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Chapter 4
Batteries

Curious clay jars containing a carbon type rod and an unknown substance have been unearthed in Egypt. When these relics were discovered in the late 19th century archeologists where at pains to describe what they may be. Modern science now tells us these devices were most probably batteries and their role was in electroplating.

Electroplating was, and still is a form of metal coating applied to metals using electricity. Its use in the metal trade thousands of years ago has only recently been discovered. This is a case of the more we discover the less we know. Maybe young Benjamin was not the first to electrocute himself after all! It is possible that what we have discovered about electricity, is in fact only a rediscovery of ancient knowledge.

Without the battery modern life would be vastly different. Imagine hand starting your car every morning! The world could even be slightly more peaceful without battery powered devices. Hand cranked phonographs would still be the rage. Kids would not pester parents for "power" for toys.

Well we have the battery and without it a solar system would be all but useless for the battery stores the electricity our panels produce when in sunshine so we can have light in the dark.

The batteries we are talking about here are known as lead/acid batteries. Let's look at a typical lead/acid battery. Under the bonnet of most cars is one! It consists of a plastic box with 6 caps on it, it weighs a fair bit and if it goes kaput the car won't start. The car variety is usually rated at 12 volts however the first thing to learn about lead acid batteries is that they actually produce 2 volts.

This 2-volt nominal storage is the same whether the battery is tiny or as large as a house. Lead plates in acid produce battery storage of 2 volts always! Your car battery with its 6 vents or caps is actually 6 lead acid battery's arranged in series to make a 12 volt device to start the car. A battery capacity (or how much power you can get out of it) is measured in amp/hours. Simply put this is how many amps the said device will give you aver a one hour period. You can convert this to watts or watt-hours with Ohms law. Don't get bogged down here! This is simple stuff. Your average rocket scientist out designing satellites finds this easy and so can you!

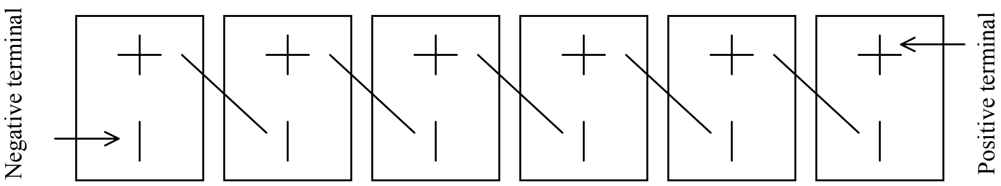
Take an easy example: You have a battery with a manufacturer-stated capacity of 100 amp hours. The battery is a twelve-volt item (actually six batteries in series in one box) and you want to run a light with it. This battery (in theory) will provide 100 amps of electricity for one hour. It will also provide 1 amp of electricity for 100 hours or 50 amps for 2 hours. Perhaps you might want 25 amps… then it will last 4 hours. Pretty simple really!

What about watts? Later on you will be calculating the electrical requirements for your satellite in watts, your battery capacity in watts will help. Mr. Ohm helps again. In the case of the above mentioned 100 amp-hour 12 volt battery 12 (volts) x 100 (amps) = 1200 watts.

We could run one appliance rated at 1200 watts for one hour or 12 appliances rated at 100 watts simultaneously for one hour. We could also run an appliance rated at 100 watts for 12 hours. Or a 600 watt appliance for 2 hours…

A quick summary of lead acid batteries so far:

- A lead acid battery is a 2-volt device.
- 12-volt car batteries are actually 6 x 2-volt batteries joined in series in one box.
- Battery manufacturers state the capacity of their products in amp/hours.
- An amp/hour is the number of amps that can be delivered in a given time frame. (one hour)
- This can be converted into watt/hours or watts using Ohms law. (amps x volts)



6 x 2 volt cells connected in series to make a 12 volt battery

Now that you know without a doubt that lead acid batteries are actually 2 volts each lets look at a typical installation of 6 of them arranged in series to give us a common voltage of 12. For simplicity I will refer to this as a 12-volt battery. (See diagram above.)

12 volts is actually what is known as the nominal voltage. It will vary. The voltage may be as high as 13 when the battery is fully charged and not connected to anything. It will rise to 15 or higher when we charge it. It will fall to 11 or lower when the battery is "flat". A battery is regarded as flat when it can no longer provide current at a suitable voltage to power what we connect to it.

You may have noticed the "in theory" bit when I previously mentioned manufacturers stated battery capacity. A battery manufacturer will almost always state capacity as amp-hours over time.

Battery manufacturers seem to have decided that suitable time frames are: 5 hour discharges, 10 hour discharges, 100 hour discharges and 120 hour discharges. This is because the same battery will perform differently over different lengths of discharge time. To confuse things a bit more a battery may have no capacity stated at all, instead it will have a figure called CCA or cold cranking amps. This is all because there are actually different batteries for different purposes. They may all be lead in acid however a battery used for starting a car will differ in construction to a solar battery. A few common types of battery follow:

Car starting battery.

This is probably the most common 12-volt lead acid battery on the planet. It has been designed to start a car, so often the manufacturer will not even state its capacity in amp/hours. Instead it will be rated in CCA or cold cranking amps.

This is how many amps can be delivered to the starting motor of the vehicle. Typically a car may require 100 CCA. A large truck may require 400 CCA or more. This type of battery is specifically designed to provide high current for short periods.

Its construction will be different to a solar battery. It is of limited use in a solar system and not designed for solar power. Discharges to any depth more than that required to start an engine will rapidly destroy starting batteries.

Electric vehicle battery.

Electric vehicles take many forms from wheelchairs to forklift trucks to cars, boats golf buggies and a whole heap more. The battery manufacturer will usually state a battery capacity over 10 hours for these batteries. This will be listed as capacity (C10). A C10 rate describes a planned use of the stored electricity over a period of around 10 hours prior to recharging.

These batteries are often sold as solar batteries and can be an excellent choice. In addition to being able to take charge and discharge rapidly they are often very strong and can take heavy vibration.

Trojan L16 electric vehicle battery

Standby battery.

These batteries are commonly available second hand. Their design is for providing emergency power. Standby batteries are common in telephone exchanges, radio stations, shopping centers and places where emergency power will be needed in case of electrical failure from mains supply. These batteries typically spend 90 - 100% of their life fully charged.

The occasional power failure may pull them into use for a short period, but generally they sit around doing nothing but being maintained by a battery charger.

Repeated heavy use however often destroys standby batteries. They are not very strong and do not take the bumps of regular transport. Their suitability as a solar battery is questionable.

You would not consider standby batteries as a new battery, however typical installations that require reliable power backup replace these batteries whilst they are in seemingly perfect condition. They are common at scrap metal dealers and can represent good value for certain installations if their cost is that of scrap lead only. They are however unsuitable for mobile systems as the vibration of travel will often shake them apart.

Solar battery.

These batteries have been specifically designed for solar systems and often have a stated capacity of C100 or C120 or both. As their name states they have been built specifically for a solar electrical installation.

The capacity is stated over 100 hours, as this is what the manufacturer envisaged when they designed the battery. A typical long discharge followed by slow recharging.

In most cases these are the preferred batteries for a solar installation. They are often similar to electrical vehicle batteries.

Electrical vehicle batteries may however be a better choice for some types of solar installation due to their more compact size and greater durability under harsh conditions.

Battery capacity versus time.

Lets look again at battery capacity. Battery capacity is stated in amp/hours over time. The amp/hour capacity of a given battery will vary with the length of time it takes to discharge. Thus if the stated capacity of our 100-amp/hour battery is at C10 its capacity will be greater at C100! Its not magic, its just the way lead acid batteries deliver electricity.

There is no need for a chemistry lesson here; we just want to know about solar power. All that is needed here is the knowledge that a lead acid battery will provide more energy if it is discharged slowly.

Thus the manufacturer of a well-known electric vehicle battery states the capacity as 360 amp/hours at C20, 287 amp/hours at C5 and 206 at C1. C1 is an extremely fast discharge however this battery can do it.

Another battery manufacturer states that their solar battery has a capacity of 218 amp/hours at C120, 210 amp/hours at C100 and 150 amp/hours at C25. As you can see here, a bit of planning regarding battery size can be a help to the well being of your solar system.

The life of a battery is measured, not in years but in cycles. Assuming a battery is never used and always kept fully charged its life is pretty well indefinite. Once you start discharging your battery and recharging it deterioration starts.

Battery life is stated in cycles; a cycle being a period of discharge followed by recharging. The more you discharge a battery prior to recharging, the larger the cycle. Our 100 amp/hour 12 volt battery will have a far longer life if it is only discharged by say 20 amps than if we discharge it by 60. If it is discharged by its full 100 amps every time it is used its life will be very short indeed. When planning your battery size a 50% discharge is about as high as is recommended for regular cycling.

The same manufacturer of the 210 amp/hour solar battery mentioned previously states that the life of their battery is as follows: 7500 cycles to a 10% discharge, 2500 cycles to a 50% discharge and 1200 cycles to an 80% discharge. Their warranty states 5 years full replacement provided the battery is not discharged any deeper than 80% If we were to use this battery every day using 50% of its capacity we could expect it to last us around 2500 days or 6.8 years.

The manufacturer of the 360 amp/hour vehicle battery assumes in an electric vehicle the battery will always be heavily used. They state the life as 500 to 600 cycles to 80% discharge.

Although the manufacturers don't state a figure it can be assumed that these batteries will last much longer if only cycled to 50% or less. Extensive use of this battery in the solar industry has shown this to be a fact.

Two more things dramatically reduce battery life, the first is leaving a battery in a discharged state.

While it is quite ok to cycle the battery down then up, cycling it down and leaving it that way for any length of time will quickly ruin it. A lead acid battery can be destroyed in just a few weeks when left in a discharged state.

The next variable that will affect battery life is the type of water you tip into it.

Lead acid batteries need water from time to time. The process of recharging removes water from the acid and it must be replaced. Using anything other than distilled or de-ionized water will result in reduced battery life.

Acid is not normally added to batteries after the initial fill. Level changes in battery electrolyte are a result of water leaving the acid, not from acid consumption.

A quick recap on information pertaining to batteries so far…

- A lead acid battery is a 2-volt device.
- 12-volt car batteries are actually 6 x 2-volt batteries joined in series in one box.
- Starting batteries differ in construction from deep cycle batteries.
- Suitable batteries for most solar installations are electric vehicle or purpose built solar batteries.
- Battery manufacturers state the capacity of their products in amp/hours.
- An amp/hour is the number of amps that can be delivered in a given time frame. (one hour)
- This can be converted into watt/hours or watts using Ohms law. (amps x volts)
- The slower a battery is discharged the larger it's total capacity.
- The number of discharges followed by recharging determines battery life.
- Discharge followed by recharge is called a cycle.
- Discharge should normally be limited to 50% of battery capacity or less.
- Leaving the battery discharged or using impure water will further reduce its life.

Recharging a battery.

Recharging a battery means putting electricity into the battery in a form that the battery will accept. The voltage must be higher than the battery in order for electricity to flow from the charging source to the battery and current should be enough to allow the battery to charge in an efficient time frame. A lead acid battery likes a certain style of charge as well…

In order to simplify things a bit the example here is for a deep cycle 12 volt 350 amp/hour (C10) battery. Of course we already know that this is actually 6 x 2-volt batteries…

When a lead acid battery is "flat" it will have a voltage of around 11. When it is fully charged it will have a voltage of around 12.8. In order to fully charge it we will have to take the voltage to around 15 and keep the voltage at this level for a period of time. Our charging supply will therefor have to be greater than 15 volts. No problems with solar panels, we have already learned that the Voc of a typical panel is around 20.

We also need current or flow from the charging source to the battery. Finally we need to charge the battery in a manner that is efficient for the battery capacity. It's not that hard. Let's start with charging current.

10% rule.

A battery will only accept charge efficiently at around 10% (or less) of its C10 capacity in amps.

Example using 350 a/h C10 battery.

10% of 350 = 35. The maximum rate of charge our 350 amp/hour battery will accept efficiently is 35 amps.

We can put in more current, and we most certainly can put in less. Putting in more will not be as efficient however and it will come to a point where we will either have to exceed 15 volts or limit the current back to 35 amps in order for charge to occur.

Using less current will take a longer period of time. The time the battery will take to charge is also fairly easy to calculate. If your 350 amp/hour battery was totally discharged to 0 amp/hours capacity then the 35 amp charger would take 10 hours. (10 x 35 = 350) If we limited the discharge to a more respectable 175 amps (50%) recharge would take 5 hours. Easy…

Well the more astute folk out there who have studied up a bit more than the average bloke or spoken to the local "expert" could well jump up and down at my statements.

Unfortunately like most things battery charging is not 100% efficient. In reality it is only around 95%.

Further diminishing the accuracy of our mathematics is the unfortunate reality that charging a battery is only around 95% efficient to around 95% capacity. The final 5% will take longer. Also as the battery becomes more charged its acceptance of charge will be less.

When we started charging our 50% flat 350 amp/hour battery bank 35 amps poured in just fine. Three quarters of the way into the charge period however the voltage rose to 15 and the regulator reduced the current to 20 amps and things slowed down!

Mathematically we required 5 hours for a recharge. Well somewhere we had to leave the mathematics to the rocket scientists. Reality has shown that our 50% flat 350-amp/hour battery will actually take 6 - 7 hours to fully charge using a 35 amp battery charger.

As written above the said 12-volt battery should be taken to 15 volts to fully charge. Why 15? Good question; the actual end point charge voltage is dependant on a number of things, the most important being temperature and battery type. So far we have assumed a few things and talked about only one type of battery, the good old "flooded type" wet cell deep cycle battery. This is the one you can take little caps off and add water to. It is an old style battery and still the only type manufactured for deep cycle "heavy duty" use by major battery manufacturers.

At the risk of offending some I will state here that flooded lead acid batteries are still the best type for all small solar installations and most larger ones.

The reason for this is that this type of battery will take "abuse" without faltering. While leaving it hanging around in a discharged state will rapidly cause its demise, overcharging will cause very little harm and in fact is occasionally a good thing.

We can look into it and see the gasses being formed (use safety glasses here), top it up, stick a thing called a hydrometer into it for testing and even cut it open and "operate" on it with tools if we feel so inclined. (I leave the latter to total battery heads!)

The only downsides are that flooded batteries contain liquid acid, which will rot your cloths and burn your skin if you are careless. Flooded batteries also need topping up with water and can smell and vent gas, therefore requiring well ventilated positioning.

Other types of lead acid batteries are a gelled type. Gelled lead acid batteries have had the acid turned into a jelly like substance and the associated caps found on flooded cells have been removed. You can't look in or test internally. You can't replace the jelly and if you overcharge or over voltage one of these things you risk damage.

15 volts is considered too high a voltage for most gelled batteries. 14.4 is the recommended maximum unless it's extremely cold.

I digress slightly here however, we were dealing with a 350 amp/hour flooded cell heavy duty type of battery, pretty tough and impervious to the occasional overcharge. We can take the voltage up to and indeed over 15 for rapid charging, and occasionally an overcharge is good. 15 is only a general limit.

The effect of temperature:

Before we go on to battery charging however the effect of temperature should be noted.

Battery manufacturers have stated the capacity of their products in amp-hours.

More correctly the stated capacity is in amp-hours at a given temperature. The temperature chosen is 25^{0}C. Variations away from this temperature effect capacity and voltage.

Any warmer than 25C is not usually a problem however as the temperature climbs above around 35C the charging voltage should be reduced slightly. Capacity will remain around the same.

It is when the temperature drops below 25C that the battery will start to disappoint. You can expect around a 1% drop in battery capacity for every degree C below 25C.

When your battery reaches 0^{0}C its capacity will be around 25% less than its rated capacity.

The same electrical load on a cold battery means that the battery is being cycled more heavily.

In addition to loosing capacity in cold a battery will not charge as efficiently and will require a higher charge voltage to become fully charged.

Quality solar regulators and battery chargers have temperature compensation circuits to automatically adjust charge voltage if there is a variation in battery temperature. It does however pay to keep your batteries warm for maximum efficiency. This will mean a purpose built container, inside a warm room or providing some form of battery heating.

Insulation alone will not help. Just a thermos eventually goes cold so will an insulated battery.

Two stages of battery charging:

Stage 1. Bulk charging stage. This is where current is "poured in" until the voltage rises to a set point determined by either a solar regulator or a battery charger. This voltage is usually around 15 for a 12-volt lead acid battery. The depth of discharge and amount of current going in determine the length of time required at the bulk setting.
An almost fully charged battery will not be at this stage for very long, maybe not at all. A deep cycle 350-amp/hour battery discharged to 50 % will be at this stage for 3 hours or more on a 35-amp charger. If we increased the charge current to say 70 amps the battery would remain at this stage for less time however as it would rapidly reach 15 volts, then be at stage 2 for a longer period. When it reached stage 2 the charge regulator would in all likelihood reduce the amount of current to… 35 amps. If we removed the caps from the battery and looked in during stage 1 (while wearing safety glasses) we wouldn't see much, just the odd bubble coming to the surface.

Stage 2. Absorption stage**.** This is the stage where our battery has reached 15 volts and the voltage is kept constant by reducing the current. The final amount of charge is slowly taking shape. Unless we used the 70-amp charger previously mentioned, then a large portion of stage 1 will occur prior to the battery reaching 15 volts. An ammeter measuring the charge current would show a gradual reduction in charge current (assuming a pwm style regulator or charger) and donning the safety specs and looking inside would see a fine fizzing or bubbling of all cells as they formed gas. It is the formation of this gas that results in water usage. This gas is a highly volatile explosive mix of hydrogen and oxygen and is the breakdown of water due to electrical flow. Wow! Determining the length of time at absorption can be difficult. A device called a hydrometer may be useful, the battery charger may work it out for us or we may just take a bit of a guess remembering that rocket scientists are employed elsewhere. Around an hour or two is all that is usually needed. When your battery reaches the absorption stage it is usually at least 75% full. After an hour or so a three-stage charger, if employed will then go to stage three and lower the voltage down from 15 to a lesser amount. (13 -14volts) This reduces or eliminates the fizzing and water consumption and keeps the battery at a "maintenance setting" useful for long term storage. If the charger in use is any good it will detect use and return rapidly to the bulk charge mode if current is drawn from the battery. The majority of lower cost chargers don't have a stage three and are disconnected (manually) at the end of stage two.

Out in the real world however things are unfortunately different: A quick look under the bonnet of our car will show us a battery that is permanently connected to a battery charger. The battery charger is called an alternator and until it fails or the drive belt falls off we hardly know of its existence.

This device charges a battery in a slightly different way. Unless you are an electronic whiz and have built yourself a three-stage alternator regulator (then you wouldn't be reading this) your car starting battery only has single stage battery charging. It simply takes the battery voltage to around 14.2 volts and keeps it there. This is for several reasons, but mostly due to the fact that your car battery seldom discharges below around 5% of capacity. An allowance is also made so that on a long drive your car battery will not be overcharged and water consumption will be minimal.

The problem here is that 14.2 volts is not enough to fully charge your car battery unless you drive long distance. Most flooded cell car batteries have a relatively short life due in part to not enough charge.

Tap water at service stations compounds the problem further. Pure distilled water and a monthly charge to 15 volts with a quality battery charger will greatly extend the life of a flooded lead acid car battery.

Having an in tune, easy to start car and never using the battery when the car engine is not running will further extend battery life.

Our lead acid battery charging education so far can be summed up as follows:

- In order to charge a lead acid battery we need a supply of a higher voltage
- The higher voltage allows current to flow from the charging source to the battery.
- There is a "10% rule" to determine a battery acceptance of charge.
- The 10 % rule states that 10% of C10 is the maximum efficient rate at which a battery will accept charging current.
- Battery charging will happen in two stages, a bulk and an absorption stage.
- A battery is only around 95% efficient at best in accepting charge and only this efficient to 95% full.

Battery safety

A quick discussion on safety is warranted in any information discussing batteries.

Firstly in Australia alone several dozen folk are hospitalized every year by battery injury.

You don't need to take my word for this a quick conversation with any doctor will reveal a knowledge of this type of emergency.

The most common type of injury is caused by battery explosion. Yep these things can go bang and spray you with acid! No need to panic here! A few simple rules will eliminate you from risk.

During battery charge a combination of hydrogen and oxygen gasses are formed in the water contained in battery acid. It is these gasses that will cause a battery explosion. In order for an explosion to occur a spark is needed and the gas must be confined.

Removing the caps from a battery undergoing charge will reduce the possibility of a gas building up (gas confinement) inside the battery. When practical we will remove battery caps prior to charging.

It is however not practical to remove the caps from a solar system battery bank. It should be noted in a solar installation however that no connections or disconnection are made during charging.

Prior to making or breaking connections on a solar battery bank all forms charge and discharge should turned off to minimize spark risk. The caps should also be removed to vent gasses rapidly.

Disconnecting or connecting two different voltages will cause a spark.

When using a battery charger it should be turned off when connecting and disconnecting it. This will reduce the spark risk.

In a solar installation we will bolt our battery connections together to eliminate a solar supply spark.

A battery should always have adequate ventilation and should never be used or placed inside a sealed compartment. (See battery installation in chapter 7)

Safety spectacles should always be worn when looking inside a battery, positioning a battery or maintaining a battery. Of all places acid can contact the eyes are the most sensitive.

Looking away can be a good policy when actually making a disconnection that may spark.

Knowing what to do in case of acid contact can avoid a trip to hospital!

In the event of acid contact the first thing to do is flush the area with copious amounts of water. You should know where the water is prior to working on any battery. Baking soda or milk will neutralize acid and can be applied to acid burns or spills.

It should be noted that to reduce the risk of sparks causing explosion battery manufacturers carefully seal between the terminals of a battery and the case. Hitting a battery terminal can easily break this seal. Hitting terminals onto the battery post is common in the automotive industry… Once this seal is broken acid often causes terminal corrosion. Do not hammer a battery terminal onto your battery! Don't do it! There is always another way. If corrosion builds up on a battery terminal it is a sure sign that the seal around the battery terminal is broken.

A less common although still potentially harmful or fatal risk with batteries is the short circuit fire/explosion risk. Short circuiting a battery with an installation spanner or other metal device can cause massive current flow. This current flow can be so high that steel spanners can literally burn. The molten steel can cause massive skin burning as well as causing a battery explosion.

A battery terminal spanner should always be insulated. In the case of vehicular batteries the earth (negative) terminal should always be disconnected first and connected last. This minimizes the risk of positive to vehicle chassis short circuits.

Battery state of charge:

Nothing seems to cause confusion more than determining how charged a battery is. All sorts of "experts" will have all sorts of opinions. Different ways have advantages and disadvantages.

Here is a guide to determining your battery state of charge. It should be stated from the outset that nothing will beat experience here. In order to determine you battery's well being or otherwise experience is everything.

Experience can't be taught however and until you buy and use your solar storage here is the best available information to get you started.

Testing battery state of charge.

The most common way of testing a battery state of charge is by using a hydrometer. At least this is the most common written way.

Most battery technicians however don't seem to use one. I certainly don't and I have been working with batteries for well over a decade! Last time I looked at mine the rubber bulb was perished beyond use.

A hydrometer is a device that, after donning your safety specs you put into a battery cell and suck up a sample of acid.

The hydrometer actually consists of a glass container with a calibrated float inside. It measures the specific gravity of a liquid and a comparison is made to the specific gravity of water.

Simple really you just suck up some acid, read the density and then squirt it back into the cell. It works beautifully on a battery that is new, or been charged for a really lengthy time.

Specific gravity can be extremely accurate. Pity readings completely out of whack with reality can also easily occur. We also need to know what density the acid in our particular battery needs to be. Standby batteries have a lower specific gravity electrolyte in them than solar batteries. Car batteries have a higher density.

No need for alarm here however, a hydrometer is actually a really useful tool. One day mine will work again. Some battery manufacturers may supply you with one to test your newly purchased cells.

Hydrometer testing procedure:

- Firstly we get a pen and paper.
- Review if necessary safety procedures and be aware of a water supply.


Hydrometer

- Put on safety specs.
- Next, the tops of the battery should be clean. Dirt and rubbish falling in as the caps come off is detrimental to battery life.
- Put on your specs, remove the battery vents and take out a sample of acid. It should be noted here that you should either have some covers over your cloths or your old rags on. Acid burns on the designer labels are expensive ones! A tiny splash not visible to the eye will result in ugly holes in most materials next time they are washed.
- Your acid sample, gained by drawing battery acid into the hydrometer should be sufficient for the actual hydrometer float to rise in its container but not high enough for it to hit the top.
- The reading should be taken from the acid surface to a freely floating hydrometer. The float should not touch the sides of its container.
- Note down the reading and carefully return the acid back to the cell it came from. Proceed to do all cells.

Your specific gravity readings should correspond approximately to the table below. Specific gravity will vary according to battery type and age. New solar batteries are supplied with specific gravity information. Your battery dealer should be able to supply specific gravity information for other types of battery.

Specific gravity @ 20^0C	State of charge
1.280	Full
1.240	75%
1.200	50%
1.160	25%
Less than 1.160	Flat

What if the batteries don't meet specific gravity expectations?

Unfortunately in the real world things often don't seem to be the way they should!

The first problem you may encounter is that the hydrometer does not float or shows a specific gravity lower than 1.160 but you know your battery is not flat. It still starts the car or powers the inverter. The lights are still bright and all seems well.

The most likely problem here is that your batteries have been topped up with distilled water in the previous months. This distilled water is lighter than the acid and tends to sit on top of the more dense acid below it. As you can only get the tip of your hydrometer into the top of the cell its only natural that all you can draw out is this water.

The next problem is called stratification. It is similar to the above water problem however you don't need to add water for batteries to suffer from it.

The acid simply settles into heavy and light layers inside the cell and the heaviest stuff is naturally on the bottom of the battery out of reach of your hydrometer.

Do not attempt to shake a battery! This will certainly cause some damage as associated bits of lead and deposits in the base of the cell container mix throughout the (rather complex) system of lead plates inside. The only answer here is to give you batteries a good "boost" charge.

Acid should never be added either! Do not add acid to any battery without a completely scientific reason under the supervision of a qualified battery technician. Acid does not leave a battery, water evaporates out of it and is removed by electrolysis. Add only pure distilled or de-ionized water.

A boost charge involves taking a 12 volt battery to 15 or even 16 volts, leaving it in this state for several hours or longer and allowing the bubbling and gassing that is freely happening inside to mix your acid back to even distribution throughout the cells.

For optimal battery performance and life this "boost" charge should happen every 1 - 2 months. Some voltage regulators perform this function either automatically or manually. Permanent connection battery chargers such as are used for standby batteries also automatically perform this function.

If you have a smaller system or a simple regulator that will not perform a boost charge it is possible to bypass the solar regulator periodically and connect your solar panels directly to the battery.

It is also possible in some solar installations to perform this job with a battery charger. It is this lack of "boost" charge in cars (except on really long distance driving) that shortens car battery life.

15 - 16 volts will allow the battery acid to mix in a reasonably short time. Voltages of around 14 will eventually cause mixing however it will take 24 hours or more. A 12-volt battery will produce gas and bubble once above around 13.8 volts.

Well specific gravity is one way to test for state of charge, there is however another.

Multimeter

Battery state of charge by voltage reading:

You can to a certain extent measure state of charge with an accurate digital voltmeter. The battery technician is never without one.

An accurate digital voltmeter connected to a solar system provides a good visual indication of what is happening in general and can be observed throughout the day if placed in an easily viewable location. It is this regular observance of accurate voltage that will lead to an understanding of your solar system more than any other.

Accurately and instantly telling the state of charge is however not always possible and slightly harder than just wandering up to the battery and connecting your whiz digital voltmeter/multi-meter you purchased at the local electronic store. We will stick to a 12-volt battery here for simplification.

Already stated is the fact that the voltage of a 12 volt battery will vary between 11 and 15 volts under normal use. A small battery will go even lower than 11 volts with a heavy electrical load connected. The key to understanding voltage compared to state of charge is the understanding that voltage on a battery will change with any charge going in or with any load connected. A flat battery with even a small solar panel charging it will almost always show over 12 volts. A battery with a load connected to it will have a lower voltage than if the load was disconnected.

The only way to accurately determine any semblance of state of charge is to measure a static battery (one with no connections) after it has "sat" unused for a couple of hours or more. Even a tiny electrical load like a car clock will make a (slight) difference.

Out in the real world however your solar system will almost never be in a static state. This is where experience comes in. I can't teach this experience to you. You will however become confident in "guessing" your battery state with observation.

Static voltage	State of charge
12.8	100%
12.6	80%
12.4	60%
12.2	40%
12.0	20%
11.8	Empty.

Remember that these voltages are "static". A fully charged battery with a heavy load running from it may drop to 11 volts or lower. A battery under charge will be as high as 15 or more. A battery that is fully charged with a charger connected and reading 15 volts will take 4 hours or more disconnected from the charger before the voltage falls all the way to 12.8. Older batteries and standby type batteries may exhibit slightly lower voltages for similar levels of charge.

Finally a battery that is fully charged may exhibit a phenomena known as voltage dip. During the first use after fully charged the voltage might dip by up to .5 of a volt and then recover! This phenomenon has caused bafflement and concern for even highly experienced battery technicians!

Finally because all lead acid batteries are actually 2 volt devices it will be common in your encounters with things solar to read voltages pertaining to 2 volts. The manufacturers of 2-volt batteries have no idea what voltage systems these batteries will be connected to and will specify anything to do with voltage as a 2-volt figure pertaining to one cell only. You multiply this figure by the number of cells you have to obtain the corrected system voltage. (Times 6 for 12 volt systems)

A quick voltage lesson you can try with your car:

When you decide to finally go out and purchase a solar system one of the first requirements will be an accurate multi-meter. These devices are available from any electronic store for very little cost. You need one that will measure voltages up to around 40 or more with 2 decimal precision.

Lift the bonnet of your car and connect one to the car battery positive and negative terminals. Read the static voltage. With the meter connected to the battery and leads and fingers clear of moving parts have an assistant start the engine. Observe a heavy voltage drop as the car starter motor cranks over the engine. Observe again how voltage rises when the engine starts and the car alternator begins to charge the battery. Observe once more the voltage decaying after the engine is stopped. With the engine off, turn on the headlights and watch the voltage fall, then rise again after the lights are turned off. Pure rocket science performed on the family clunker!

Before we progress to the nitty gritty of inverters and solar design Let's again look at 2-volt batteries and the manufacturer stated capacity. If you buy six, two-volt cell, lead acid batteries and join them together to make a 12 volt battery you join them together in series.

Let's say for argument sake you choose 6 x 200 amp-hour 2 volt flooded lead acid cells in individual containers. When you join them together in series the 200 amp-hour capacity will remain the same. You have built a 200 amp-hour battery bank of 12 volts. If you build up 2 such battery banks and then join them together in parallel you will have a 12 volt 400 amp-hour battery bank. If however you join the two 12-volt banks together in series you are building a 200 amp-hour 24-volt battery bank. Now some folk find this confusing however if we recall Mr. Ohm's law: $400 \times 12 = 200 \times 24$ which of course is the same capacity at a different voltage.

Batteries best like being joined together in series by the way. Paralleled up batteries are harder to charge fully. Batteries in parallel should in theory be exactly the same type, capacity and age. Joining batteries in parallel can void warrantee and should be avoided if possible.

Parallel connection.

I have stated previously that it is not recommended to join batteries together in parallel. The main reason is that it is possible (and probable) that one or several cells in one bank may be weaker than the rest. These cells will not charge correctly and the battery bank will not be as large in capacity as mathematics would lead you to believe. Charging current will tend to flow to the best cells only.

In the real world however parallel connection is often done. If you are in a situation where you wish to join batteries together in parallel the following points should be followed.

- The batteries should be the same size
- The batteries should be the same brand and model
- The batteries should be the same age

The above rules aren't always followed! I have seen battery banks made up with all sorts of different batteries working well and if you wish to experiment due to availability or budget restraint it may work well. If you choose to use batteries in parallel however it will help if the banks can be separated and charged in individual "cell strings" occasionally to equalize cell voltages and properly mix electrolyte.

In order to allow easy charging cells should always be paralleled in series strings instead of pairs of 2 volt cells.

The following diagrams represent 3 battery banks made up with 200 amp-hour cells.

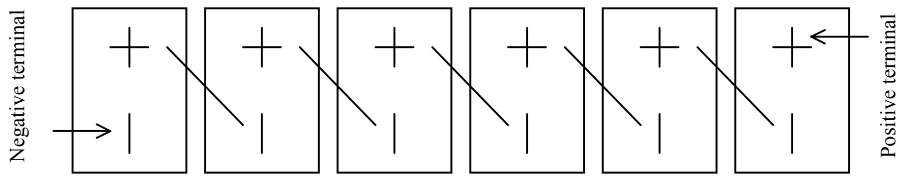
Bank one is a 12 volt bank with all 6 cells connected in series.

Bank two is a 12 volt bank comprising of 12 cells. Two groups of 6 cells in series are joined together in parallel.

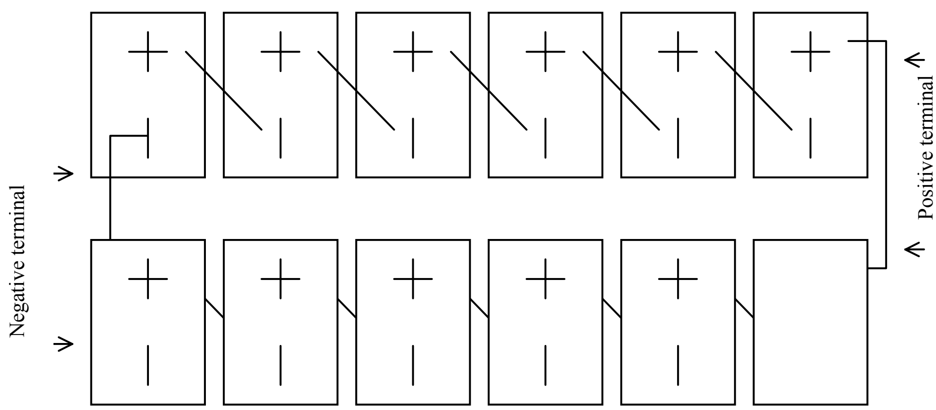
Bank three is a 24 volt battery bank with all cells joined in series.

Bank 2 and 3 both have the same energy storage however the voltage (potential) differs.

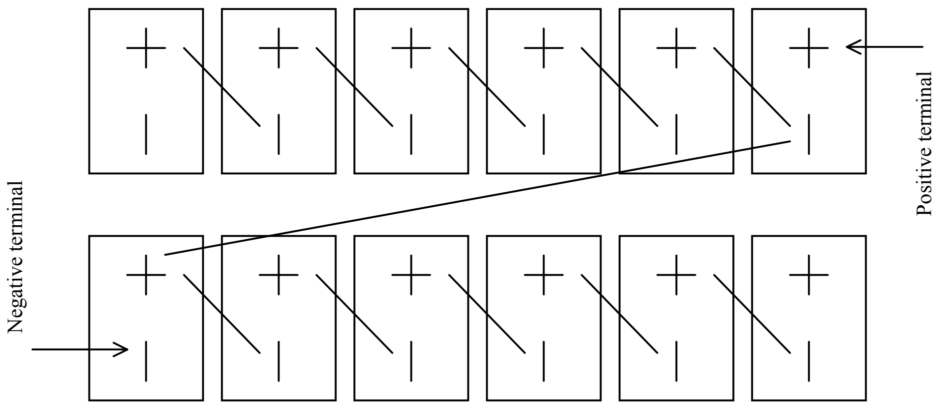
12 volt 200 amp-hour battery (6 x 200 amp-hour cells in series)



12 volt 400 amp hour battery (2 parallel banks of 6 x 200 amp-hour cells)



24 volt 200 amp hour battery (series connection of 12 x 200 amp-hour cells)



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