**Characteristics of commonly used rechargeable batteries**

**What is the best battery?**

Below is a summary of the strength and limitations of today's popular battery systems. Although energy density is paramount, other important attributes are service life, load characteristics, maintenance requirements, self-discharge costs and safety. Nickel-cadmium is the first rechargeable battery in small format and forms a standard against which other chemistry are commonly compared. The trend is towards lithium-based systems.

**Nickel-cadmium**- mature but has moderate energy density. Nickel-cadmium is used where long life, high discharge rate and extended temperature range is important. Main applications are two-way radios, biomedical equipment and power tools. Nickel-cadmium contains toxic metals.

**Nickel-metal-hydride**- has a higher energy density compared to nickel-cadmium at the expense of reduced cycle life. There are no toxic metals. Applications include mobile phones and laptop computers. NiMH is viewed as steppingstone to lithium-based systems.

**Lead-acid**- most economical for larger power applications where weight is of little concern. Lead-acid is the preferred choice for hospital equipment, wheelchairs, emergency lighting and UPS systems. Lead acid is inexpensive and rugged. It serves a unique niche that would be hard to replace with other systems.

**Lithium-ion**- fastest growing battery system; offers high-energy density and low weight. Protection circuit are needed to limit voltage and current for safety reasons. Applications include notebook computers and cell phones. High current versions are available for power tools and medical devices.

Table 1 summarizes the characteristics of the common batteries. The figures are based on average ratings at time of publication. Lithium-ion is divided into three versions: The traditional cobalt that is commonly used in cell phones, cameras and laptops; the manganese (spinel) that power high-end power tools and the new phosphate that competes head-on with spinel. Lithium-ion polymer is not listed as a separate system. Its unique construction performs in a same way to cobalt-based lithium-ion.

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1. Internal resistance of a battery pack varies with mAh rating, wiring and number of cells. Protection circuit of lithium-ion adds about 100mW.
2. Based on 18650 cell size. Cell size and design determines internal resistance. Larger cells can have an impedance of <15mOhms,
3. Cycle life is based on battery receiving regular maintenance. Failing to apply periodic full discharge cycles may reduce the cycle life by a factor of three.
4) Cycle life is based on the depth of discharge. Shallow discharges provide more cycles than deep discharges.
5) The self-discharge is highest immediately after charge, and then tapers off. The capacity loss of nickel-cadmium is 10% in the first 24h, then declines to about 10% every 30 days thereafter. High temperature increases self-discharge.
6) Internal protection circuits typically consume 3% of the stored energy per month.

7) The traditional nominal voltage is 1.25V; 1.2V is more commonly used to harmonize with lithium-ion (3 in series = 3.6V).
8) Lithium-ion is often rated higher than the nominal 3.6V. Based on average voltage under load.
9) Capable of high current pulses; needs time to recuperate
10) Applies to discharge only; charge temperature range is more confined. Delivers lower capacity at lower temperatures.
11) Maintenance may be in the form of 'equalizing' or 'topping' charge to prevent sulphation.