$)[11]	$0.04	$0.12	$0.10	$0.14	$0.29
Commercial use since	1950	1990	1970	1991	1999

[1] Buchmann, I., "What is the perfect battery?", www.cadex.com, April 2001

Battery capacity

- capacity - amount of stored energy
  - typically specified in (misleading) unit of *ampere-hours* (A·hr)
  - multiply A·hr rating by battery voltage V to get energy units Watt·hr recalling
    - unit of energy is Joule = Watt·sec
    - power P is rate energy E is being generated or dissipated, P = dE/dt
  - given a 12V lead acid battery rated at 2.0A·hr – approximately how long would the battery be able to supply a fixed current of 1.5A to a device?

$$P = 12\text{V} \times 1.5\text{A} = 18\text{W}$$

$$\text{E} - \text{E}(0) = 2.0\text{A} \cdot \text{hr} \times 12V = 24W \cdot \text{hr}$$

$$= \int_{\lambda=0}^{t} \text{P} d\lambda = 18W \cdot t$$

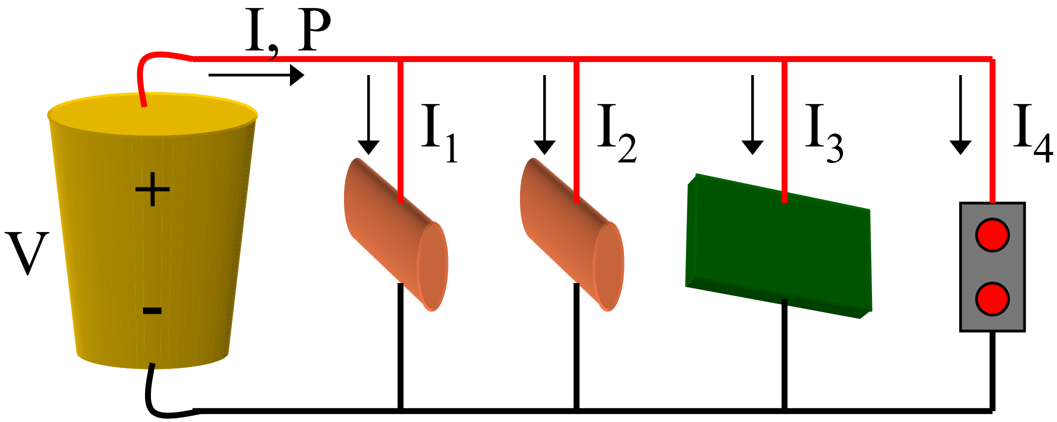
$$\Rightarrow t = 24W \cdot \text{hr}/18\text{W} = 1.3\text{hr}$$

or using A·hr rating
(reason for A·hr units now seen)

$$t = 2.0A \cdot hr / 1.5A = 1.3hr$$

Power budget

- battery "size" determined by operation time and current draw



  - node equation: $I = I_1 + I_2 + I_3 + I_4$
  - multiply by battery voltage V to get power equation:

$$P = VI = VI_1 + VI_2 + VI_3 + VI_4$$

  - assuming constant power P and given a specified run-time t, battery capacity can be found via $P \cdot t$

Power regulation

- goal: provide constant voltage to a load even as input voltage and load vary
- linear regulator
  - cheap, dropout voltage ⇒ $V_{in} > V_{out}$, linear ⇒ $I_{in} = I_{out}$ ⇒ lost power = $I_{in}(V_{in} – V_{out})$ (= 0.5A (12V – 5V) = 3.5W for 12V battery, 5V linear regulator and 0.5A current draw)
- dc-dc converter (switching regulator)
  - expensive, capacitors or inductors are switched in such a way that $V_{out} \geq V_{in}$ or $V_{out} \leq V_{in}$, often over 80% efficient