



N0AX

HANDS-ON RADIO

Experiment #80 — Battery Capacity

What makes a *good* battery? The most common answer is battery capacity, or as it is commonly evaluated, *battery life*. What battery life really means is *the time over which a battery can operate a specific piece of equipment in a specific manner*. The life of a battery can vary greatly, depending on how the equipment is used, so battery lifetime in hours or days isn't really very useful. What determines lifetime is battery capacity.

The units of battery capacity are in amp-hours, abbreviated Ah and represented by the letter C in equations. This is a measure of how much energy the battery stores, similar to watt-hours or kilowatt-hours that measure energy in your home. Large batteries are rated in amp-hours while smaller batteries, like AA or coin cells are rated in milliamp-hours or mAh.

Energy and Charge

There is something a little strange about Ah. Amperes (coulombs / second) times hours (3600 seconds / hour) yields coulombs, not

joules. How do you get energy from charge? Amp-hours is really a measure of charge. It tells you how many electrons are available to deliver energy from the battery as they flow through your circuit.

The energy carried by any one of those electrons is determined by the electro-motive force (EMF) that pushes it through the circuit. You can measure the EMF as the open circuit battery terminal voltage, V_{OC} , with no load attached. For example, a high-impedance voltmeter attached to the terminals of an alkaline cell might read 1.55V. The current drawn by the meter is very small and its effects can be neglected. That means there is 1.55 V of EMF available to push the electron from wherever it resides in the battery, out through the negative terminal, through the external circuit, and back into the battery. (Actually, that specific electron may never make it all the way around the circuit. Even at 1 A of current flow through a 20 gauge wire, individual electrons are only moving at about $\frac{1}{2}$ mm/s.)

Since Ah or mAh gives you charge, the number of available electrons, to find the total amount of energy available, multiply V_{OC} by the Ah rating by 3600 sec / hr. A typical AA battery is thus rated to store a theoretical maximum of $1.55 \text{ V} \times 2 \text{ Ah} \times 3600 \text{ s / hr} = 11,160$. That's a lot of energy and a good reason to respect batteries!

Chemistry Types

Where does the 1.55 V come from? Why not 1.2 or 1.8 V? The battery's open circuit voltage is determined by its internal chemistry, meaning the types of chemicals stored in the battery, and the chemical reaction that occurs as electrons are allowed to flow between the battery terminals. Due to the differing affinity for electrons by the atoms making up the chemicals, electrons will flow from one atom to another if there is a path between the atoms. The media that makes up the path is called the *electrolyte* and it is usually a liquid, paste or gel.

The voltage that drives the electrons from one atom to another is called the *electropotential* and it depends on the exact chemicals used. Table 1 lists the chemistry of several common battery types and the nominal voltage you can expect from a fully charged battery supplying

a light load. Table 2 compares the capacities of different types of battery chemistry and cell sizes.

Discharge Curves

Battery capacity is a useful number, but it does not represent the more complex behavior of a battery in actual use. The calculation of stored energy assumes that battery voltage is constant until the battery is discharged. Battery voltage is not constant, however; rather, it slowly drops as more and more energy is delivered because the internal resistance of the battery increases as the chemicals supplying the electrons are used up. Battery voltage

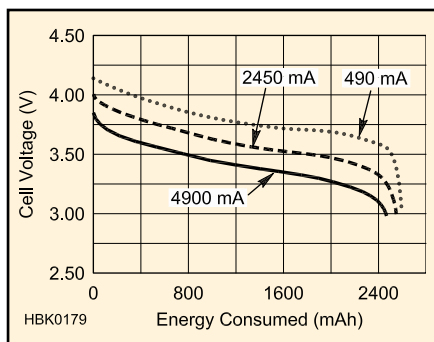


Figure 1 — Typical Li-ion battery discharge curves at three discharge rates.

Table 1
Battery Types

Chemistry	Nominal Voltage (V)
NiCd	1.2
NiMH	1.2
Carbon zinc	1.5
Alkaline	1.5
Lead acid	2.1
Li-ion	3.5-3.7

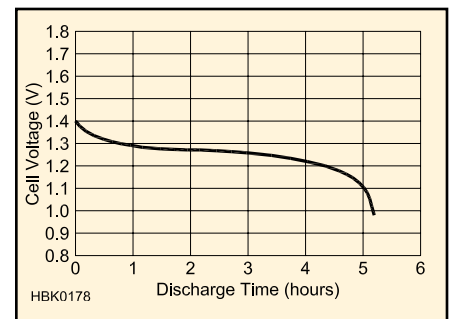


Figure 2 — Typical NiMH battery discharge characteristic. The load on the battery must also be specified for actual discharge curves.

Table 2
Typical Battery Capacity

Cell Size	Chemistry	Nominal Capacity (mAh)
AAA	Alkaline	1000-1300
AAA	NiCd	250-350
AAA	NiMH	800-1200
AA	Alkaline	2000-3000
AA	NiCd	600-1000
AA	NiMH	1700-2700
C	Alkaline	6000-8000
C	NiCd	2000-3500
C	NiMH	3000-5500
D	Alkaline	12000-20000
D	NiCd	5000
D	NiMH	3000-12000
9 V	Alkaline	500-650
9 V	NiCd	120
9 V	NiMH	200-350

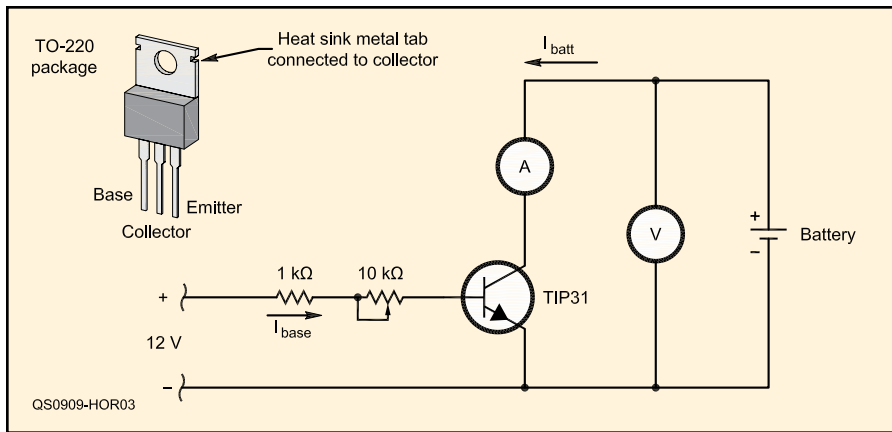


Figure 3 — This circuit draws a constant value of battery current, controlled by the 10 kΩ potentiometer.

eventually drops to a level at which the equipment it is supplying no longer works and the battery is considered dead. Even though there may be additional energy left in the battery, it can't be delivered at a high enough voltage to operate the equipment. This is the battery's end-of-life voltage.

If the battery's terminal voltage under load is plotted versus the amount of energy used, the result is a discharge curve. Typical discharge curves for a rechargeable lithium ion (Li-ion) battery are shown in Figure 1. At higher battery current, terminal voltage falls to the end-of-life level faster than for a lower current, even though the same amount of energy has been used. If the end-of-life voltage is 3.25 V, only 2100 mAh can be delivered if discharged at 4900 mA, but 2550 mAh is available at a discharge rate of 490 mA. The discharge curve can also be plotted against time as shown in Figure 2. Different types of batteries can be compared by drawing identical currents from them and comparing the times at which they reach their end of life voltage.

Battery Up!

We're going to do two battery test experiments. The first will illustrate how a specific type of battery performs at different current levels. The second will compare different types of batteries. Start by acquiring a fresh trio of alkaline AA cells to sacrifice in the name of science. To control current through the batteries, connect the circuit in Figure 3 using a battery holder or clip leads and a rubber band to make the battery connections. Use a pair of locking pliers as a heat sink for the transistor as in Experiment #381.¹ Set the meter reading current to a scale appropriate for measuring about 100 mA.

Measure and record battery voltage. Note

the time, set the 10 kΩ pot to maximum resistance, and apply power. Reduce the pot's resistance until current is about 200 mA — you can fine tune with the power supply voltage if the adjustment is too sensitive. Adjusting the TIP31 base current to keep battery current approximately constant, record battery voltage and current once per hour until battery voltage drops to 1.0 V — our end of life value. For a 2000 mAh battery, it should take no more than 2000 mAh / 200 mA = 10 hr. (You can suspend the test by turning off the power supply.) Graph the results as in Figure 2.

Reset the pot to maximum resistance and swap in a fresh battery. As before, note the battery voltage, then adjust base current until the battery current is 500 mA and record battery voltage every 30 minutes or so until battery voltage reaches 1.0 V. Repeat with a battery current of 1 A. You should now have three discharge curves that look somewhat like those in Figure 2.

Why not just hook up a fixed value resistor and measure voltage versus time? Because battery voltage changes as the battery is discharged, the amount of battery current would also change according to Ohm's law. A constant current is a better and more repeatable test.

Now find some different types of AA batteries, such as carbon zinc, NiCd, and NiMH and repeat the 500 mA current test. Compare the discharge curves. Which battery type is better?

Parts List

- Transistor, TIP31 or equivalent.
- Potentiometer, 10 kΩ, preferably linear taper.
- Resistor, 1 kΩ, ¼ W.
- Batteries, three each, size AA — alkaline, carbon zinc, NiCd and NiMH.

Recommended Reading

Here's a treat for readers interested in electro history. Check out the Wikipedia (www.en.wikipedia.org) entry on the *Baghdad Battery*, an ancient artifact that may or may not have been used for electrical purposes 800 years before Alexander Volta created the first galvanic pile and got a kick out of some frog legs.

Next Month

It's still antenna season out there in many places, so let's revisit transmission lines with some handy gadgets called synchronous transformers that are used for impedance matching chores. Q57

New Products

ARRL/TAPR DIGITAL COMMUNICATIONS CONFERENCE DVD SET FROM ARVN

◇ The 2008 ARRL/TAPR Digital Communications Conference (DCC) was a three-day event held in the Chicago area that showcased the latest developments in Amateur Radio digital communications. Amateur Radio Video News (ARVN) has produced a set of six DVDs that include the conference presentations — 21 in all. Producer Gary Pearce, KN4AQ, arranged the DVD content around topics including packet radio, software defined radio, APRS, Winlink, D-STAR and satellites. One DVD documents several introductory sessions on HF digital voice, D-STAR, DPRS and D-RATS. Another documents the three-hour Sunday Seminar, an in-depth look at the development of the Mercury HPSDR software defined receiver. The DVDs are professionally produced with quality video, audio and navigation menus. Intended for individual viewing or club meeting programs, the DCC video collection offers a fascinating look at what amateurs are doing with digital communications technology. Detailed information on contents of each DVD and a sample video are available on the ARVN Web site. Price: \$15 per DVD or \$75 for all six. For more information or to order, visit www.ARVidNews.com.



¹Previous Hands-On Radio columns and a complete parts list for all experiments are available to ARRL members at www.arrrl.org/tis/info/HTML/Hands-On-Radio.