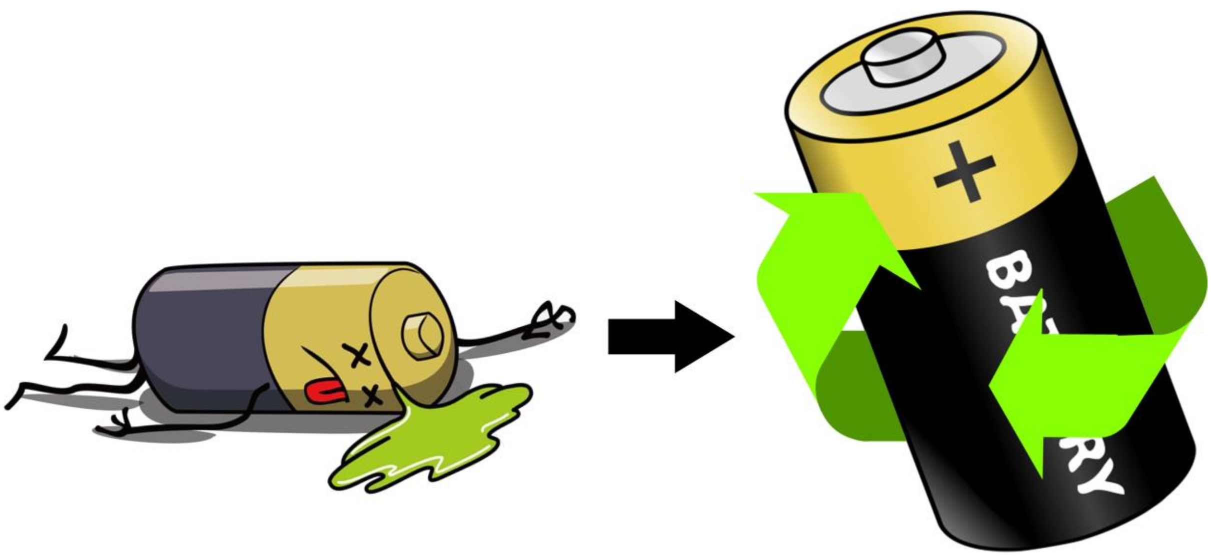
RECONDITIONING RECHARGEABLE BATTERIES

NEW LIFE FOR OLD BATTERIES

Now YOU CAN Recondition Batteries!!

"The Complete Household Manual for Reconditioning Rechargeable Batteries"



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Introduction –

Rechargeable batteries, also known as storage batteries and accumulators come in a variety of shapes, sizes, scales, and uses. They can be used for anything from stabilizing megawatt systems on electrical distribution networks to a tiny button cell in a small gadget. One thing is for sure; they are everywhere these days – many of our commonly used goods have them: laptops, cell phones, tablets, automobile starters for cars, motorcycles, golf carts, wheel chairs, and electric cars even use them for acceleration.

Why Recondition a Battery? –

Ever notice how when you first get a new device the battery life is long and reliable; only to wear out, not take a charge, or the battery life will run out quickly and it will need to stay plugged in for power? Well now there is something that you can do about this. Rechargeable batteries use what is known as **secondary cells** because their electrochemical reactions are **electrically reversible**. This can make all the difference between hundreds of dollars over and over again and be used to your advantage if you know what you're doing.

This report contains a plethora of methods for getting the most out of rechargeable batteries including how to take care of them to get the max battery life, how to test them to see if they can be reconditioned, how to recondition them if they can be, and finally how to also do this with car batteries. You can use this information to prevent yourself from ever again buying a new battery for a device whose battery can be reconditioned instead, to properly care for your rechargeable batteries, as well as to help your friends and family do the same, or even to start a part time business reconditioning batteries for people.

Memory Effect –

When you first get a device that uses a rechargeable battery, usually, the way to do it by the manual is to charge it *fully* before its first use. There's a good reason to make sure the battery gets a full charge before the inevitable pattern of usage begins.

Typically, you get the device, charge the battery, use the thing for a while until it needs to be charged again, and then repeat. Very often, (as with cell phones, for example) we just get in the habit of charging our devices when the battery is "low" or even partially discharged at half percent or something like that. Or we over-charge devices by plugging them in and forgetting about them for a while. Unpredictable charge cycles cause the wear of a battery premature to its useful life by training it, if you will, to lose charge over unpredictable patterns of discharge and is what is referred to as the *digital memory effect*.

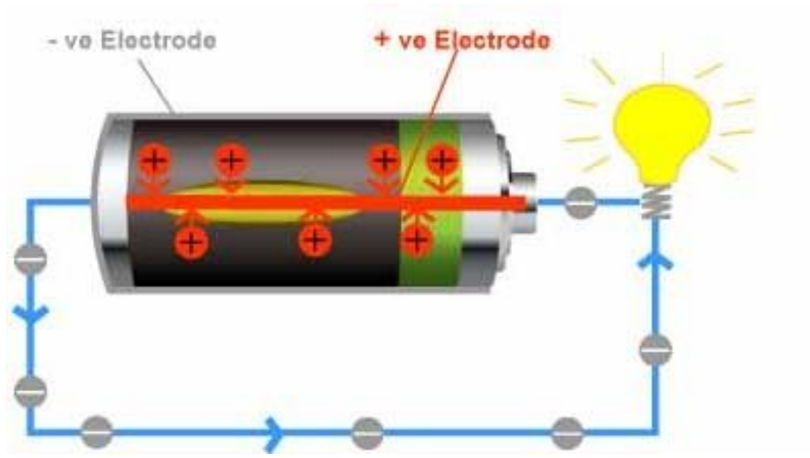
What actually causes the digital memory effect to is the growth of initially finely divided crystals inside the battery; the details of which are not as important here as the fact that this occurrence can often be reversed and the battery life revived by using the procedures covered in this book.

Quick Overview of How Batteries Work –

Even though there are multifarious types of batteries, the basic concept by which they function is the same for all. Batteries are potential chemical energy, as in, they *store* electrical energy in chemical form.

Even though we often use the term battery and cell interchangeably, batteries may contain any number of cells. A *battery cell* really refers to the working chemical unit inside a battery.

There are three main parts that make up a battery cell: a positive electrode (anode), a negative electrode (cathode), and a solid or liquid separator called the electrolyte.



Only when a battery is connected to an electrical circuit does a chemical reaction take place in the electrolyte causing ions (atoms with a positive electrical charge) to flow through it one way, with electrons (negatively charged ions) flowing through the outer circuit in the opposite direction. You can think of it as the inner core / pointy tip of the battery being positively and the outer shell as well as the bottom of the battery being negatively charged when hooked up to a circuit. The electrons generated through the cathode try to reach the positive ions of the anode; however they cannot pass through the electrolyte (whether solid, liquid, or gel) that separates the two electrodes because of its chemistry so they take the route through the outer circuit instead. This is energy that can be harnessed to power devices.

The Chemical Types of Rechargeable Batteries –

Most of the stuff we use has batteries of three specific chemical types: nickel cadmium (Ni-Cad), nickel metal hydride (Ni-MH), and lithium-ion (Li-Ion). Although from the outside different battery types may look the same, there are significant differences between them outlined below.

Ni-Cd (nickel-cadmium) batteries: are the second oldest of battery types we cover in this book. They are the oldest battery type that we use that suffers from the digital memory effect. Recent developments with nickel-metal hydride (Ni-MH) and lithium-ion (Li-Ion) batteries have rivaled the cost effectiveness by lifespan of this battery. However they are still used more often than other battery types when a very high discharge rate is required.

Advantages –

- The most significant advantage of these batteries is that they are more difficult to do damage to than all of the other battery types. This means that they can maintain a level of **deep discharge** for long periods of time. So well in fact that they are usually stored deeply discharged. This helps this type of battery last a lot longer than lead-acid batteries, for example, which are not as stable and will be irreversibly damaged if discharged below a minimum voltage.

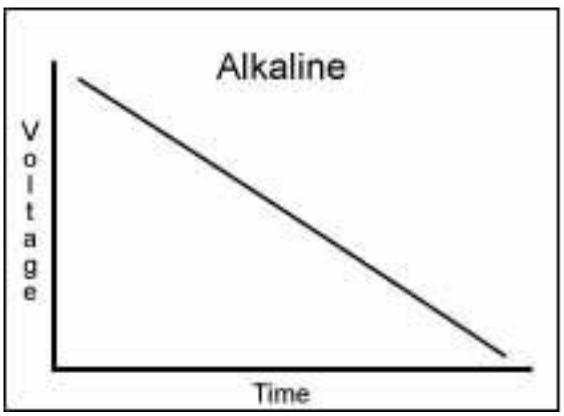
- The energy density is high making these batteries smaller and lighter weight than lead-acid batteries. When size and weight is an issue these batteries are preferred to others.

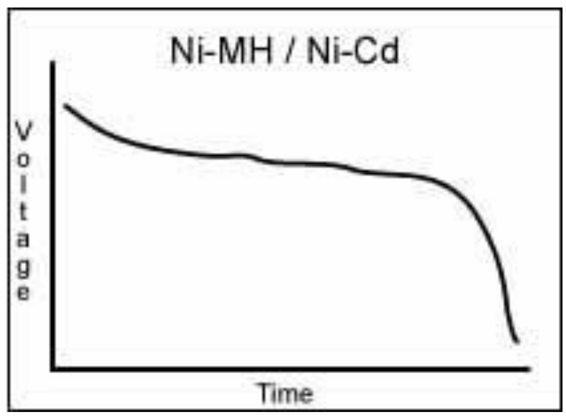
- Ni-Cd batteries compete directly with alkaline batteries in consumer electronics. Alkaline batteries' chemical reaction however, is not similarly reversible so they are not rechargeable. Therefore Ni-Cd batteries have a much longer total lifetime at 1 to 2 years.

- This battery can achieve a higher maximum discharge rate than the other battery types because of its slightly lower internal resistance which can be important for certain applications such as with power tools.

Disadvantages –

- A big disadvantage is that this battery exhibits an extreme negative temperature coefficient meaning that as the cell temperature rises, the internal resistance drops making the charging method more complicated. This is in contrast to lead-acid batters that can simply be charged by a dynamo connection with a basic electromagnetic cut out system to prevent them from overcharging. Connect a dynamo to a Ni-Cd battery and it will exhibit thermal runaway, where the charging current would keep rising until the cut-off system stopped it (uncharged) or the battery destroyed itself. This is the primary reason why this battery type was is not used to start engines.





- The self-discharge rate on these batteries is at its peak at full charge and does down with a lower charge state. This is the reason that devices that use this type of battery often give faulty measurements on their battery level.

- They have a high sitting discharge rate at 20%, meaning that after about a week of no use they will lose a fifth of their charge.

- They are also an extreme environmental hazard because of their use of the heavy metals nickel and cadmium

Ni-MH (nickel-metal hydride) Batteries: are a newer development than and very similar to Ni-Cd batteries.

Advantages –

- The advantages of this battery type are nearly the same as Ni-Cds with their high capacity and ability to hold a stable voltage while being discharged. This battery works great for devices that pull a high energy drain such as digital cameras.

- The capacity is 2 – 3 times that of similarly sized Ni-Cd batteries.

- They do suffer from the memory effect but not nearly as bad as their Ni-Cd counterparts.

Their total lifetime is longer at 3 – 4 years because they can go through more discharge cycles. They are less toxic and are now more cost effective than them as well.

- Initially they cost more than Ni-Cd batteries but their total lifespan makes them more cost effective.

<u>Disadvantages</u> –

- Traditionally they have an even higher sitting self-discharge rate than Ni-Cds (around 30% per month compared to 20%) under identical conditions. This has created a preference for Ni-Cd batteries for products in cases where the current draw on the battery is actually less than the battery's own discharge rate (remote controls for televisions for example). Recently, low self-discharge (LSD) Ni-MH batteries are available which have impressively lower discharge rates than either Ni-Cd or traditional NiMH batteries.

- Finally, it has a slightly higher internal resistance and consequently has a slightly lower maximum charge rate than the older Ni-Cd battery type.

Li-Ion (lithium-ion) Batteries: are the most recent of the three mentioned battery types to be commercially available.

Advantages –

- This battery type has *all* of the above mentioned advantages of the other two types.
- They have the longest life span of rechargeable batteries at 4 – 5 years because they can go through 300 – 500 discharge cycles.
- They don't suffer from digital memory effect at all.

Disadvantages –

This battery will lose approximately 10% of its useful capacity each year of use. Once again, this loss is due to a gradual chemical reaction that takes place within and currently there is no way to prevent or reverse this process.

Taking Care of Your Ni-cd, Ni-MH, and Li-Ion Batteries –

There are good general practices to develop with the care and maintenance of your batteries to ensure that you get maximum use out of them. We'll cover each battery individually as the methods vary per chemical type.

Nickel-cadmium batteries: are most subject to the *memory effect*. Below are the methods that you can use to prevent/reverse this process.

- **Important note** – the first three discharge cycles on these batteries help determine the behavior of the following cycles. The first time you use a device with a Ni-Cd battery, make sure and use the ***deep discharge method*** listed below. Also be sure to do this for the first three discharge cycles.
- As often as is practical, use devices with this battery type until the battery level is nearly or entirely diminished before recharging it. Doing this more often than charging the battery again after using it up only halfway or so will help the battery "remember" its extended cycle. This is different from the method listed below because you can use your device while you're letting it charge.
- After the first three discharge cycles on a device, about once a month put the battery through a *deep discharge cycle*. This is done simply by draining the battery fully by using your device until it stops operating and then recharging it fully before using it again.

- Room temperature is ideal for this battery type.

Nickel-metal hydride batteries:

- If you have a Ni-MH battery that needs to be stored for more than two weeks, put it through a deep discharge cycle and then charge it to 50% capacity before putting it in storage.
- This battery is ideal at cool temperatures. They are even more susceptible to overheating and should be taken care to avoid heat.
- Even though this battery suffers less from the memory effect, it still happens. Put this battery through a deep discharge cycle bi-monthly or so.

Nickel-cadmium and nickel-metal hydride batteries both:

- Try to remember to check on your device every so often when you plug it in to charge to **prevent overcharging**. As soon as it says 100% charged it is good to go. Leaving it on the charger will only decrease its overall battery life. (Something to check into: some devices have chargers available that have an electromagnetic cut-off built in to prevent them from overcharging.)
- If you have a device with a Ni-Cd battery that you only use periodically then take the battery out. Sometimes devices remain turned on when the battery is already completely run down. This will put a continued drain on the battery which can cause it to reverse polarize which will ruin it.
- Avoid exposing them to high temperatures if possible.

Lithium-ion batteries: because this battery doesn't suffer from the memory effect, the battery life depends on the number of discharge cycles. This makes the care methods different from Ni-Cd and Ni-MH batteries. Below are some things you can do to extend the life of a Li-Ion battery.

- Keep this battery type fully charged as often as possible. Keeping this type on the charger actually extends the battery life by preventing it from going through discharge cycles and does not harm the battery in the process.
- Condition this battery type every so often by charging it deeply (overnight works well) and then operate the device until it shuts down. With lithium ion batteries, this is called *calibrating the battery*.

- Also avoid high temperatures with Li-Ion batteries. Room temperature is ideal for them.
- Before you put them in storage, the ideal is to make sure that they are charged just below half at around 40% of full capacity.
- Make sure you are using a charger made for lithium-ion batteries.

Battery Type:	**Self Discharge / Month:**
Lead-acid	4 – 6%
Nickel-cadmium	15 – 30%
Nickel-MH	30%
Lithium	2 – 3%

Useful Tools and Supplies –

At minimum you'll need an electric multimeter to at least check on the health of your batteries.

Essential:

There are also some essential and useful supplies that you'll want to keep around for **more serious battery testing** as well as for **maintenance and reconditioning**. Here are some essential items that you are going to want to pick up if you don't have already.

- A multimeter (an adequate one will cost $10 - $20)
- A set of alligator clip test leads (less than $10)
- A good pair of safety glasses or goggles ($10 - $15)
- A smart charger
- A battery tester
- A battery analyzer (battery load tester)

All battery charging and testing instruments have prices that vary by battery type, output capabilities, and other features. Now we'll go over what they are used for with some product examples and later in the book we'll go over more on how to use them.

Smart chargers: A *smart* charger detects when the battery is fully charged and then adjusts to a trickle charge. This is useful for many reasons, the main one being that you won't over charge your batteries even if you forget about them.

It is better to charge batteries on a trickle-charger because the slow steady charge keeps the electrical resistance lower while charging which will overall keep the battery working longer. Often, however is not practical to charge your battery this way, say for example, when the battery dies on your motorcycle and you don't have all day to wait around for it to charge. *Dumb* chargers are usually lower in amplitude because they cannot detect when a battery is fully charged.

Smart chargers on the other hand, will allow you to charge your battery quickly when you need to without the worry of overcharging it (say you have other things to do than watch the battery). Smart chargers can be used as trickle-chargers as well when the level of charge is adjustable which is good for when you can wait longer for a battery to charge.

Some examples of battery testers –

About $10. This one works on alkaline and rechargeable batteries of sizes:

- AAA
- AA
- C
- D
- 9V

About $20. “Pocket Size AA/AAA/9v/C/D Battery Tester Checker Meter”

About $25. This battery tester can deal with alkaline and rechargeable batteries of sizes:

- AAA
- AA
- C
- D
- 9V
- CR123A
- CR2
- CRV3
- 2CR5
- CR-P2

About $80. “ZTS Multi Battery Tester - ZTS MBT-1”

This one is fully automatic. It will detect the battery size and type and works to test pretty much any battery that you would come across.

How to Test Batteries –

There are three ways to test batteries. It can be done with a multimeter, a battery tester, or with a battery load tester. We'll cover all three methods starting with the least expensive option; a multimeter.

Testing with a multimeter:

Multimeters allow you to take several different types of measurements (hey! That's why it's called a *multi – meter*!). Usually you have the choice of measuring direct current (DC), alternating current (AC), electrical resistance (ohms), AC voltage, and DC voltage. (DC is the kind of current you get from batteries and AC is the kind that comes out of your wall).

When the probes are disconnected, they should display 0V (zero voltage). Ambient voltage from your home (which is a big radiator of 60 Hz) might make them flicker a bit.

In the center of the instrument there is a rotary dial where you choose what you are going to measure.

There are two sorts of measurements that can be taken directly with a multimeter on a battery and they are voltage (no-load) and resistance (no-load). "No-load" simply means that the battery is not putting out any power while the measurements are being taken.

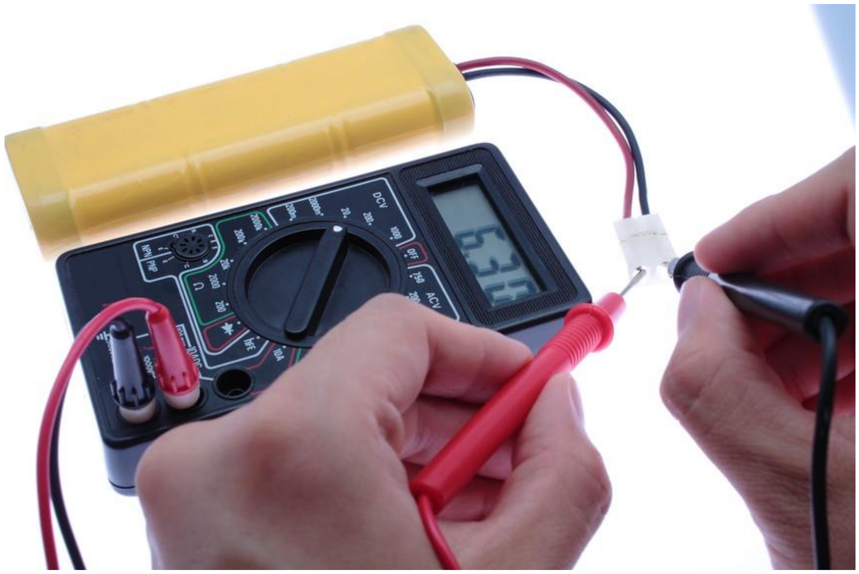
Battery testers and battery analyzers work in a different way. They use resistors to apply a load to measure the output. While these tools will tell you more about the current condition of the battery, multimeter measurements do provide useful and actionable information as well, so we'll cover how to take those measurements and what they can tell you.

1. First set the dial to the type of measurement that you want to make. Typically the ones available are:

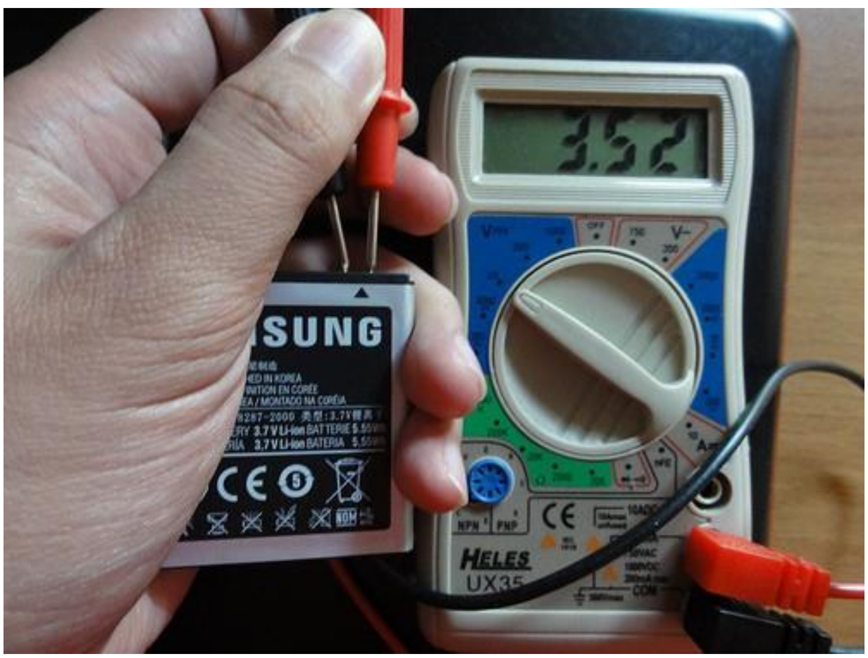
- Alternating current (AC)
- Direct current (DC)
- AC volts
- DC volts
- Ω or ohms = electrical resistance

On most multimeters, the measurement options will have more than one output range as an option so that you get a more accurate reading. The multimeter above has 5 ranges. The top range is 750 VAC or 1000 VDC, to switch between DC and AC the button the upper right needs to be pushed.

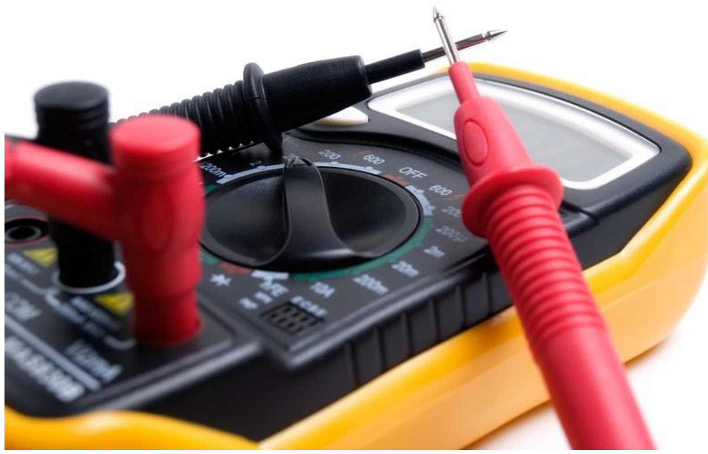
Often there are two separate modes for AC and DC voltage. Both will have a “V” but a DC indication will have two lines (both a solid and a dashed one) and AC indication will have a wave next to it. And this particular meter has the double line for DC voltage and 5 ranges from 200mV to 600V. The lightning bolt tells us that this voltage is extremely dangerous.



2. Touch the probes on the multimeter to the appropriate positive or negatively charged battery terminals. Red will always indicate positive and black will always be negative.



3. To get an accurate reading, hold the *tips* of the probes tightly to the appropriate contact (as oppose to the sides of the probes).
4. Try to avoid directly touching the metal prong on the probes when taking a measurement as it may distort the reading as well as you may get zapped.



5. Before taking an ohms (resistance) measurement, calibrate the ohm setting to zero. On a digital multimeter, this is done by touching the two probes together. Be sure the dial is set to ohms.

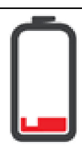
6. On an analog meter, you'll see there is a knob or a screw that must be adjusted to zero for calibration.

7. Keep the probe tips clean to avoid extra contact resistance between the probe tips and the battery terminal. Residue on the tips will only interfere the reading.

How to interpret your reading –

Only measure the no-load voltage and no-load resistance of a battery when it is fully charged.

Below, **Table 1** summarizes how to interpret measurement results.

<u>Table 1</u> **Voltage reading:**	**Interpretation:**
 110 – 120% *nominal voltage*	A sign that the battery is in top condition.
 95 – 110% *nominal voltage*	The battery is working fine, no need to recondition.
 Less than 100% *nominal voltage*	The battery is not taking a complete charge. If it is a Ni-cd or Ni-MH battery then try reconditioning it.
 0 V	This indicated a dead battery and cannot be reconditioned. Try to see if it can be brought back to life with the rejuvenation process covered in later section.

Note:

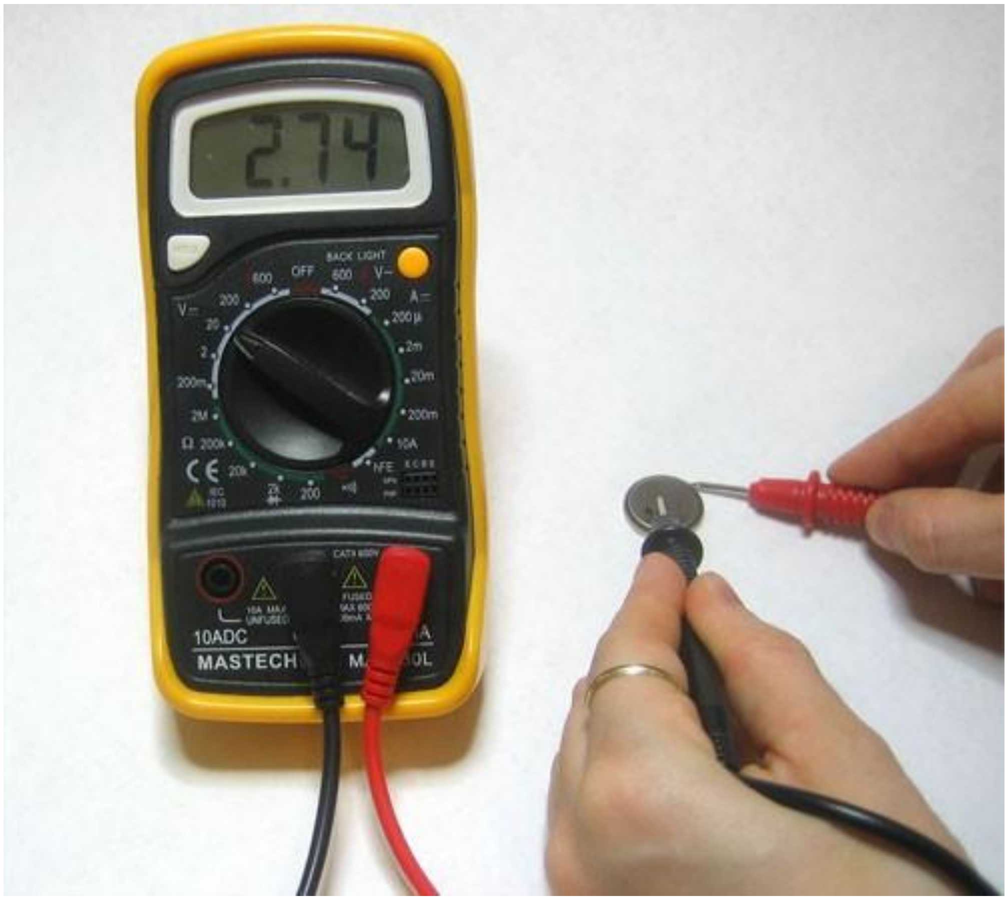
- *Nominal voltage* means an approximation oriented around the minimal expected voltage for a new battery. What happens actually is that a battery sold at 1.25V for example, will initially output a higher voltage at say around 1.3V and will gradually lower and lower.

- Say you want to check a rechargeable AA battery. You set the dial to the 20VDC range, and get a reading of about 1.3V. You know the battery is good as that is what a fully charged NiMH battery will measure.
- There is no way to measure voltage with only one multimeter probe because voltage is always measured between two points. If you ever come across instructions telling you to measure a battery at certain locations, what you do is put the negative probe to the ground and the positive probe to the area that you are measuring. Putting the negative probe on the ground acts as a reference voltage (which should be zero).
- If you are getting readings that seem inaccurate, it helps to use a reference voltage to determine if your measuring device is working right. Even if all you do is test a new 9V battery, it will help you determine the accuracy on your other readings.
- Unless indicated otherwise, assume DC voltage.

Table 2 **Ohms reading:**	**Interpretation:**
Infinite ohms (OL or overload)	There is an open connection somewhere or the battery is plain dead. Look for an open connection and if you can't find one, try rejuvenating it.
Resistance between 0 and infinite (OL)	This is a normal reading. If this is a reading you get regularly, then it will likely increase to (OL) over time.
0 ohms	There is an internal short in this battery or in the wiring. If you can't find a wiring short you then try a rejuvenation process.

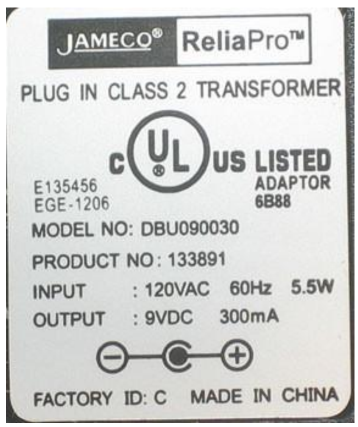
Here are some examples of measurements taken with a multimeter –

1. This shows the measurement of a rechargeable AA battery set to a 20VDC range. At 1.29V, this about what a fully charged NiHM AA battery will measure. Practicing with small batteries is a great way to get the hang of your new hobby.



2. Here is a voltage measurement on a lithium 3V coin cell. The reading is at 2.7V and with these small coin cells, that means it's near the end of its life.

3. Testing wall wart plugs (adapters that plug into your wall) can come quite in handy, especially if you build your own circuits. This one is a **transformer-based** adapter.



See how it is labeled as transformer. You can also tell that it is a transformer because it’s a block that is heavy for its size. It requires 120V of AC power (U.S. power scale). The nominal output for it is 9VDC at 300mA.

The symbol below the output statement shows that the middle is positive and that the outer part is negative; so we place the ground (negative, black) probe on the outside and the positive probe on the inside of the adapter tip.

Is this adapter broken? It is measuring at 14V which is much more than the 9V that the label says. Actually, this is entirely normal. Wall adapters that are transformer-based and are almost always unregulated. This means that the output will not be guaranteed to be any *particular* value, but rather at least the voltage mentioned in the label. So when drawing 300mAh, it is guaranteed to have a voltage of at least 9V.

Because the voltage is unregulated, the supplied voltage will droop as more current is pulled from it. That is why even in an *open-circuit* state (connected to nothing), the measured output is as high as 14V. (Remember, devices have to be plugged in - for you to take a measurement otherwise there is no drawn current to measure).

4. Testing wall output:

This test almost too easyyoto do - u just have to insert the probes into a wall socket (or extension cord). Doing this scares a lot of people and don’t do it if it does though ironically, this is just what multimeters are made for. Around 120V is an expected measurement.

How to use Battery Testers –

The only thing a battery tester measures is: **the remaining useful charge of a battery**.

They measure voltage while load is being applied to the battery. This works the same as with built in battery testers. Cell phones and laptops have battery testers built right in so you know when to plug in. The built in testers draw current from the battery even when the device is turned off so long as it is properly plugged in. Just from that you can see the battery meter displayed, it is drawing a load from the battery.

However, you may need to check on the life of a battery that doesn’t have a built in monitor and you would use a *free standing* battery tester. You can also use free standing battery testers on disposable batteries to see if there is any useful charge left in them or if they are ready to be discarded.

With free standing battery testers, an appropriate resistance (load) is applied to the battery for testing. There are battery testers made to test only certain types and sizes of batteries and thus have only one resistance level built in. Others are made to test a variety of types and sizes of batteries. These have multiple resistance levels built in and you usually specify the size and type of battery before measurement.

Using a battery tester –

It is actually pretty easy to get the hang of using battery testers.

1. You need to connect the battery to the device properly. Each battery tester is different so see to the instructions on yours.
2. On the instrument, you need to choose the settings for the size and type of battery, unless you have one that automatically detects this information.
3. Start the test the way the instructions have you do with your particular battery tester.
4. Take down the reading from the screen or dial.

Depending on the quality of the tester, it will tell you plainly whether the battery is still good or not - or give you a percentage of useful capacity currently remaining.

Note: If you test a rechargeable battery that has just been charged and it does not measure at least 110% of its nominal voltage, it is a good candidate for reconditioning.

Using a battery analyzer to test batteries –

Battery analyzers provide more complete information about the capacity of a battery than both multimeters and battery testers. This is done by taking a battery through its entire discharge cycle and measuring its capacity as the total amount of useful current that the battery can deliver in amp-hours (or even as specific as milliamp-hours). That is why *battery analyzers* are often called *battery load testers*.

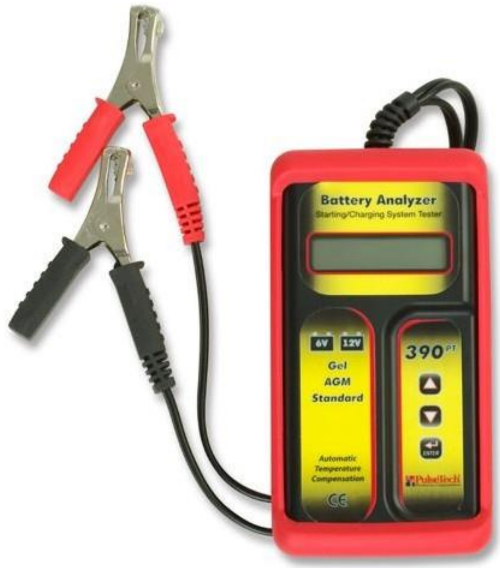
You should only use battery analyzers on rechargeable batteries because single use batteries will not be able regain charge back after the test which would be pointless.

The way that a battery powers a device, is by sending an electrical current through it when it is turned on and operating. Therefore, it is very useful to measure the amount of current a battery can produce and the length of time that it can produce it at. If a battery can deliver a total of 300 mAh (milliamp-hours) for example, then it can provide 300mah of current per one hour, or it can provide 100 milliamps every 3 hours. This works for any combination of current and time that multiplies to 300 (in this case).

In general, battery analyzers are more expensive than both multimeters and battery testers. As with all battery measurement instruments, the prices vary by voltage and battery-type range.

Many battery analyzers are made specifically for 6 and 12V batteries of all types. You can also get a combination smart charger/battery analyzer. For heavy duty batteries there are more robust battery analyzers that can test at high voltages and hook up to your computer for computation power which delivers very accurate results. There are even industrial level battery analyzers (for our purposes, we will be ignoring these industrial level battery analyzers that cost thousands to several thousands of dollars).

Examples of battery analyzers:



About $30. This instrument has a 100 amp load test used for 12V batteries and a 50 amp load test for 6 volt batteries.

About $45. “OTC 3181 130 Amp Heavy-Duty Battery Load Tester”

This one also works on 6 and 12-volt batteries - 130 amp load test.

About $75. “Multi-Current Universal Smart Charger with Compact Digital Battery Analyzer for any 9.6 -18V NiMH / NiCd Power Packs”

This one is specifically made for rechargeable batteries. It charges takes measurements for packs at least 9.6-volts to packs up to 18-volts.

About $160. “West Mountain Radio CBA IV Computerized Battery Analyzer”

This computerized battery analyzer can take measurements for *virtually any size and type of battery of any number of cells that equal up to 55V*. There is an optional temperature probe you can purchase which is a very good idea to get because overheating can kill a battery or ruin a reconditioning process.

About $400. “OTC 3167 SABRE Heavy-Duty Battery And Electrical System Diagnostic Tester”

This battery analyzer tests on all battery types for 6 and 12-volt batteries from a CCA range of 50-2000. It can even test on batteries because it has a mode to accurately test on lead-acid batteries just above the minimum voltage (lead-acid batteries should not go below a minimum voltage).

About $900. “Computerized Two Channel Precision Battery Analyzer for All Rechargeable Batteries up to 18V 120W”

This one tests, conditions, and charges all rechargeable batteries up to 18V.

The battery analyzer in the first example will work simply as a load tester for the 6 – 12-volt range. The combination smart charger/compact battery analyzer described in the third example may be a better buy than the second because it is also a smart charger for $30 more and can test up to 18V. Even the more expensive analyzers mentioned in example 5 and 6 have a pretty limited voltage range for their price range.

If you are just going to be testing and reconditioning a few batteries, then you may not want to spend the money on a battery analyzer. If you don't have any supplies from the get-go then it might be wise to get a battery smart charger/analyzer which can do two jobs for you.

The "West Mountain Radio CBA IV Computerized Battery Analyzer" I would most recommend if you are going to invest in a battery analyzer (even though it's not a charger) simply because it is extraordinarily versatile in being able to test on nearly every sort of battery chemistry while also having a range of up to 55V. It is also a decent price for all of its features at $150. This type of battery analyzer is great for the type of testing and reconditioning that we'll be going over in this book.

Diagnosing With a Battery Analyzer –

We'll be using the "West Mountain Radio CBA IV Computerized Battery Analyzer" mentioned in the previous section. It is a computerized analyzer so you need to install the included software to be able to run a test after connecting the device to your computer through a usb cable. Below are the steps to take once you're set up to run a test:

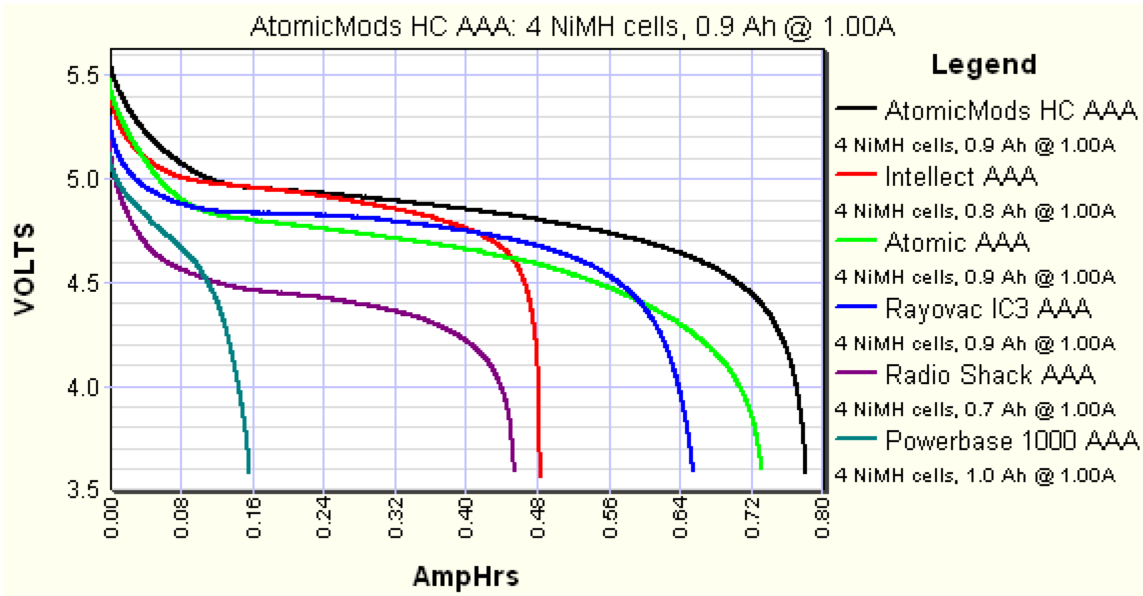
1. Make sure that the battery you are testing is fully charged. This will tell you the most about its capacity.
2. Connect the analyzer to the battery. Place the positive (red) clip of the analyzer on the positive battery terminal and the negative (black) clip on the negative battery terminal. No matter how many times you do this, it is good to double check the connections before moving forward because reversing the process could ruin the battery.
3. With this analyzer, the software has you assign a name to the test. It helps to be descriptive with this, perhaps with the date etc so that you can easily find your results later.
4. Then the software has you select the battery type. If you are testing a rechargeable battery, then it'll be one of the types that we discussed earlier. Either way, you'll find the battery typed labeled somewhere on the battery.
5. Enter the capacity of the battery in amp-hours (Ah). If the battery only has the milliamp-hours (mAh) labeled, then divide that number by 1000 to convert it to amp-hours.
6. Enter the nominal voltage described on the battery or pack).
7. Now enter the number of cells that the battery has. If you cannot see how many cells are in a battery pack, then divide the *total nominal voltage* labeled on the battery pack by the total n*ominal voltage per cell* for that battery type. **Table 3** below shows the voltage of each cell for each battery type.

Table 3 **Common Batteries** **Chemical type:**	**Battery size:**	**Nominal voltage :**	**Nominal capacity:**	**Rehchargeable?:**
Alkaline	AA, AAA, C, and D	1.5V	2,400 (AA) 12,000 (D)	No
Alkaline or Zinc-carbon	9V	9V	?	No
Li-MnO2	Coin Cell	3V	?	No
Li-ion or Li-poly	Various sizes	3.7	2200 mAH	Yes
Ni-MH or Ni-Cd	AA, AAA, C, D	1.2V	1300 - 2900 varies by brand (Ni-MH) 600 - 1000 depends on brand (Ni-cd)	Yes
Six-cell lead-acid	Car battery	12.6V	?	Yes
Zinc-carbon	AA, AAA, C, and D	1.5V	500 – 1000	No

For example, if you have a battery pack labeled:
NiMH 8.4V 5000mAh
Then the nominal voltage is 8.4-volts. Divide that by the nominal voltage for nickel-metal hydride batteries (NiMH) which is 1.2 and equals you'll get 7, which is how many cells are in the battery pack.

8. Leave the *test amps* and *test cutoff voltage* at their default values set by the program.
9. Now click on the start button that shows up on the screen. Now, the analyzer will take the battery through its entire discharge cycle electronically. While this is happening, the battery voltage, current, and

cumulative amp-hours and watts are displayed on the screen. You'll see the battery temperature if the optional probe is used where you can also manually input an automatic shutoff temperature.



Once your test is complete, on screen there will be a graph showing voltage plotted in relation to amp-hours. The results will look something like the graph above. This graph is a result on a test of a variety of popular Ni-MH AAA batteries on the market with a 1 amp load and default cut-off point.

These battery packs each have a nominal voltage of 4.8-volts because they contain 4 cells each that have a nominal voltage of 1.2. The graph shows us which battery has the best capacity - which would be "AtomicMods HC AAA battery" at .9 amp-hours.

How to interpret test results –

If you are measuring battery capacity at least 95% of the rated capacity or more, then the battery is still good to go and reconditioning it is unnecessary.

If however, the measured capacity is between 50% and 95% full capacity, then it may be worth it to you to recondition the battery. On the other hand, if your measurements under 50%, then try rejuvenating the battery and *then* reconditioning to bring it back to full capacity. Refer to **Table 1** for more interpretation information.

How to Recondition Rechargeable Batteries –

There are three ways to recondition a battery.

1. Remember the ***deep discharge method*** from the section on taking care of rechargeable batteries? While, when you *recondition* a battery, you are virtually performing the same process. Putting your device through a deep discharge cycle is a very simple way to recondition a battery: Just use your device until it stops operating.
   This process should be repeated up to three times, but if you don' see an improvement after the third attempt, then try rejuvenating and if that doesn't help then the battery cannot be saved.

2. **Note**: if you are reconditioning batteries on a power tool then run it without drilling, screwing, or anything like that. Just drain the power no-load.

3. An even better way to recondition a battery is to use a battery analyzer to take it through a *deep discharge cycle* because it is a more controlled process.

   Once again, we'll demonstrate using the "West Mountain Radio CBA IV Computerized Battery Analyzer".
   Reconditioning a Battery with a Battery Analyzer:

   1. Charge the battery to about 90% of its nominal voltage. Use Table 3 if you need to calculate what voltage that would be for a pack. For this step, performing a battery test on the battery fully charged makes the most sense because the testing procedure takes the charge level down to about 90% nominal voltage. When you're done with the test, all of the battery info (chemical type, voltage, etc) should be loaded. Leave all of this information on the screen because we'll be needing it again.
   2. Next, you'll only be changing two of the settings, the *test amps* and the *test cutoff voltage*.
   3. For reconditioning, the test load on the battery should be set between 10 – 20% of the rated capacity in amp-hours. For example, if the listed capacity on the battery is 800 mAh, then first divide by 1000 to convert to .8 amp-hours. Now multiply .8 by .1 (10%) and .2 (20%) to figure out the appropriate range. In our case, the *test amps* need to be set between .08 and .16 amps.
   4. Set the *test cutoff voltage* to 1/3 of the battery's nominal voltage. For a pack of 7 Ni-MH cells is labeled to be 1.2V per cell, the nominal voltage of the whole pack (if not already labeled that way) would be 8.4-volts; so we would set the *test cutoff voltage* to 2.8V.
   5. Click the "start" button to begin the reconditioning process. Your batteries will be discharged at the *test amp* rate that you specified in step 3 and will continue to discharge until it reaches the *test cutoff voltage* level.
   6. Once again, the printout on the screen will show the pattern of amp-hours vs voltage during the test. This time we don't need this information however.
   7. Now your battery should be recharged fully and then tested to measure the new capacity.

Most of the improvement will be noticeable after the first reconditioning. As mentioned in the beginning of the section, if you don't see an improvement after the third reconditioning, then try the rejuvenation process that's in the next section and if you still don't see an improvement after that, then the battery cannot be saved.

3. This process is doing the same thing as the battery analyzer, but manually. You do this by discharging the battery from 90% capacity to about 50% with a current of about 1/10 of the rated capacity in amp-hours.

   How to recondition a battery without an analyzer:

   1. First bring down the battery voltage on the battery that you want to recondition to about 90% of its nominal voltage. If you have a 12-volt battery pack then you will bring the voltage level down to 10.8V and if you have a 9-volt battery then you should bring it down to about 8.1-volts, etc. If you have a battery tester, an easy way to do this is to start with a battery that you have just completely charged and then put it through a battery test. If you don't have a battery tester but you do have a multimeter, then another way to do this is to charge the battery up, use the device for a little while, and then test it with a multimeter until you're down to around 90% full capacity.

   2. To find the current that you'll use to recondition the battery, use the following formula:

   3. Reconditioning current = amp-hours/10 where amp hours is the rated capacity of amp hours on the battery. If only a mAh value is given, then as was discussed earlier, divide that number by 1000 to convert it to amp-hours. For example, if a battery pack has a capacity of 1400 mAh, then that is 1.4 *amp-hours* and a tenth of that would be .14 amps. So .14 would be the current you should use for the test.

   4. Calculate the resistance that you'll need to deliver the desired test amps. Use the formula:

   5. Resistance (ohms) = battery voltage (have at 90% capacity)/*test amp hour.* For example, the 6V battery pack will be at 5.4V for the test. Then you would divide 5.4 by 1.4 (because that is what we determined as the test amp hours) which is 3.857. So the resistor used for this reconditioning current must be at least 3.8 ohms. A higher resistance will work fine, but it has to be at least and around that resistance level.

   6. Now the required wattage rating for the resistor needs to be calculated. Use tgis formula:

   7. Watts = (battery voltage)x(amp hours)

   8. We'll use the 6V battery as an example again. That would be 5.4 (volts) x 1.4 (amps) which equals 7.6 watts. So we know that the resistor must be rated to handle at least 7.6 watts.

5. Now calculate the *cutoff voltage*, which will be half of the nominal battery voltage labeled. Back to our 6-volt example, that would leave our cutoff voltage at 3-volts.

6. After you've gotten a hold of the required resistor, you need to connect it to the battery using alligator test leads. It doesn't matter which end of the resistor is connected the positive or negative battery terminals as long as they're both connected to the resistor with the leads. Also connect your multimeter to the battery terminals (the proper way with the positive and negative probes) so that you can continuously monitor the battery voltage. You can use the alligator clips to steady the multimeter probes.

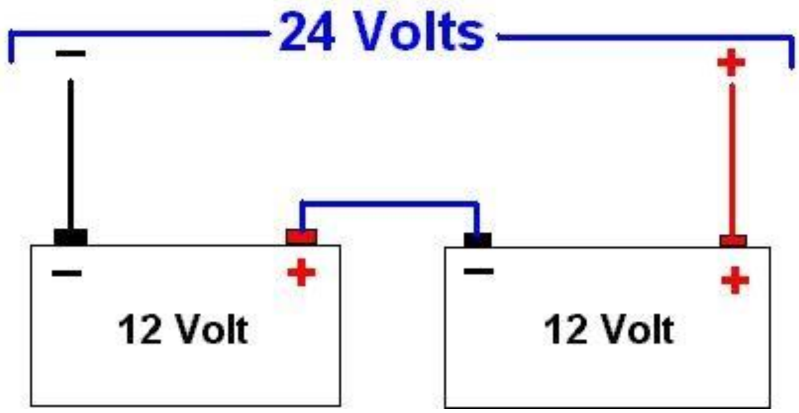
7. It will likely take around 3 to 4 hours for the test to discharge the battery to the cutoff voltage; however this greatly depends on the condition of the battery. You must continuously monitor the battery voltage with this method. If you let the battery level discharge to below 1/3 of its nominal voltage, the battery will probably ruin.

8. Finally, recharge and the battery and retest it to check for improvement. Once again, you only want to do this process up to three times to improve capacity.

How to Rejuvenate Rechargeable Batteries –

If you have a battery that didn't respond to reconditioning or isn't even in good enough shape to be a good candidate for reconditioning, then it may be possible to bring it back to life with a "rejuvenation" process. It is similar to shocking someone's heart to life again. Basically what you do is apply a voltage somewhat higher than the nominal voltage to the battery terminals.
Sometimes you can identify a single bad cell in a pack, in which case you can do this rejuvenation process to that particular cell and then assemble the pack back together. There is also a section below on how to fix a reversed cell.

1. Find a good battery to act as the "life giver" to be used to apply the voltage to the battery you wish to rejuvenate (it must be charged). You could use a 9V battery, a 6V dry cell battery to use on small, low voltage batteries, a 12V car battery, or even a power tool battery to use on higher voltage batteries.

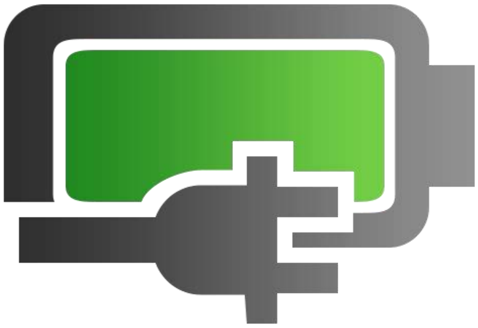


You can even hook up two 12-volt batteries in a series (or two of another size) to get more power, if needed. The positive terminal on one battery is connected to the other's negative terminal. Now you have 24-volts of power to rejuvenate with.

Note: putting voltage sources in parallel isbean very dangerous if there's a difference in output between the two batteries. The difference in internal resistance will cause an over current (short) situation through one of the loads (cells) and may cause a cell to explode or catch fire. Make sure the batteries are of the same chemistry, state of charge, and voltage if connecting them in series.

2. Connect your alligator test leads to the appropriate positive and negative terminals on the "life giving" battery.
3. Now, touch the other end of the negative alligator clip to the negative terminal on the battery you're rejuvenating and then **very briefly**, for about 1 – 3 seconds, touch the other positive clip to the positive battery terminal.
4. Now test for the voltage of the rejuvenated battery. If it is still not at or close to its nominal voltage, then try repeating the whole process this time tapping the positive terminal about three times with the designated end of the positive alligator clip. If once again you still don't see any results then the battery cannot be saved.
5. However, if the rejuvenation process was a success (congratulations!) then it needs to be fully recharged. Then you may also need to recondition the battery to get it to its best capacity.

How to Fix a Reversed Cell



A weak cell in a battery pack can sometimes cause that cell to reverse its polarity so that the positive terminal is instead of a negative charge and the negative terminal is instead of a positive charge. This most likely occurred because the battery pack was discharged down to a very low level. This has the weak battery taking a charge from the other cells in the opposite polarity.

You have to take the battery apart to diagnose and fix this problem.

1. Use a multimeter to test the polarity of a single cell by making contact with the positive and negative probes to the appropriate battery terminals. If the multimeter shows the cell to have a negative voltage when you do this, then the cell does have a reversed polarity. There is an appropriate positive and negative wire connected to the terminals with a ring terminal clapped down to test the single cells of the battery pack in the example below.
2. Often, applying a charge of around 4.5-volts to a reversed 1.2-volt cell will “shock” its polarity back to the correct way. Try this smaller voltage of a shock first and only if that doesn’t work then try a higher voltage up to just under 9-volts.
3. If you get the polarity of the cell back in the correct direction, then assemble the battery pack back together then and fully recharge it. You don’t want to wait around for the pack to discharge and the cell to reverse again.

Lead-Acid Batteries:

The reason that lead-acid batteries wear out is different than why Ni-Cd batteries do. This battery should never be deeply discharged and will remain fully charged because when you are driving you are recharging the battery. This constant charge doesn't hurt it because these batteries do not suffer at all from digital memory effect. In fact, keeping this battery type charged will only help increase its life because it will go through less discharge cycles. What actually causes the dwindling of these batteries are the destructive chemical reactions that take place within, over time. Many times, this battery type can be reanimated to function fully using the methods covered here.

Advantages –

- Simple to manufacture and inexpensive
- Well understood, mature, and reliable when used correctly
- Among the lowest self-discharge rates for rechargeable batteries
- Capable of high discharge currents in bursts

Disadvantages –

- Low energy density limits use to stationary and wheeled devices
- This battery type cannot be stored in a state of discharge
- Allows quite a limited number of full discharge cycles – best for standby applications that only require high power on occasion
- The lead and sulphuric acid composition make this battery extremely bad for the environment
- They have transportation restrictions because a spillage could be a hazard
- If improperly charged thermal runaway can occur

Maintaining and Reconditioning Lead-Acid Batteries –

Most of the time, we only think about our lead-acid batteries when they fail to start our automobile engines. However, your vehicle's battery is not high maintenance. Just a small amount of care and attention will help insure that you get the most of your car batteries sometimes even adding years of use. Lack of general care and maintenance combined with cold weather will expose borderline batteries that worked fine in the summer, but don't possess the power for starting in the cold. It's a great idea to catch a bad battery before you discover this later on during one of the coldest days of the year. If however you do only consider your car once a year, fall would be a good time to do some required maintenance.

Car battery testing and maintenance is fairly simple and only requires a few basic tools. With the infinite number of lead acid batteries in use, many are discarded or taken out of use every day. It is not uncommon for a discarded lead-acid battery to still possess a good amount of useful battery life. Now you can take advantage of these batteries that are good to go once they're tested, reconditioned, and taken care of using the following methods.

Some background info on this battery type –

Being the oldest type of rechargeable battery, lead-acid batteries were invented way back in 1859 by French physicist Gaston Planté. This battery has changed little since the 1880's although improvements in composition materials and methods of manufacturing have continued to bring improvements in energy density, lifespan, and reliability.

Flat lead plates immersed in a pool of electrolyte compose all lead-acid batteries. The addition of water is a regular requirement for most lead-acid batteries. Low maintenance ones are sold with excess electrolyte calculated to compensate for water loss over an expected lifespan.

Note: Lead acid batteries do not suffer from digital memory effect.

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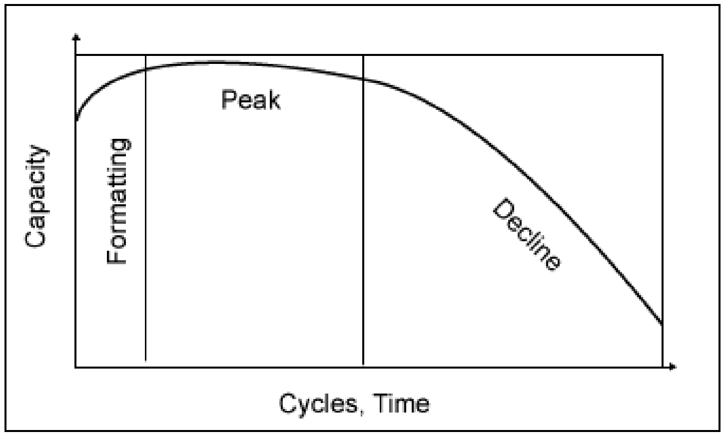


Lead –acid batteries go through three life phases called: *formatting*, *peak*, and *decline*.

Formatting: try to imagine lead plates that are sponge-like and are being exposed to liquid. Exercising the plates allows more absorption of liquid, similar to the squeezing and releasing of a sponge. This will enable the electrolyte to better fill in the functional areas; this is an exercise that increases the battery capacity. (This really only applies to deep-cycle batteries and requires 20 – 50 full cycles to reach maximum capacity. However, there isn't a need to apply extra cycles for the sake of priming because field usage itself exercises the plates. Still, manufacturers recommend going easy on the battery until it is broken in.)

A lead-acid battery has a relatively high power-to-weight ratio, despite having both a very low energy-to-weight ratio and a low energy-to-volume ratio, due to their ability to produce high surge currents. This feature, along with low cost, has made these batteries a favorite for use in motor vehicles to provide the high current that is required by starter motors.

Starter batteries don't require any priming as the full cranking power is present right at the beginning (although CCA readings will go up slightly with early use).

A deep cycle battery will produce 100 – 200 cycles before it starts a gradual decline in capacity. They should be replaced when they drop to 70 or 80%. Although some applications do allow lower capacity thresholds, the retirement should never fall below 50% capacity because the aging occurs rapidly once the battery is past its prime. Give the battery a fully saturated charge of 14 to 16 hours. Operations done in moderate temperatures assure the longest service times. If at all possible, avoid deep discharges; charge often.

Types of Lead Acid Batteries –

- *Starting Batteries* – These are used to start and run engines and can deliver a very large current for a short amount of time discharging by about 2 – 5%. If deeply discharged, these batteries will quickly degenerate and will fail after only 30 – 150 cycles. However, they should last for a very long time when used correctly.

- *Deep Cycle Batteries* – These are used to store electricity in autonomous power systems (such as solar and mini-hydro), for emergency back-up and electric vehicles. They are different in that they are designed to discharge by as much as 80% of their capacity over thousands of discharge cycles. True deep cycle batteries have solid lead plates and those that do not are referred to as semi-deep cycle.

- *Marine Batteries* – A marine battery is usually a hybrid that falls between the description of deep cycle and starting batteries, although some are true deep cycle batteries. They are never meant to be discharged below 50%.

In cars, starting, lighting, and ignition (SLI) batteries are typically used. Only around 2 – 5% of the charge is used when starting the car and then is replaced by the alternator right away as they are designed to be at full charge when starting a car. These batteries are also not really meant to be discharged below 50%. Doing so can damage the plates and shorten the life of the battery. Because of this, deep cycle lead-acid batteries are found in RV's, marine applications, golf carts, motorcycles (of all sizes), and many other engine powered devices that can't be constantly charged like in a car.

SLI and deep cycle batteries can both be either vented or sealed.

Vented batteries are built with a removable cap to provide individual access to each cell. They expel water vapor or hydrogen and oxygen gas fumes through the vents when they heat up. That is why this type of battery needs to have distilled water added to the cells periodically to keep the plates immersed.

Sealed batteries (often referred to as maintenance-free batteries) do not have access providing caps on the cells. They're designed this way on purpose to prevent gassing and thus less loss of water from the electrolyte solution. The only way to add water is to gain access to the cells by drilling holes and then using plastic plugs.

The Most Common Problems –

The typical problems that we'll be going over how to remedy are *sulfation*, *corrosion,* and *internal shorts*.

Corrosion: is known as the softening and shedding of the lead off the battery plates and occurs primarily on the grid. Altogether, this chemical reaction cannot be avoided because the electrodes in the lead-acid are always ready and reactive. All you can do is drastically slow down this natural phenomenon by limiting depth of discharge, reducing the cycle count, operating at a moderate temperature, and controlling overcharging.

Prolong overcharging is a great contributor to grid corrosion. This is particularly damaging to sealed lead-acid batteries. While flooded (vented) lead-acid has some resiliency to overcharge, sealed units must operate at a correct float charge. Smart chargers with variable (float) voltages that adjust by temperature are good to use for vented batteries to help keep corrosion in check and are common use for stationary batteries.

In order to attain maximum surface area, the lead of a starter battery is applied in a sponge-like form. Over time with use, chunks of lead fall off and reduce the performance.

A sort of white powder visible on the battery terminals means that they are corroded. This would be a result of oxidation between two different metals connecting the poles. Corrosion of the terminal can eventually lead to an open electrical connection. Most corrosion problems can be solved by changing the changing the terminals to lead if they are not already.

Internal short: this describes a general battery fault if no other definition is given. Battery users will often judge lead acid batteries as being simply being "shorted" when they are not working, so we're going to go over what a shorted lead-acid battery truly is.

The lead inside a lead-acid battery is mechanically active and when a battery discharges, the lead sulfate causes the plates to expand (especially in deep-cycle units). During charge, this motion reverses and the plates contract. Even though the cells do allow for some expansion, the growth of large sulfite crystals over time can cause a break that increases self-discharge. Also, this mechanical motion will cause the lead material to *shed* off the plate. As the lead debris sheds to the bottom of the battery container, a conductive layer forms. Once the contaminated material fills the allotted space inside the sediment compartment, the now conductive liquid reaches the plates and creates a shortening effect. The term "short" isn't the most appropriate one for this process. *Elevated self-discharge* or *soft-short* would be a better term to describe the battery condition.

It is difficult to immediately detect soft-shorts because the charge itself will sort of wipe out all evidence. Except for perhaps an elevated temperature on the battery housing, a soft-shorted battery will functionally entirely normal after the charge. However, once the battery has been rested for 6 – 12 hours, it begins to show anomalies such as a lower open-circuit voltage and reduced specific gravity (concentration of acid). You'll also get a low capacity reading because self-discharge will have consumed some of the stored energy.

Shorted batteries account for 18% of battery failures, a drop from 31% five years earlier according to the *2010 BCI Failure Modes Study*. This reduction may be due to improved manufacturing methods over the years.

Mossing is another form of a soft-short. This will happen if there is a misalignment of the separators and plates as a consequence of poor manufacturing practices. When this happens, the lead plates become naked. The exposure will produce a formation of conductive crystal moss around the edges of the plates, which causes elevated self-discharge.

Another cause of shorts is *lead drops*, where large chunks of lead break apart from the welded bars connecting the plates. Unlike a soft short that develops gradually with general use, a lead drop will often occur early on in a battery's life. This will cause a more serious short and perhaps even a permanent voltage drop. The shorted cell may have a tiny bit of or no charge at all and an electrolyte solution with a specific gravity close to 1.00. This is mostly a manufacturing defect and once it happens cannot be repaired.

The most extreme type of short for lead-acid batteries is mechanical failure in which the suspended plates become loose and come into contact with one another. This creates a sudden high discharge current that can lead to excessive heat and thermal runaway. Poor manufacturing again, as well as excessive shock and vibration are the most common causes of this failure.

How Lead-Acid Batteries Work –

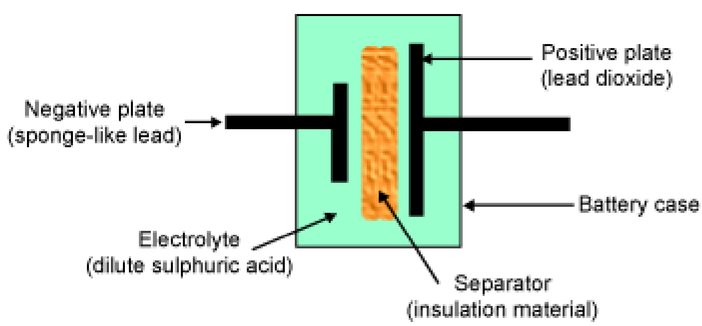
Let's take a quick look inside the functions of a wet lead-acid battery. Even though you do not need to know what the inside of a lead-acid battery looks like to recondition it, knowing the ins-and-outs may provide some extra help. You can gain an understanding of how lead-acid batteries get to the point where they can't take a charge and what you can do to prevent or fix this occurrence.

Inside, the cell of a lead-acid battery is made up of two lead plates. One of these plates is connected to the positive terminal and the other is connected to the negative terminal. In between, they are separated by insulation material. The whole apparatus is enclosed in a plastic battery case and submersed, until it covers the top of the plates, with a solution of water diluted sulfuric acid called the electrolyte.

Lead-acid batteries do not generate voltage on their own. Before a lead-acid battery can produce voltage, it must first receive a forming charge with a voltage of at least 2.1-volts per cell from a charger sending an electrical current through it backwards. Only then will they produce an electrical current through a device connected between the two terminals (your car's electrical system for powering headlights, radio, the engine starter, etc.). That is why these batteries are often referred to as *storage batteries*, because they can only store a charge.

The size of the lead battery plates and the amount of electrolyte determines the amount of charge this type of battery can store. The size of the storage capacity is measured as the amp-hour (AH) rating of a battery. The typical 12V battery used in RV and marine crafts has a rating of 125 AH, meaning that it can supply 10 amps of current for 12.5 hours (or nearly any other combination of amps and current that equals 125). Lead-acid battery cells can be connected in parallel series to increase the total AH capacity of a battery.

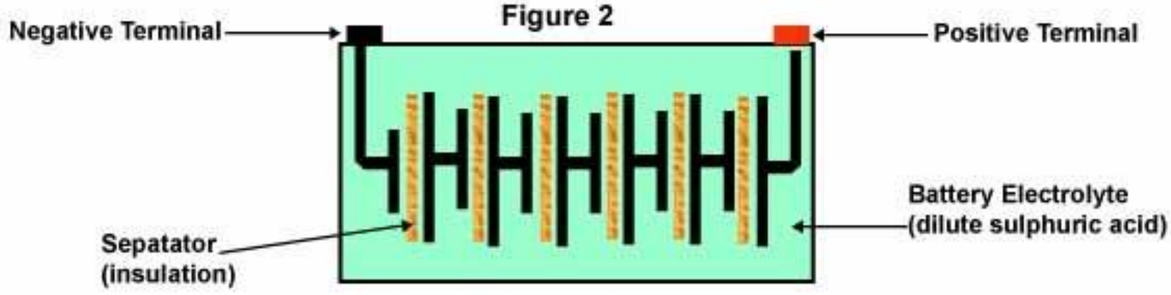
Figure 1



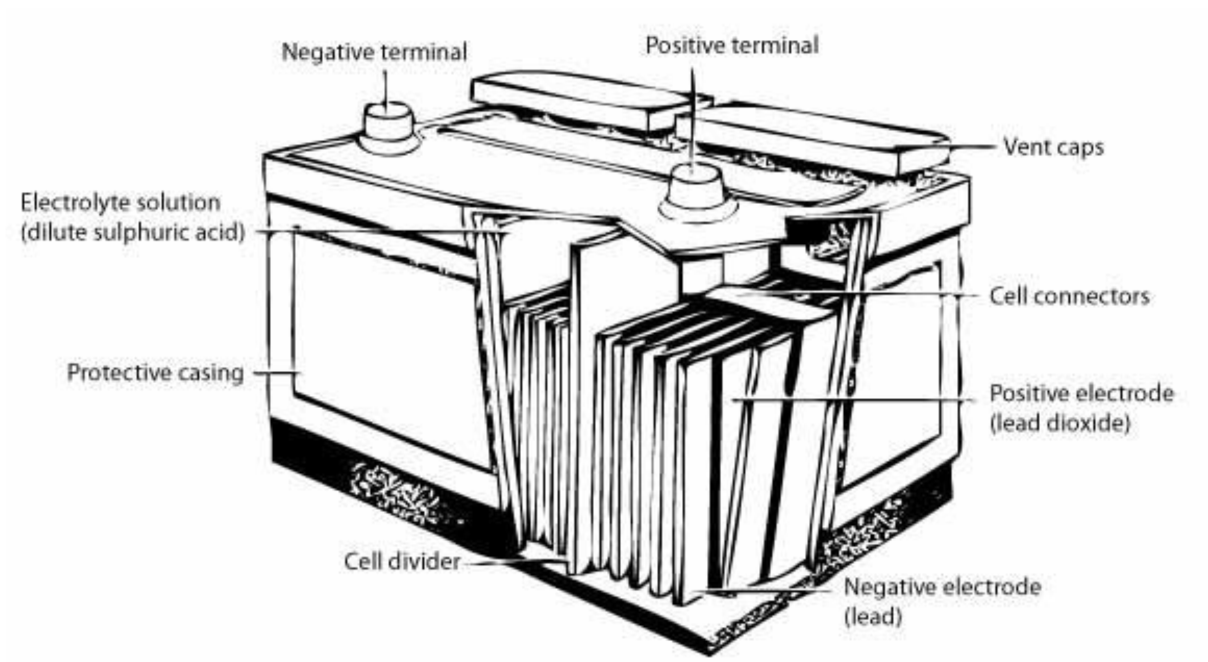
The inside of a *single* lead-acid battery cell has one negative plate and one positive plate and looks like the diagram above. Its nominal voltage would be 2.1 volts.

However, it is rare that a lead-acid battery consists of a single cell. For a long time, the standard automobile battery was made up of three identical 2-volt cells connected in a series to have an output of around 6-volts. However, quite some time ago the standard was switched to 12-volt batteries with six identical cells. They can be made up of any voltage which is a multiple of two by combining the right number of cells in series. Although 6 and 12-volt are the most popular, they are produced in an array of other voltages.

Figure 2



In this diagram of a typical 12V lead-acid battery above, six single 2.1-volt cells have been connected in a series so that fully charged; this battery will produce a total of 12.6-volts.



Each cell holds lead plates of different compositions within the sulfuric acid solution. Lead dioxide plates linked to the positive battery terminal react with the acid to form lead sulphate, which has the plate giving up its electrons, leaving it positively charged. Then the pure lead plates linked to the negative battery terminal react with the sulphate ions to also form lead sulphate. Therefore, the pure lead plates supply two positive charges and so, are left negatively charged.

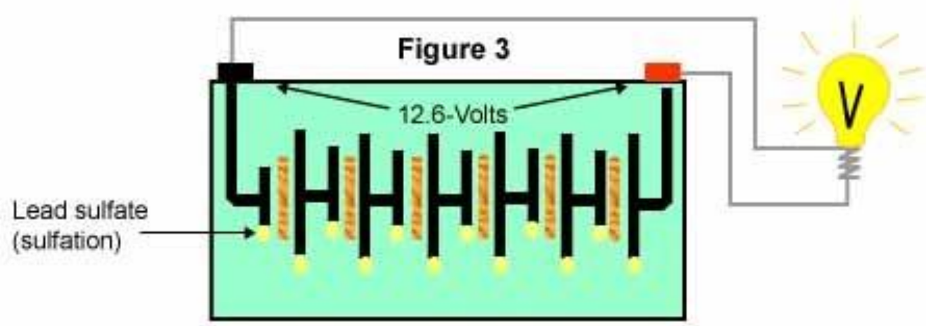
This passage of electrons from the lead oxide plates to the pure lead plates is the actual current of electricity generated by the cell which can be used for power. The lead sulphate in each cell is broken down which results in lead dioxide being re-deposited on the positive electrode and the pure lead being replaced on the negative electrode when the battery is recharged.

The Lead-Acid Battery Discharge Cycle –

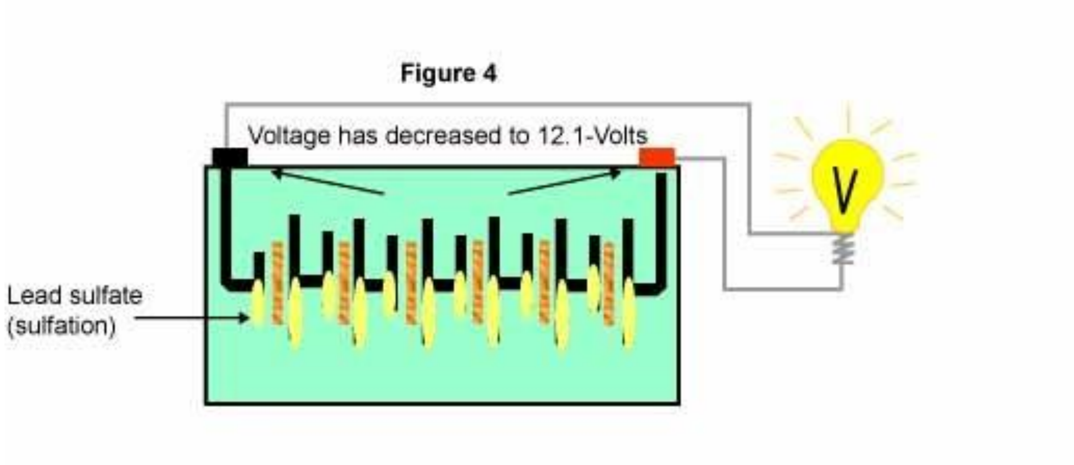
If you do any lead-acid battery testing and or reconditioning, then you will come across the term *sulfation* or *sulfating*, so here we'll go over what that is, how it affects the batteries, and what it means to you.

When a lead-acid battery is functionally discharging, the lead dioxide of the positive plate and the pure lead of the negative plate chemically react with the sulfate in electrolyte solution and create a substance called *lead sulfate*, water, and electrical energy in the process. This lead sulfate substance builds up gradually as the battery discharges getting in the way of proper functions.

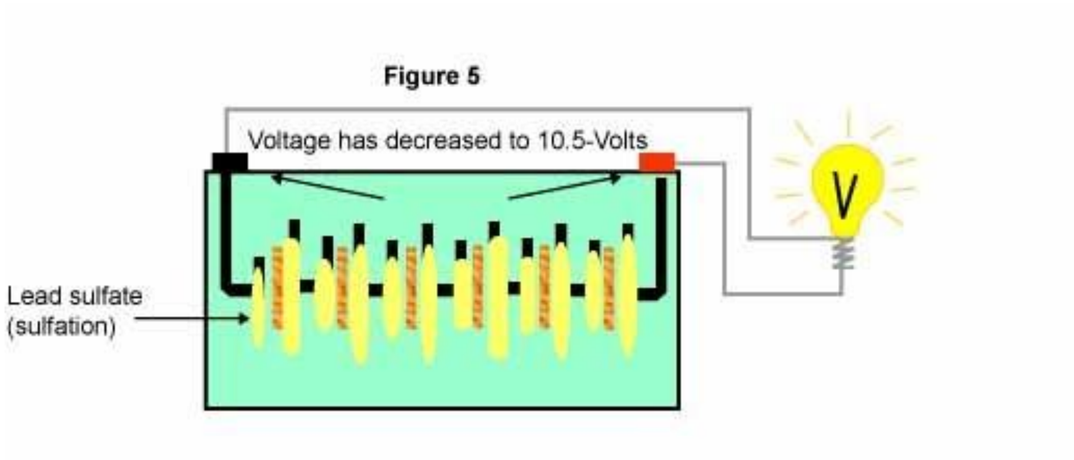
Lead-acid batteries must be maintained a certain way if they are to remain of good use for a long time. That's where *desulfation,* the method for reconditioning lead-acid batteries comes in, which we'll cover in the next section.



In the figure above, a fully charged battery is connected to a light bulb (load) as the chemical reaction between sulfuric acid and the lead plates produces the electricity that lights it. This chemical reaction *also* starts to coat both the positive and negative plates with a substance known as **lead sulfate**. This whole process is also called **sulfation**, which is shown on the image by the yellow build-up on the plates.



Lead sulfate build up is a normal occurrence during a discharge cycle on a lead-acid battery and starts once the battery charge descends below 75%. As the battery continues to discharge, the lead sulfate covers more and more of the lead plates and the battery voltage gradually decreases from its fully charged state of 12.6-volts.



This diagram shows a lead-acid battery fully discharged*. The plates are heavily covered with lead sulfate and the voltage is now 10.5V. This is the lowest safe level that you want to allow your battery to discharge.

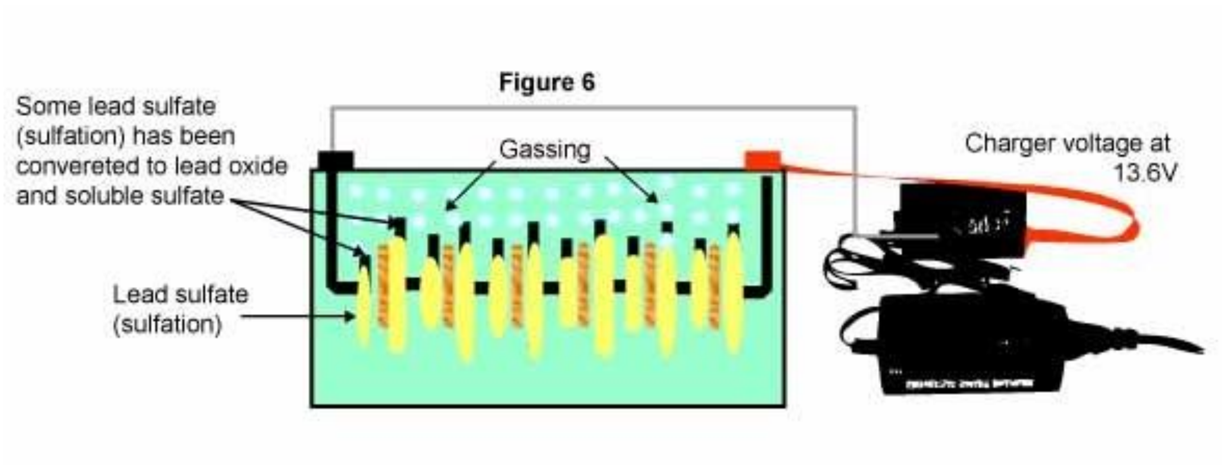
Note: *discharged meaning at an acceptable level of discharge. You will severely damage a 12-volt lead-acid battery if you discharge it below 10.5-volts!

Now lead sulfate nearly entirely covers most of the battery plates. It is a soft material, which can be reconverted back into lead and sulfuric acid, ***if*** the discharged battery is immediately put on a charger. If you don't, the lead sulfate will begin to form hard crystals which cannot be reconverted by a standard battery converter/charger with a fixed voltage. Most converter/chargers are set at 13.6 fixed volts.

Always recharge your lead-acid batteries as soon as possible to prevent loss of battery capacity due to sulfation. If you discharge the battery below the safe 10.5-volts mark, or allow it to remain in a partially discharged condition for too long, the once soft lead sulfate will turn into hard lead sulfate crystals on the battery plates. Once it has been *sulfated*, the battery's resistance will increase, causing it to heat up while attempting to be recharged which will prevent it from actually taking a charge. The crystals will also not be able to be converted back into lead oxide and soluble sulfate through the normal recharging method of 13.6 fixed volts.

The Lead-Acid Battery Recharge Cycle –

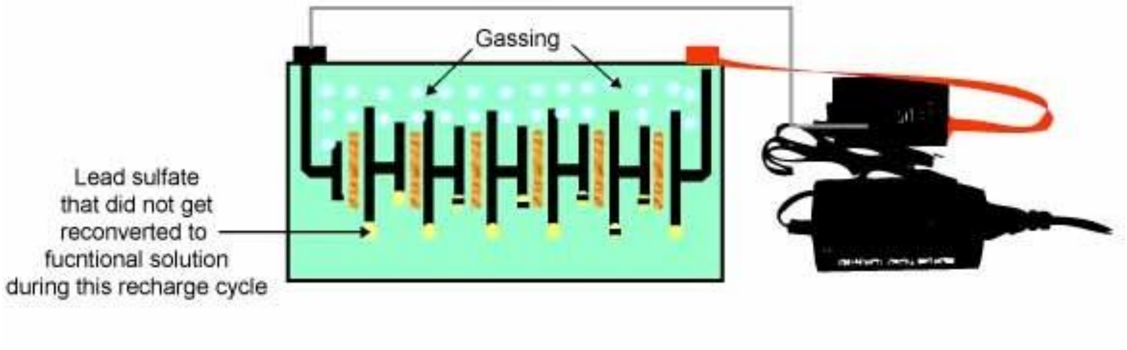
The most important thing to keep in mind about recharging lead-acid batteries is that a charger with one fixed-output voltage will not properly recharge or maintain this battery type. What you'll need is an intelligent charging system that can vary charging voltage based on the state of charge and use of your lead-acid battery. This system could be manually implemented or ran through a program on a smart battery charger.



During the recharge process electricity flows through the water portion of the electrolyte solution and H_2O is split back into its original elements hydrogen and oxygen. This gas byproduct is super flammable and the reason to avoid open flames in the vicinity and to also to vent your batteries outside. Gassing also causes water loss which is why you have to maintain their water level periodically. Sealed lead-acid batteries come with these gasses already contained allowing reunion in the electrolyte during this process. Venting is less of an issue with these batteries.

Vented lead-acid batteries still give off hydrogen and oxygen fumes. If the battery is overcharged then the pressure from the gasses will cause the battery's relief caps to open and vent which causes water loss. Most sealed batteries are sold with extra electrolyte solution added during manufacturing to compensate for water loss.

Figure 7



Now the battery has been fully recharged at a fixed voltage of 13.6-volts. Notice the sulfation that remains on the plates still. This will eventually continue to build up after each recharge cycle and the battery will continue to loose capacity until it has to be replaced.

Although you cannot prevent sulfation, you can slow it down by giving the battery an equalizing charge once every 10 discharge cycles or at least once per month. An equalizing charge is an increase in voltage to 14.4-volts or higher to help reconvert the sulfate into functional solution. We go over this in the section on reconditioning lead-acid batteries.

Testing Lead-Acid Batteries –

People discard lead acid batteries for many reasons and some can be brought back to a useful life with reconditioning, but some cannot. We'll go over three different kinds of tests, voltage, load, and hydrometer tests to use to find out whether a battery can be reconditioned back to a good capacity.

Tools: In addition to a multimeter, there is certain equipment that you'll need for testing lead-acid batteries.

- A battery hydrometer (the ones with gauges are easy to read)

- A battery terminal cleaner
- A smart charger designed specifically for lead-acids
- A plastic funnel
- Epsom salt
- Half-quart sized container

- Digital thermometer with sensor probe

Optional:

- Lead-acid battery analyzer (w/ temperature meter recommended) or all in one charger/initializer/ desulfator

But wait! SAFETY FIRST! –

Batteries produce an extremely flammable hydrogen gas. The lead-acid contained within these batteries is a hazard for living things to come into direct contact with as well. The battery has plates made of lead and a liquid solution of weak sulfuric acid. Even though the acid is considered weak, it is only weak for sulfuric acid and can cause you a serious chemical burn if you are not **attentive** and **careful**. If there is a task that you don't feel comfortable doing then don't do it.

- Wear rubber gloves and a rubber apron to protect your hands and clothes. Here the use of safety glasses is stricter. The glasses should have side protection as well as front protection. Safety goggles or a full face shield would be even better.

- Don't smoke or have open flames around lead, especially when charging a battery because the gas produced while it is charging can explode if it comes into contact with the sparks and flames.

- Whenever you are connecting or disconnecting a cable from a lead-acid battery (when charging in a car for example) it is **important** to disconnect the negative terminal first and then the positive terminal. This will help avoid a spark that could otherwise cause an explosion.

Environmental Safety –

There are also environmental concerns to consider when working with lead-acid batteries. Lead is a highly toxic substance and is considered a hazardous waste. It is of most importance to properly dispose of these batteries. Be sure to follow federal, state, and local requirements for disposing of lead-acid batteries properly.

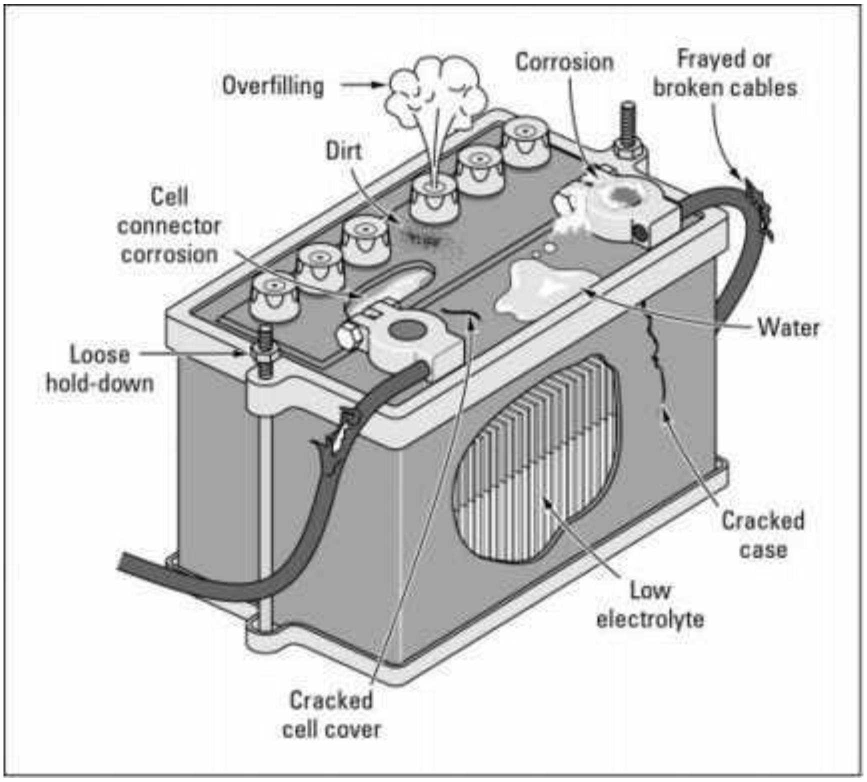
Here is a good resource on battery disposal:
http://www.ehso.com/ehshome/batteries.php#whattodo

Find a battery drop off center near you:
http://www.ehso.com/ehso2.php?URL=http%3A%2F%2Fwww.rbrc.org/call2recycle/dropoff/index.php

The first two steps: are always the same –

1. Inspect the battery:

There may be an obvious problem that you can spot such as broken or frayed cables, low electrolyte levels, a wet or dirty battery top, swollen or corroded cable terminals, or a leaking or damaged battery case. The battery fluid level should be topped off with distilled water.



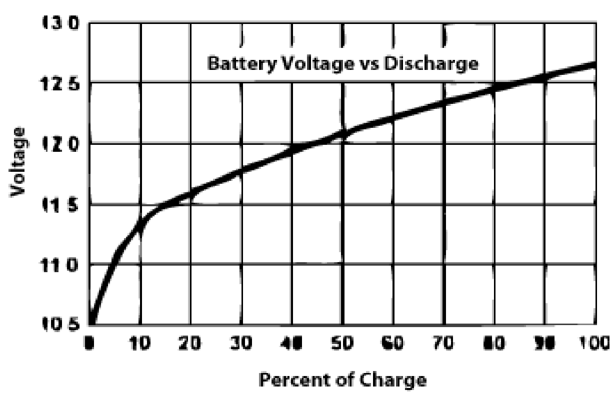
2. Fully charge the battery and then **remove the surface charge before any test**. This is done by letting the battery sit for close to 12 hours or by drawing a load of at least 20 amps (like turning on the car headlights) for about 3 minutes.

Now it is ready to be tested. If you don’t remove the surface charge, it will make a weak battery appear to be in good condition or a good battery appear in not so good condition.

1. **No-load voltage testing with a multimeter:** The battery above is at full capacity. With a multimeter, touch the positive (red) probe to the positive battery terminal and the negative (black) probe to the negative terminal and note the reading. Most battery testers will give you a no-load voltage reading when you first hook up the battery to the machine. You can use a battery tester or hydrometer for no-load tests.

How to interpret the no-load voltage reading:

The following table tells you the percentage level of charge by voltage.



<u>Table 4</u> **Battery Voltage No-Load** **Charge level**	**Voltage 12V**	**Voltage 6V**
100%	12.7	6.3
75%	12.4	6.2
50%	12.2	6.1
25%	12.0	6.0
Discharged	11.9 or below	6.0 or below

No-load testing with a battery analyzer:

When you initially hook up the test clips, most battery analyzers will give you a no-load voltage reading. Just attach the positive and negative clips on the analyzer to the appropriate battery terminals like so. If not, just look up how to do this in the manual

Above is a battery being tested no-load with a battery analyzer showing nearly 11-volts (about 10.9V). A battery usually isn't worth taking through a reconditioning process if the no-load voltage is less than 12-volts (less than 25% capacity).

State of Charge Testing with a Hydrometer –

You can measure the state of charge of each cell with a hydrometer to determine the *specific gravity* (SG) of the electrolyte. *Specific gravity* measures the concentration of the acid in the battery. Because of the chemical reaction caused by charging and discharging, the proportion of sulphuric acid (in SG = 1.8) to water (in SG = 1) in the electrolyte solution, and therefore the specific gravity of the electrolyte gradually increases during *charge* and decreases during *dis*charge.

The entire working range of specific gravity lies between the limits of 1.1 and 1.3. If a battery goes below 1.1 SG, damage may be caused by the plates becoming hydrated. If above 1.3, the plates and grids are liable to be corroded.
Use a hydrometer to check the electrolyte level to ensure that it's above the plates in all cells because if it's below the battery plates, the test can't be carried out until diluted water is added and the battery charged to mix the water and residual acid in the battery. It is important to make sure that the plates don't remain exposed to air and allowed to dry and oxidise.
On a fully charged battery, the SG is between 1.215 and 1.28 depending on the battery type. When the SG decreases to around 1.175, the battery needs charging. SG is often multiplied by 1000 and the hydrometer scale marked accordingly.

SG readings ought to be in contrast to a temperature of 25°C. A significant contrast to this temperature will cause a change in density to the electrolyte. This needs to be taken into account when SG is measured. A significantly lower temperature will cause the battery to be sluggish. The amount of change that the SG lags behind the charge or discharge is by an amount that depends on the characteristics and dimensions of individual cells and rate of charge or discharge owing to the time required for the diffusion of the electrolyte. Due to this, the SG will continue to increase for a short period of time after the charge has been terminated and may similarly continue to decrease after the charge has been terminated; although if the end of the discharge is at a low rate, then the lag may not be noticeable.

Only distilled water should be added to the electrolyte. Water with impurities will only cause problems in the battery. Do not add acid. Do not take a SG reading immediately after topping with water.

Tools: If you have a battery that isn't sealed, then it is highly recommended that you use a good quality temperature compensating hydrometer. There are basically two types of hydrometers, the floating ball kind and the gauge kind. I recommend the gauge type personally because I think that they are easier to read. They can be purchased at an auto parts store for less than $20.00.

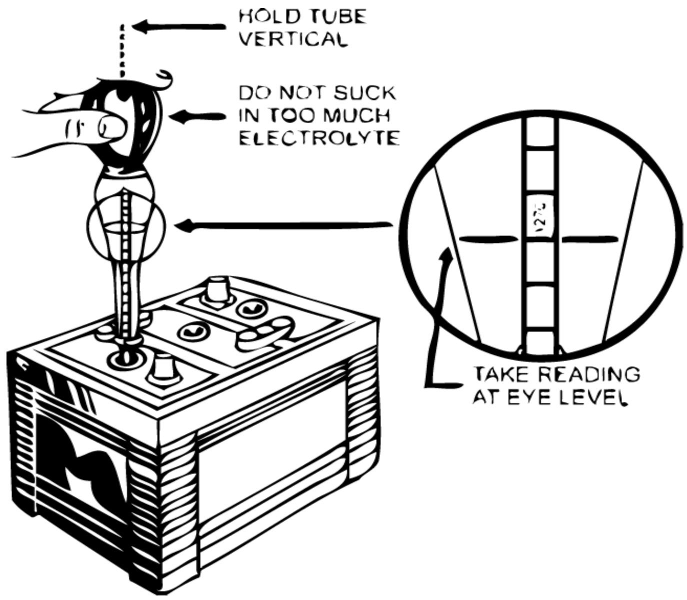
The steps –

1. Recharge the battery to 100% full capacity.

2. Remove surface charge: as discussed in the beginning of the section on lead-acid batteries.

3. To execute this test, you need access to the acid in the battery. For batteries that are non-sealed: the filler caps will need to be removed if present.

4. Draw up some of the electrolyte solution into the hydrometer and note the reading.



If most of the cells have a SG reading above 1.2 and one individual cell has a reading of 1.12 or below, the cell with the lower reading is probably dead and cannot be reconditioned. If a non-sealed battery has .030 (often expressed as 30 "points") or more difference in specific gravity reading between the lowest and highest cell, then you should equalize the battery using the manufacturers' instructed procedures.

To test sealed battery cells: You test the no-load voltage of each cell. There are a few options.

If you have found one cell that is below 2-volts and all of the others are at or above 2V, then you have found a dead cell.

1. You can use a digital multimeter with .5% accuracy or better to test on each battery cell. Don't get an analog one because it won't be accurate enough to measure the millivolt differences of a battery's state of charge to measure the output of a charging system.

2. Use a battery load tester on each cell. Do this by attaching the red clip of the tester onto the positive terminal and have the black clip connected to a wire which is inserted into the liquid of the negative side of the first cell. The voltage should be 2 or more volts. Next, connect the red clip to a wire in the second cell. Repeat until you have checked the voltage of each cell. **Table 4** from earlier in the section also tells you what the reading has to say about the state of the battery cell.

3. The third way is with a hydrometer by drilling access holes into each battery cell:

    1. Recharge the battery to 100% full capacity.
    2. Remove surface charge: as discussed in the beginning of the section on lead-acid batteries.

3. Drill a small hole to access each battery cell. There will be no filler (cell) caps. Make sure to stop with your drill bit so that you don't hit and damage the battery plates. Have some plastic plugs or corks (they're available at most hardware stores for this purpose) to plug the holes that you made.

4. Draw up some of the electrolyte solution into the hydrometer and note the reading.

Table 5	Specific Gravity	
State of Charge	SG*	OCV †
100%	1.277	2.12
90%	1.258	2.1
80%	1.238	2.08
75%	1.227	2.07
70%	1.217	2.06
60%	1.195	2.04
50%	1.172	2.02
40%	1.148	2
30%	1.124	1.98
25%	1.111	1.96
20%	1.098	1.95
10%	1.073	1.93
0%	1.048	1.91

SG * Specific Gravity @ 25°C - (77°F)
OCV † — Open Circuit Voltage per 2 Volt Cell

Load Testing with a Battery Analyzer:

To run the load test, there will be a button to press and hold for ten seconds or so. This will apply the specified load to the battery and to measure the voltage under load pressure. The battery load meter may give a reading of "good", "weak", or "bad" or it may be in voltage level.

Table 6 Battery Voltage Under Load:	Condition:
10 – 12-volts	**good**
6.1 – 10-volts	**weak**
less than < 6.1-volts	bad

Say your test results are not at least 12-volts on the no-load test and the load test results show up in the "weak" or "bad" range. First try first recharging your battery, then repeating the load test. If you still cannot bring it up to at least 8.5-volts on the third try, then the reconditioning process we're going to discuss will probably not work.

Reconditioning Lead-Acid Car Batteries –

We'll be discussing three possible approaches that you can use to recondition lead-acid batteries including applying an equalizing charge, using chemical addition, and finally reconditioning using lead-acid battery tools with built in desulfating modes.

Applying an equalizing charge:

Note: some smart chargers have this feature built in. This is for doing it manually.

This consists of charging at a higher voltage for a short period of time.

Apply an equalizing charge to the battery when it is first purchased and then on a regular basis of every 10 cycles or at least once a month. Reduced performance is also a sign that an equalizing charge is needed. This prevents battery stratification and reduces sulfation, which is the primary cause of lead-acid battery failure.

1. Make sure that the lead plates in all of the cells are covered with electrolyte solution and add distilled water during the equalizing process, if needed, in order to keep them covered.
2. Fully recharge the battery like normal.
3. Increase the charge of the battery to a voltage 5 to 10% above normal charging voltage. The equalizing voltage is typically around 14.4 – 15-volts for a 12V battery.
4. Monitor the battery temperature. Don't allow it to increase above 100°F (or 38°C) for a sealed battery and 125°F (or 52°C) for a non-sealed battery. Stop equalizing the battery and allow it to cool before continuing. It's most accurate to take the temperature of the battery right on top of the terminal if you are using a digital thermometer. You can use some duct tape to keep the sensors in place.
5. If you feel that there are too many things attached to a terminal, then tape the temp sensor midway down the side of a single battery near the center of the pack. If you do this it helps to cut a piece of Styrofoam about the width of the battery and tape it over the battery as well because of ambient temperature effects.
6. The equalizing voltage should cause gassing.
7. At least once an hour, take the specific gravity readings of each cell. Stop equalizing the charge when the specified gravity values no longer rise and when each cell is gassing evenly.
8. Let the battery discharge to 50% and then recharge it normally a couple of times. Test to see if equalizing charge has helped.

Using Chemical Addition –

This procedure uses common *magnesium sulfate*, better known as Epsom salt.

1. Measure about 7 – 8oz (250 grams) of Epsom salt.
2. Have about a half-quart of distilled water heated to about 150°F. While this temperature is extremely hot, it is not boiling. Now it doesn't have to be exactly 150°, but it does need to be hot enough for the Epsom salt to dissolve.
3. Add the measured 7 – 8oz of Epsom salt to the half-quart of hot water and stir until it is all or nearly completely dissolved.
4. You need access to the electrolyte solution in the battery, so the battery caps need to be removed or holes need to be drilled into each cell in a sealed battery.
5. If the electrolyte solution in the battery is at a proper level with the lead battery plates completely covered, then remove about a half-quart of liquid from the cells of the battery. Take about the same amount of solution out of each cell.
6. With an appropriately sized plastic funnel, add the half-quart of Epsom salt solution to the battery by putting about the same amount into each cell. Once again, make sure the plates are all completely covered.
7. Put the battery caps back on or put plastic plugs into the holes that you drilled. Then shake the battery to make sure that the Epsom salt solution is well distributed in each cell.
8. Charge the battery back up completely and then discharge it to about 50% to see if the chemical addition has improved battery capacity.

Reconditioning Using Desulfating Equipment –

You can use special desulfating equipment to recondition your lead-acid car batteries. There is quite an array of these instruments on the market. A lot of them use pulses of alternating current to break apart sulfation build up. Now certain smart chargers for lead-acid batteries come with a desulfating mode. They're lead-acid battery desulfating chargers/maintainers and probably the easiest way to desulfate a battery.

Here are a few examples:

About $50. "Battery Conditioner - Refresher - Desulfator - Our 12v Model by US Solar Energy Company"

If you are looking for a standalone desulfator, then you want to get something like this. They have both a 12 and 24-volt model.

About $110. “BatteryMINDer Battery Charger / Maintainer with Desulphator - 12 Volt 2/4/8 Amp”

This lead-acid battery smart charger also has a built-in desulfator that automatically dissolves the build-up of sulfation. This one is for 2, 4, and 8 amps. It has overcharge and reverse polarity protection. You can use it for equalizing charges.

All of the examples above are universal in that they can maintain all types of 12-volt lead acid batteries including wet, dry sealed gel, and AGM types

.

About $60. “TecMate TM-151 OptiMate 3+ 0.6Amp Desulfating Charger/Maintainer”

This device is fully automatic; the type that you can leave permanently connected to your automobile battery to maintain it.

Maintenance for Lead-acid batteries:

- Keep the battery terminals clean and corrosion free:

  You can clean battery corrosion using a battery terminal cleaner. You just slip it into the battery post and rotate it to scrape it clean.

- You can also clean the battery terminals with a solution of a couple of tablespoons of baking soda to one pint of water.

  Put a small bead of silicone sealant at the base of each post then put a felt battery washer coated with Vaseline over the post to prevent corrosion of the posts and cable connectors. Be sure to securely tighten the cable connector when you put in back onto the post.

- For vented batteries (only), add water to the battery every so often. The frequency of watering is determined by particular use and recharge cycles, therefore, it is best to check your battery water level often and add water as needed. Start with once a month and then see if that suits your needs or if you need to do it more or less often. **Only add distilled water to lead-acid batteries**. Never add tap water to your batteries as it contains minerals and impurities that will increase the self-discharge rate.

- Temperatures above 100° will increase internal discharge and sulfation so avoid leaving batteries in high temperatures.

- Don't deep cycle your lead-acid batteries as this would cause permanent damage to the battery.

- Charge deep cycle batteries often. Don't let them sit too long between charges as that will wear it down quick. In fact you cannot overcharge lead-acid batteries (unlike with Ni-cd and Ni-MH batteries). Because these batteries begin to sulfate at less than 100% charge, decreasing the amount of discharge cycles they goes through will help them live much longer. Car batteries will stay fully charged as long as the alternator is working.

  Smart chargers for lead-acid batteries have three to four steps. Three step chargers start by bulk charging by bringing the battery up to 80% capacity *at* the maximum current and voltage rating built in the charger. When the battery reaches about 14.4-volts, the absorption charge step starts where it is held at that voltage and the current decreases until the battery reaches 98% charge. After that, the float charging step starts where the voltage is held at 13.4-volts and the current is kept below one amp which will gradually bring the charge back up to 100%. This intelligent charging process is a lot more effective for lead-acid batteries and better for the battery as well. The low charge level is better absorbed, and will not cause as much heat or gassing.

- If your smart charger has a fourth step, it will be an equalizing charge which consists of applying a higher level of voltage to a fully charged battery for a short period of time.