Zen and the Art of Astro Batteries

As we get more and more sophisticated with our astronomical adventures, the toll hits not only our pocket book but our battery demand as well, which, of course is another toll on our pocket book! A correctly planned and good quality battery set-up should last you many years – so if you find yourself buying batteries once every year or two, this information can save you some bucks. The following is information I've gained from multiple sources and 20-plus years of misusing and replacing marine batteries on my sailboats (another equally exciting adventure in cash flow management). I'm no expert – I've just bought and ruined a whole mess of batteries. While I've tried to make this as accurate as possible, I'm not error proof – just ask my wife!

The purpose of this little paper is to provide information on the chemical wonders of the battery and help put us at peace with our world of star gazing. I've organized information as follows.

- **Battery Safety** – everyone should know this stuff - take the time to learn it for your own sake
- **The Bottom Line** – typical set-up - for those who just want to know the time, not how the clock works.
- **How Batteries Work** – for those who would like to understand the magic and mystery of the juice
- **Battery Comparison** – Automotive v. Deep-Cycle and The Incestual Battery Families – a description of the three types of deep-cycle batteries and their pros and cons
- **Energy Audit** – how to figure out the right size battery for you
- **Alternative Approaches for Battery Capacity** – how to best get the juice you need
- **Recharging** - nothing is free and this section talks about chargers, what to look for in a charger and what size charger you should consider
- **State of Charge -** how to tell how much juice is left in your batteries before you launch into that three-hour imaging session
- **Battery Maintenance** – does it ever end
- **Problem Batteries and Children** – what to look out for if you've got an ornery one
- **For Additional Information** – great sources for more information.

Battery Safety

While batteries are not to be generally feared, they do contain a tremendous amount of stored energy. There is easily enough energy in the 12 volt batteries we're talking about to melt a large screwdriver that is unfortunate enough to be dropped across the battery terminals. A battery's fluid or electrolyte contains sulfuric acid which will not only cause severe burns, but will go through clothing like I go through boiled crawfish. Unlike those myths told to young boys, the battery electrolyte really can cause blindness if it gets in your eyes.

When working around batteries, it's a good idea to remove jewelry, like that wristwatch with the fancy metal band or that lovely necklace and be VERY careful in the placement of your tools. It's a smart thing to wear some sort of eye protection – don't worry about looking like a geek for at least you'll be able to see those DSOs. If you get any battery acid on something, immediately flush with water and then neutralize the acid with baking powder or soda, ammonia or even an antacid medication.

Batteries can emit corrosive fumes, not unlike my Aunt Ida after she gulps down a big helping of potato salad. So be careful when storing batteries (or Aunt Ida) around sensitive equipment in areas that have poor ventilation. When most batteries are being charged, they emit explosive gases – hydrogen and oxygen – and any little spark can cause an explosion. Let me repeat this – **when a battery is being charged, any flame or spark in close proximity can cause an explosion.** Batteries should only be charged in a well-ventilated area.

And, as always – read and follow all the instructions and safety precautions that come with your equipment and batteries.

The Bottom Line

The typical set-up (N11 GPS, dew heater, etc.) will consume between 15 to 20 amp-hours for a full night of work (10 hours). To supply this demand, you need between 30 and 40 amp-hours of battery capacity (don't ask why - remember, you just want to know what time it is). My choice for supplying this power is to use a two battery system of absorbed glass mat (AGM) or gel cell batteries. The first is a xPower 300 jump starter system which has a 21 amp-hour battery (goes for about $130 but includes a 300 watt AC inverter for other uses) coupled with an 18 to 22 amp-hour motorcycle AGM battery (goes for about $80). This set-up provides high-quality AGM batteries, a trickle or float charger and state of charge LED meter (both built into the xPower 300), a redundant battery system (in case one battery fails, I am not doomed at that dark site), the capability to recharge both batteries easily from the car (but check the output voltage from your car's cig lighter - it shouldn't exceed 14 volts or you risk damaging these AGM batteries). If you've got greater demands - like CCD imaging, cooling pumps, and notebook computers that won't last 10 hours on their internal batteries, then simply get a bigger second battery - a Group U1 will give you around 32 amp-hours, a Group 27 about 90 amp-hours - at a cost of 25 to 60 pounds and $80 to $170, respectively. I'd recommend these bigger batteries right from the start except for the hauling weight they have as compared to the smaller motorcycle batteries.

I know - this ain't cheap - but in the long run, it will end up costing you less than using those "Blue Light" special batteries and chargers. While you might think it's less expensive to simply go with a couple of AGM or gel cell batteries and buy a separate charger, be careful on this road as you need a really good charger or else you'll damage your AGM's or gel cells. These types of chargers start at around +$100 bucks. The xPower set-up is a high quality rig - good company - been around a long time, etc. The only real pitfall, besides higher initial (not long-term) cost, is that the AC charger is small and can take a couple of days to fully recharge both the batteries. The solution for repeated night usage is an hour or so charged in the car followed by the AC charge for the rest of the day (you've likely got to run some errand anyway for the significant other - so it's no big whoop). Or you can opt to put the larger battery on a regular charger for about 15 to 30 minutes for a bulk charge (as long as the output voltage on the charger is below 14 volts) and then switch over to the small float charger.

There you have it. I know there may be lots of folks who disagree with this set-up. That's cool, there are a bunch of alternative approaches - it's a free country - until you start buying replacement batteries. I got my xPower unit from www.store4power.com (no, I don't get any kick-backs) and any local motorcycle or marine shop is a good source for the second battery. Another word of warning - a sealed lead acid battery (a.k.a. maintenance free) is not the same as a gel cell or an AGM - make sure you get a gel cell or AGM.

How Batteries Work

I'll use a standard wet cell battery for this explanation. The specifics for gel cells and AGMs (more on these later) are slightly different but the basics are the same.

A battery is composed of several "cells". Each of these cells has both positive and negative plates arranged in an alternating fashion. All of the negative plates in a cell are connected together, as are the positive plates. Each of the cells is wired together in a series fashion. Between each of the plates is a non-conductive spacer. Each plate looks like a grid and it's this grid that provides a path for the juice (electrons) to flow as well as providing a place for the "active material" to be held. The active material in a positive plate is lead dioxide and in the negative plate it's sponge lead. The plates are immersed in sulfuric acid. When a battery is used, the acid combines with the plates to produce lead sulfate and water and some free electrons that you use. As this reaction occurs, the water dilutes the acid and slows the reaction, reducing the current and lowering the voltage. When the battery is charged, the water is driven from the acid as oxygen and hydrogen (hence the bubbling you hear) and the spent lead sulfate and dioxide is converted back to its active material - sponge lead and lead dioxide.

In describing a battery, you can simplistically think of it in three terms - how much juice the sucker has (it's capacity), how fast the juice flows (current), and how much pressure the juice is under (voltage).

The pressure at which the juice flows is based on the number of cells in a battery. A single cell in a lead-acid battery will produce about 2.1 volts due to this chemical reaction and it does so regardless of the size or the number of the plates in a cell. Since most batteries have 6 cells, we get 12.6 volts of juice pressure.

The capacity of a battery - the amount of juice it has - is driven primarily by the amount of lead it has - a big thick plate of lead (think deep-cycle battery types here) can store a lot more electrons than a thin little plate (think automotive batteries here). The current produced by a battery - how fast the juice flows - is dependent on how much of the acid can "touch" or combine with the lead in the plates. This is why the lead is typically porous, so the acid can touch or filter in through more of the lead. While discharging, the porous nature lets the water seep out of the lead to be replaced with fresh acid. While charging, this seeping process is simply reversed.

On thick plates, the flow of juice is limited by the rate at which the acid and water can percolate in and out of the plates. What happens on these thick plates is that once the initial surface juice (electrons) is given up, the pressure or voltage drops as the juice must now come from deeper in the plates. This voltage drop does not mean the battery is dead or dying - in fact, if you let the battery "rest" disconnected for 15 to 20 minutes, the movement of acid and water through the plates will come to equilibrium and the voltage will return. Ever noticed that while cranking an old car, if the battery starts to die – and if you let it sit for a few minutes, the battery seems to have a little more juice - this is due to the diffusion rate of acid and water through the lead.

Battery Comparison

I'll discuss the differences between batteries in two ways. First, I'll compare automotive or cranking style batteries to deep-cycle batteries. Second, we'll look at three main types of deep-cycle batteries, each one different in terms of its construction and chemistry.

One way to classify batteries is by using the cranking v. deep-cycle comparison. I was going to use the boy v. girl analogy here, but was sure to get myself into trouble! So let's just call these automotive (cranking) batteries and deep-cycle batteries. Automotive batteries are a poor choice for us star gazers. They have thin plates which, while allowing production of a lot of instantaneous juice flow (current), it's only for a short time. Since we don't have high current demands, like the starter motor on a car, short bursts of high current flow is not important to us. Automotive batteries can't handle the repeated deep discharges we'll subject them to on our outings without being damaged. When automotive batteries are deeply discharged, some of the active material literally falls out of the plates. When this is done repeatedly, the battery literally falls apart internally. Cheap automotive batteries can die with as few as a dozen complete discharge-charge cycles. Even high quality automotive batteries can't handle more than about 30 to 40 deep discharge cycles.

Deep-cycle batteries on the other hand have strong, thick plates. The active material is denser and the plate separators are heavier. While there is some shedding of material with every discharge cycle, it's nowhere near the amount from a thin-plate car battery. Deep-cycle batteries are the hands down choice for us. They can tolerate repeated discharges and charges like no automobile battery can and they withstand more physical abuse, not that we're like that, but we could have a little whoopsy when hauling stuff to that really dark site.

The real key for us in judging a battery is the number of times we can cycle it. When comparing manufacturers' claims of life-cycles, it's really important to know what standard they used. Some use a 50% discharge-charge cycle, others can use 80% or even 100% duty cycles. In general, the greater the depth of the discharge, the fewer cycles we'll get out of our battery. Deep-cycle batteries come in three families of flavors – wet cell, gel cell and absorbed glass mat.

The Three Incestual Battery Families - The Wets, Gels and AGMs

"Wet Batteries" (a.k.a. flooded cell) are the standard, traditional battery - the original breed. They have removable vent caps that allow you to add water to each cell. These are the least expensive batteries but are sensitive to maintenance charging rituals and have the highest rate of self-discharge. Some wets have no vent caps. They are billed as maintenance-free or sealed lead acid (SLA) batteries. If you over-charge these puppies and boil off the electrolyte, exposing the plates to air, you start to kill them. Good quality, properly maintained deep-cycle wet cells can handle more abuse than the other families - more discharge cycles, more overcharging, etc. The key, however, is proper maintenance - which is something we typically take for granted. Hence, in real life, wet cells don't last nearly as long as some of the other families since we don't maintain them the way we should.

"Gel cells" are the second family - close cousins to the wets. They have their electrolyte in a goop the consistency of cold aloe vera juice that becomes quite viscous after a few minutes. The gel itself is a mixture of sulfuric acid, fumed silica, pure water, and a phosphoric acid which produces a thixotropic gel (whatever that is - I just call it goop). They have vents but no vent caps (not to be confused with maintenance-free wet cells), so they are very sensitive to being over-charged. If you dry out the goop, you can't replace it. The vents hold the pressure in the battery to about 1.5 PSI above ambient pressure causing the hydrogen and oxygen gas to recombine into water while it's being recharged. They can have thinner plates than wet cells which means they usually don't have quite as much capacity as a similar sized deep-cycle wet cell.

Finally, we've got the "absorbed glass mat" or AGM battery, which is really just a sister of a gel cell but with even less electrolyte. These rascals have a glass mat that's tightly compressed between the positive and negative battery plates and soaked with acid. They have recombinant vents, like the gels, that force the gases to combine back into water. In addition to providing equal saturation of acid across the entire plate, the glass fibers embed themselves into the plates like reinforcing rods in concrete which provides for excellent plate support. The dense packing of the mat also allows for greater juice flow as compared to the gels and wets.

Some general and specific comparisons of these three families are shown in Tables 1 and 2.

Table 1. Relative Comparison of Deep-Cycle Battery Types

Relative Comparison Factor	Wet Cell	Gel Cell	AGM
Cost	Low	High	High
Weight per amp-hour	Low (sort of!)	High	High
Damage from Overcharging	Low (can still do the poor bugger in if repeated)	High – can't replace electrolyte	High – can't replace electrolyte
Number of Life-Cycles	High – up to + 1000 for high quality deep-cycle (theoretically), medium to low in real life	Low – around 300 to 500	Medium around 500 cycles
Damage from spillage or cracked case	High – a big problem here	None	None
Maintenance requirements	High – keep adding water and more frequent recharge when sitting idle – say once per month	Low – approx recharge once every 3 months while not in use	Low – approx recharge once every 3 months while not in use
Shock and Vibration Resistance – not a big concern for us gazers	Medium to Low	Medium	High
Gas Release while Charging (read explosion and corrosion potential)	High	Medium to Low	Low
Rate of Self-Discharge (while sittin' around waiting for clear skies)	High – 6% to 7% per month	Low – 3% per month	Low – 3% per month
Shipping	No	Yes- UPS	Yes – UPS
Charge Acceptance Rates (lower means longer time required to recharge)	High	Medium to Low	Medium
Voltage Drop During Discharge	High	Medium	Low

Table 2. A Specific Comparison of Group 24[1] Deep-Cycle Battery Types

Specific Comparison Factor – Assuming a size Group 24[1]	Wet Cell – good quality deep-cycle	Gel Cell	AGM
Cost	$90	$170	$170
Weight (lbs)	45	56	59
Amp-Hour Capacity	75	73	79
Marine Cranking Amps [2]	675	575	810
100% Duty Life cycles (as advertised – varies by brand)	350	350	500

[1] Group 24 is simply a standardized size of battery. Other sizes include U-1, Group 27, Group 29, etc. Batteries of the same group have similar (not exact) physical size and capacities.

[2] Marine Cranking Amps are the number of amps a battery can deliver over 30 seconds at 32° F. It provides an indication of the charge acceptance rate of a battery. It's the same as Cold Cranking Amps (CCA) except for the temperature rating (32° F v. 0° F for Cold Cranking Amps).

One group of off-breed batteries I didn't mention are the NiCads. These are actually the most effective battery for our needs. Problem is that they are still extremely expensive. You'd be much better off investing in that new eyepiece than investing in NiCads, at least for now.

So now that you know some of the principle differences, what's the recommendation? My choice is to go with either the AGMs or gels. There is more variety and availability in AGMs for the sizes we're talking about. I have personally gone the AGM route. You can't go wrong with gels so long as you invest in a high quality charger ($60+) that's specifically designed to cope with the lower charging voltages of this breed. I would stay away from the wet cells. Too much risk of rolling over in the trunk while going down those bumpy back country roads. Too much maintenance – filling, recharging, etc. Too easy to damage. Stick with AGMs or gels and be happy – be at peace with your power source.

The Energy Audit - Sizing Your Battery

Don't panic – we're not talking the IRS here. What we are talking about is a way to figure out how much juice you really need. It's a little like a scavenger hunt on either the internet or through the manuals that came with all your electron-consuming astronomy equipment – as well as any other equipment you'll want to power while out at that really dark site.

What we're trying to drive towards here is an estimate of the number of amp-hours you're going to need. An amp-hour is simply the number of amps being pulled, times the number of hours of consumption. For example, if you need 2 amps for 12 hours, you will consume 24 amp-hours.

Here's the drill. You need to first make a list of all the things you're going to plug into the old battery - your scope, dew disruptors, blinky lights (this is a must if my lovely wife is within 100 miles of you), robofocusers, etc. Now, go hunt down the manual for each of these items or do a search for them on the internet. Your quest is to determine how many amps each of these marvels of modern science draw. Note that some might be listed as "mA", which means milliamp. To convert mA to amps, simply move the decimal point three places to the left, i.e., 750 mA is equal to 0.750 amps.

The dew heaters will likely give you fits. Besides being one of the largest juice hogs, when you couple them with controllers you're not real sure how many of those little sparkers they're gulping down. Kendrick controllers along with others provide for automatic on/off operation - so they don't use the full current all the time. You'll need to take a guess here (don't worry - you'll be doing more guess work in just a minute - this stuff ain't real precise). I've inferred from Kendrick's literature that you can plan on anywhere from 40% to 60% of full heater current draw in normal operation - more or less depending on the controller setting. Ron Keating's new DewBuster is supposed to use even less. So, just pick a number that seems reasonable – if you live in the swaps back home in Louisiana – that dew heater is going to be cookin' more than if you're in the dark dry skies of New Mexico. I'd go slightly to the high side on your estimate just to be sure.

Now that you've got your list complete, here comes the other fun part - you need to estimate about how long you will be running each of these little rascals for the evening – expressed as a percentage of your total viewing time. For example, I could assume 100% usage on the scope, 60% on the dew heater, 25% on the CCA imaging set-up. Pick whatever seems real for your particular usage. Now that you've got the approximate percent of usage, you need to pick the high-end of your observation sessions duration - 6, 8, or even 10 hours for those who don't have to go to work the next day to pay for all this stuff.

If all this is not enough, you need to consider one more factor – how many days are you going to try and feed these devices without a recharge – think of that last great 3-day star party. If you're going to attempt this – you need to factor this into your equation – along with the funds for a back brace to schlep all those heavy batteries around that you're going to need.

To put it all together is a math exercise so simple even Jethro Bodine could do it. But just in case, I've included a sample spreadsheet on the next page to help out. All you need to do is to take the current draw (in amps) for each device and multiple it by your estimated percent of usage for a viewing session. Add this product up for all your devices and then multiple the sum times the duration (in hours) of your viewing session. There you have it – your energy audit results. I'm guessing if you're a typical non-CCD imager like me, you're somewhere in the 15 to 40 amp-hour range.

Example Energy Audit Spreadsheet

Device	Load (amps)	Percent Usage	Amp-Hours
Scope			
Nexstar 11 GPS	0.75	100%	0.75
Dew Heaters			
Orion 20 Watt w/ DewBuster Controller	1.67	40%	0.67
Telrad Heater w/ DewBuster Controller	0.88	40%	0.35
Lights			
Blinlky Tripod LED's	0.025	100%	0.03
Laptop			
Dell Dimension 8100	3.5		
Total for 1 Hour Session:			**1.80**
Hours per Session			10
Total for Entire Session:			**17.95**
Battery Life Factor (double your battery double your fun factor):			2
Battery Capacity Required to Support Session:			**35.90**

OK – now you know how much you need – so how big a set of batteries do you need? Here's an important rule – the amount of juice (amp-hours) in your batteries should be double your computed demand. That's right, take your total demand and multiple it by two. That's how much battery capacity you need. This is not simply a safety factor, it's a serious cost saving factor. As I'll discuss in a second, repeatedly using more than 50% of a battery's capacity significantly shortens its life span. It's a whole lot cheaper on your pocket book and more friendly to the environment if you work with batteries with twice the amp-hour ratings that you think you will need.

Let's assume we get a 20 amp-hour (Ah) nightly load. We could use a 20 Ah battery, but then it would experience a 100% discharge. No battery should ever be fully discharged, as it has extreme effects on its life. For deep-cycle batteries, we should normally use the 50% discharge mark as the target. This means, you would need 40 Ah of battery capacity to support your 20 Ah nightly load. Occasionally, this set-up could handle an 80% discharge and take it in stride.

Why use the 50% discharge mark? This is a nice even number - and if you look closely at the chart in Figure 1, below, you will notice that you can just about double the number of life cycles for a battery if you stay at the 50% discharge range as compared to 70% or more. You get another doubling of life at about the 30% discharge rate – but this typically means hauling around too much weight – this is supposed to be a fun hobby, not a triathlon. Additionally, there is an age factor. Over time, the battery ages and loses capacity and performance. This is from the progressive shedding or plate material and also from the gradually erosion of the positive plate grids. Then there is the temperature factor. The colder a battery, the less capacity it has. And since we're prone to go out into the wild yonder on those clear winter nights, this is not a factor to be ignored, as shown in Figure 2. The economics result in fewer dollars in the long-run for a battery worked at 50% cycles vs. a battery worked at 70% or more.

Finally, there is the issue of rate of discharge. This will not be important to most of us, but if you're pulling lots of amps over time, the effective capacity of your battery is reduced. This is shown graphically in Figure 3. Again, for most of us, this final reason to use the "double your battery size, double you fun" approach is not real important. However, the prior factors are meaningful to us low power users. So remember – double your pleasure, double you fun with double the computed capacity in your batteries.

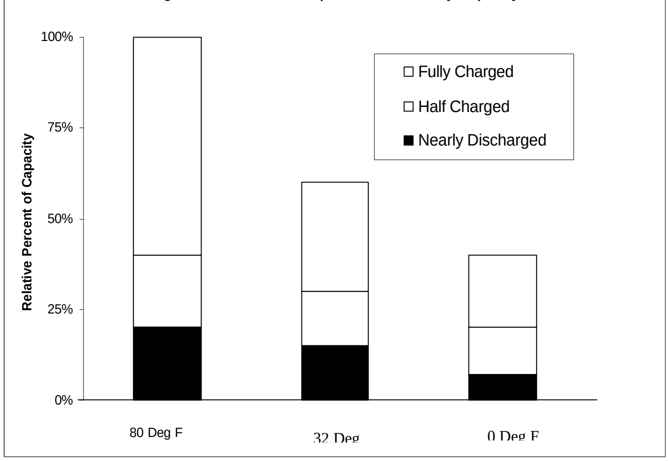


Figure 2. Effects of Temperature on Battery Capacity

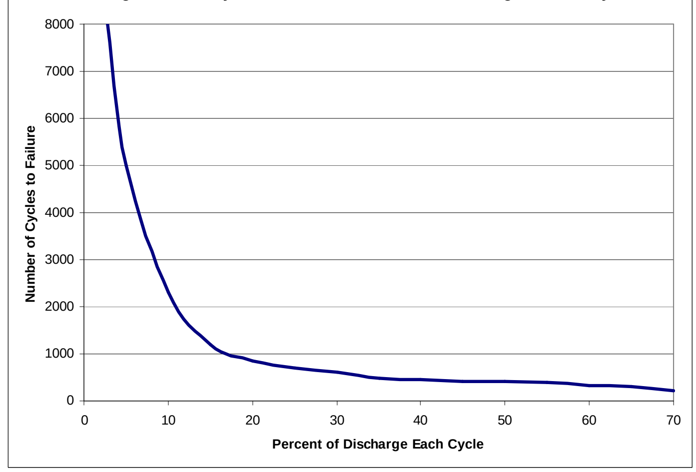


Figure 1. Life Cycles as a Function of Level of Discharge for Each Cycle

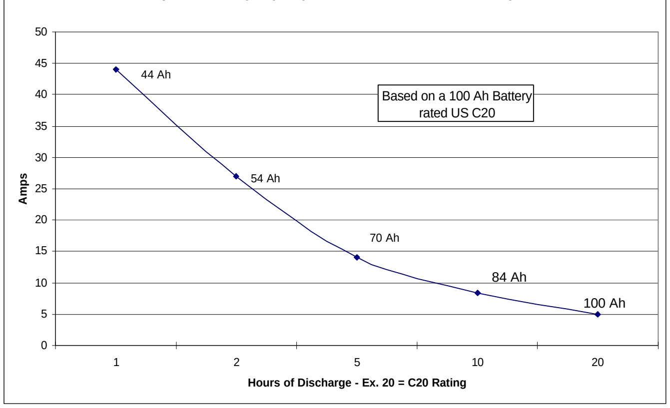
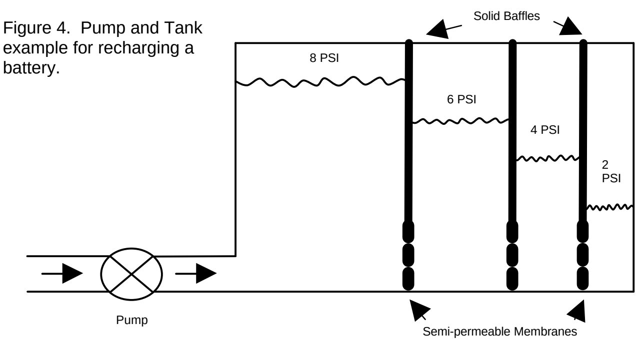


Figure 3. Battery Capacity as a Function of Rate of Discharge

Figure 4. Pump and Tank example for recharging a battery.



Alternative Approaches for Battery Capacity

So by now, you've probably realized that the 12 amp-hour jump starter system you bought from X-Mart doesn't cut it. But Jim, you say, this little bugger works fine for me. This may be true, but you will likely have to buy a new one every year. You end up spending a lot more over time than you would by getting the larger capacity batteries in the first place. A properly sized battery and a good charger should results in literally years of use prior to biting the big one.

There are a multitude of approaches to get the whopping capacity that you've just figured out that you need. My advice is to not put all your eggs in one battery basket. While there are some very high quality, deep cycle, high capacity batteries out there, it sure would be a shame for that sucker to fail right at that once in a lifetime moment. So, I say you should have a two battery system - with the batteries hooked in parallel (this means connect the positive lead of one battery to the positive lead on the other battery, and negative lead to negative lead). Now you've got a redundant system - if one fails, you've still got the other one to pull you through, albeit with less goodies humming away.

When using two batteries, you don't have to use the same size, but it's a good idea to use the same type - two AGMs or two gels. It's not a great idea to mix types. First, you will likely need two different chargers - since wets, gels and AGMs have different charge voltage requirements. Second, since the voltage per cell is slightly different between these families of batteries, cross-breeding can lead to having less capacity as one battery will simply discharge into the other.

So the best set-up in my book is to use two batteries of the same type. You have a single charger along with a single charging and maintenance routine. Easy as apple pie.

Recharging

So far, we've talked about types of batteries, their construction, and how to size them. None of this will provide an effective trouble-free DC system unless we have an effective way to recharge the batteries. When talking about recharging, a good analogy to use is a closed water tank having a series of baffles inside it, the lower sections of which contain semi-permeable membranes (water can flow in one direction but not the other), see Figure 4, above.

A pump represents the charger and it pushes in water (current) on one side and the main section of the tank fills. The rising water is initially contained by the membrane, but as the water rises in the first section of the tank, the air trapped on top is pressurized. The increase pressure forces water through the membrane at the bottom into the second part of the tank. Over time, the second section starts to fill, air pressure rises and water is pushed through the membrane into the third chamber. In the same way, the surface areas on the plates in a discharged battery are the first to be recharged, but thereafter it takes time for the charge to diffuse into the inner sections of the plates. The surface voltage must build up on the accessible areas of the plates, like the pressure building in a section of the tank, before the inner portions of the plate can be recharged. Surface voltage is what is measured by a voltmeter when placed across the battery terminals and it is also what the charger must contend with when trying to pump more current into the battery.

In our analogy, if the pump stops, the water will slowly work its way through the membranes until the different pressure zones in the tank are equalized. In the same way, if charging is stopped, the voltage differential inside the battery will slowly equalize until the battery reaches an internal equilibrium, known as open circuit state (this assumes there is no charge being put into or taken out of the battery).

If a really large pump is used on a small tank, it will drive up the pressure in the first section of the tank before much water has seeped into the other sections. If the pump has a pressure switch, it will quickly reach its set-point and shut down, even though the inner chambers are not yet filled. In the same way, if a high-output charger is put to work on a small battery, it will rapidly drive up the surface voltage on the plates without doing much to charge the inner plate areas. If you try and increase the set-point on the pump to a higher pressure, you could rupture the membranes. Similarly, if you increase the voltage on the charger to drive more current into the battery, you can ruin the battery by buckling the plates or sustain other forms of damage from overcharging.

The voltage regulator in the charger is akin to the pressure switch in the pump. It switches the charger off when a pre-set voltage is reached. When a battery is deeply discharged, its voltage drops. The voltage regulator on the charger senses this and tries to drive full current into the battery to raise the voltage. Initially, the battery will be able to accept a large current flow, just like with the first section of the tank is filling. Once the plates' surface areas are charged, the battery will accept only smaller amounts of current. This, in turn, drives up the surface voltage on the plates. When the voltage set-point is reached, the charger will shut down. The process of acid diffusion will start and almost immediately lower the surface voltage on the plates causing the charger to turn back on. As the battery becomes more fully charged, it accepts less and less current, which causes the charger to stay shut down for longer periods of time.

When we use deep-cycle batteries, we drain them slowly which allows time for the battery to equalize. This means we're pulling charge from the inner sections of the plates - which take the longest time to recharge. In fact, the charge times for the last 10% to 20% of a battery's capacity can take many hours to complete. To help increase the pace of recharging, multi-step regulators/chargers were developed. These multi-step regulators/chargers maintain relatively high voltage settings which boost the charge rates until a battery is almost fully charged. Then, they trip to a lower setting to avoid overcharging the battery. Most of multi-step chargers have three phases: bulk charge, absorption charge and float charge. During the bulk charge, the charger maintains maximum current output until the absorption voltage point is reached, typically in the range of 14.2 to 14.4 volts. At this point, the charger trips into the absorption phase. If the constant current of the bulk phase was to continue, it would drive the battery up to damaging high levels of voltage. During the absorption change, a constant voltage is maintained by the regulator (14.2 to 14.4 volts for a wet cell or AGM, 13.8 to 14.0 volts for a gel cell) and the charger provides only the current that the battery will accept. The absorption phase provides the time for the inner portions of the plates to absorb the charge. This charge phase continues for either a set amount of time or until the battery's charge acceptance rate at this voltage declines to 2% of the battery's amp-hour rating - the specific mechanism used to terminate this phase depends on the charger. At its termination, the battery will be nearly fully charged. Once the battery reaches this state, the charger goes into the float charge mode. The charger trips to a lower constant-voltage float setting, typically between 13.2 and 13.5

volts) which protects the battery from overcharging over extended charging times. For gel cells and AGMs, this float voltage is critical. Most cheap chargers float at a much higher voltage which will lead these batteries to the grave pronto.

A fourth charging state referred to as “equalization” is sometimes available on chargers. Equalization should only be used on wet cells - never on gels or AGMs. During equalization, the voltage is driven up to 15 to 16 volts. The purpose is to address sulfation in wet cells. Sulfation occurs when the inner regions of the plates don't get fully recharged. Equalization is a controlled overcharging of the battery which helps break down the sulfate crystals in the plates. More chemistry than we need to get into here. It is an effective way of occasionally bringing a dead wet cell back to life - if its death is due to sulfation.

For most of the batteries we'll be working with in our gazing adventures, a 5 to 10 amp charger should be more than sufficient for our needs. The typical rule of thumb is around for sizing a charger is to stay within 7% to 15% of battery capacity. Again, make sure that if you go down the gel or AGM family path you get a charger that is specifically designed for these types of batteries. The set-point voltages for wets, gels and AGMs are different, with wets having the highest voltage set points. Using a regular old wet battery charger on gels or AGMs will overcharge them - resulting in something akin to sudden battery death syndrome. Another feature you may find on chargers is a switch for "deep-cycle" batteries. This does not mean the charger will work for gels and AGMs. It does mean that the charger will have slightly lower set points, which allows more time for the thick plate deep-cycle batteries to absorb the charge in the inner regions of their plates - a good thing for wet cells.

One final comment about gels and AGMs, I don’t want to scare you on this, but just in case I’ve not made the point on having the correct charger for these puppies, I should mention a little, albeit rare phenomenon called “thermal runaway”. This is quite similar to a nuclear chain reaction with almost equally devastating results. A curious electrochemical reaction can take place inside a gel or AGM battery if it is overheated while being charged. The phenomenon can be the result of too high of a charging voltage, which will overheat any battery, environmental temperature that’s too high or a combination of both elements. Instead of tapering off, the charging current actually increases as the battery temperature increases. In extreme cases the electrolyte and binder material can be forcibly ejected from the battery vents – think run and hide here. Obviously the battery will be destroyed as will any equipment you have in the vicinity. The point here is to pay attention to the battery's location and charging voltage limit.

I would not be fair to the tree lovers among us if I didn’t include a comment on the use of solar cells for recharging. While solar cells are the epitome in renewable resources, they are not very practical for us. A standard 6 watt panel can be counted on to produce only around 2 to 4 amp-hours per day. Solar panels are rated under a specific set of conditions – *direct* overhead sunlight and 77° F. As the temperature increases, their output decreases. If you are going to use these, you also need to ensure you use blocking diodes to keep your battery from discharging back into the solar cells. See the reference material at the end for more information on solar cells.

State of Charge - How to Tell How Much Juice is Left

There are five common ways to test the health of your battery:

1. measuring the specific gravity of the electrolyte
2. measuring the open-circuit voltage
3. using a “load tester”
4. performing a capacity test
5. keeping track of the amps going into and out of your battery.

For us, the simplest is the measuring the open-circuit voltage. The specific gravity method, while valid, is not for me. It’s messy (you will dribble acid on something), it’s highly variable on temperature - you need to keep a table or two with you to determine the state of charge based on the specific gravity at a specific temperature, and, of course, you can’t use it on gels or AGMs. For load testing, the equipment is too expensive. If you want to do a load test, simply go to a battery store and have them do it for you – bring a beer or two along to get it done for free. The load test consists of subjecting your battery to high current loads for short periods of time to measure its capacity. The fourth option, the “capacity test” requires you to simulate a load on the battery and measure the voltage over time and make computations as to the amp-hours produced – too hard for me! Finally, there is some really neat equipment in the marine market that actually has a mini-computer to measure amp-hours in and out. What would seem simple is actually quite complicated and very expensive. So that leaves us with the simple, reliable, good old voltmeter test.

While measuring open circuit voltage to assess the state of charge, you should really only use a digital voltmeter. Since the difference between a fully charged and fully discharged battery is only about 0.4 volts, it's tough to measure these small voltages on an analog voltmeter (unless it's a really expensive and accurate one).

The other thing to keep in mind is that this measurement is made while the battery is disconnected. The voltages shown in Table 3 are not valid while the battery is powering something. Also, the numbers in Table 3 are only valid after the battery has rested about 15 to 20 minutes from either a discharge or a charging session. Reason? Remember the problem of acid and water diffusion we talked about in the "How a Battery Works" section, above? That's why.

What about all those LED set-ups that measure voltage while the battery is powering the scope and other goodies? Well, it's not very accurate. The reason is that the battery's voltage is dependent on the level of current it's pumping out. As the current changes, so does the voltage. The relationship is not a simple linear one, as was shown in Figure 3 in the Charging section.

So, the only way to really use the LED set-ups while you're powering away is to do a lot of tests. The test consists of setting up your scope and equipment and starting it up. Wait until one of your LEDs change (depending on your set-up). As soon as that happens, stop. Let the battery rest for 15 minutes and then measure it's voltage and use the table below to estimate capacity. Re-start and repeat the process for each change in your LEDs. Yes, it's a pain – and it's only good for the set-up you have. As soon as you add some additional load – you would have to repeat the process. Also, as the battery ages, the test becomes null and void. Oh yeah, remember the voltage v. temperature info in Figure 2? That's something else to consider.

I can hear you now…"Jim, you're painting such a bleak picture." What do I do? I don't worry about all this at all. I use the energy audit to size my batteries and then sit back and relax and let the juice flow. Since we're using the double the capacity, double the fun method of battery sizing, it's not going to be an issue. Occasionally, at the end of a session, I let the battery rest and then measure its open –circuit voltage just to monitor how the puppy is doing. That's all there is to it. If you size it right to begin with, just relax and enjoy the marvels of modern chemistry.

Table 3. Open-Circuit Voltage and Battery State of Charge (good for batteries between 60° F and 100° F

Typical Wet Cell	Gel Cell or AGM	State of Charge
12.6 or greater	13.0	100%
12.4 - 12.6	12.8 - 13.0	75% - 100%
12.2 - 12.4	12.6 - 12.8	50% - 75%
12.0 - 12.2	12.4 - 12.6	25% - 50%
11.8 - 12.0	12.2 - 12.4	0% - 25%
Below 11.8	Below 12.2	Tank is empty

One last note on this topic. I've heard that gels and AGMs are prone to very rapid voltage drop-offs when they reach the end of their capacity – much more so than the gradual voltage drop that occurs in wet cells. I've not experienced this, but be on the look-out.

Battery Maintenance – Does It Ever End?

Just like your teeth and flossing – everybody hates it but you've got to do it - keeping your batteries looking there best is not fun, but you need to do it. The list is not as long as the "honey do" list, but it's just as important (I hope my wife never reads this). I'll start with a myth – and it is just that, a myth. You can store batteries on concrete without worrying about killing them. This is an old myth that likely dates back to the days when battery cases were wooden boxes that leaked. Today's batteries don't have that problem. I know people that swear that this is true. The only thing that is true is that these folks are not maintaining their batteries properly and they are dying from neglect and self-discharge.

Top your wet cell batteries up with distilled water. Don't let the plates get air – that's a no no. Don't use tap water – the minerals in the water set up stray galvanic currents in the battery and increase self-discharge rates, especially if the tap water is chlorinated. Keep the plates covered with ¼ to ½ inch of fluid. Don't overfill, as it can lead to spewing of electrolyte from the vent caps when charging.

Keep the tops of the batteries clean. Even a small amount of dirt or liquid can set up stray currents that can discharge your baby. Wiping with a rag dipped in a solution of baking powder, soda or household ammonia will neutralize the acid – but NEVER sprinkle baking soda directly on the battery. If any soda gets is a cell through a vent hole, it will cause explosive boiling of the electrolyte and can destroy the cell – and your shirt, since you'll be looking to see what the heck is going on in there.

Keep the battery posts clean and shinny. It helps the juice flow. A wire brush works well here.

Bring a battery to full charge any time you're going to leave it unused for a couple of days. All batteries will discharge over time when left alone – they get lonely, too, you know. A wet cell runs down faster than a gel or AGM. Figure 5 shows the rough discharge rates over time and at different temperatures. If you leave a wet cell unused and uncharged for over a month during the summer, the self-discharge will lead to sulphation, the sulphates will harden and damage the battery permanently. Recharge your wet cells at least once per month in the summer. Fully charged gels and AGMs can go about 3 months without a recharge.

Keep 'em cool but not cold. Keeping your puppies cool helps slow self-discharge. Letting your puppies freeze will lead to irreparable damage. Table 4 shows the freezing point of electrolytes for various states of charge.

Figure 5. Self-Discharge Rates for Wet and Gel Cells as a Function of Temperature

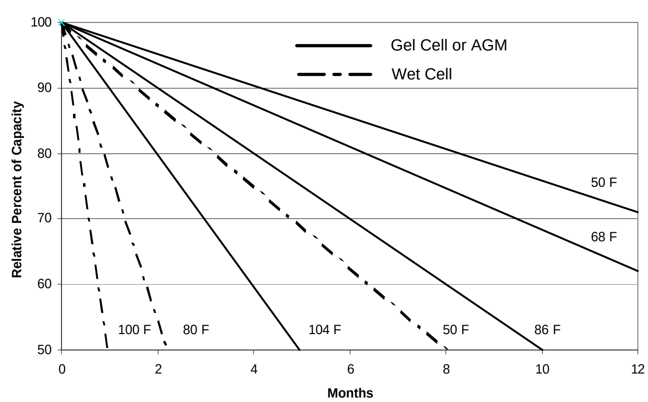


Table 4. Electrolyte Freezing Points and State of Charge

State of Charge	Freezing Point °F
100	-70
75	-45
50	-10
25	5
0	15

Finally, it never hurts to have a quite chat with your batteries at least once a week. Giving them each a name is also a nice touch that can significantly extend both your life and that of your battery. Your family and friends may initially think you're crazy, but after a couple hours of great views with loads of amp-hours to spare, they will come to appreciate your care and feeding of your battery friends.

Problem Batteries and Children – what to look out for if you've got an ornery one

Despite our best intentions, love and caring of our little battery friends, they can give us problems. Just like children, the best way to detect problems with our batteries is to be watchful of warning signs. What follows are a couple of the more common signs for which we should be on the lookout.

Battery shows nearly full voltage when under no load, but when a load is applied, the voltage drops rapidly. What we've got here is a battery that has very little capacity left. When recharging this battery, if the voltage goes up quickly, it signals that there is very little active material left. This could be due to either shedding or sulphation (on a wet cell only). In either case, this problem child will go dead rapidly in use. It's time to replace it if it's a gel and AGM. If it's a wet cell, you can try to use an equalization charging routine to address the sulphation, but it that doesn't work, you know the problem is caused from shedding and it needs to be replaced.

A wet cell that needs to be filled frequently. If this occurs, you're overcharging you battery. Fluid loss should be no more than 1 to 2 ounces for every 30 to 50 hours of charging time. If just one cell is consuming fluid, that cell probably has a short in it.

An unused battery shows significant voltage drop, say 75% or so, after only 2 to 3 weeks. In this case, your battery has some sort of internal short. This can be caused by either the shed material or dendritic growth (a battery tumor of sorts) filling the space between two plates and shorting them. If the battery is a gel or AGM, it's a goner. If it's a wet cell, there is a procedure to attempt resuscitation, but you've really got to want to save it. You drain all of the electrolyte out carefully into a plastic container – like a clean milk jug. Then fill the cells with distilled water and slosh it around and drain it out (be careful, as this will have some acid in it as well). Repeat a couple of times to try and remove the materials that have shed off the grids. Refill the battery with the acid while straining it – a pantyhose works well here. Top off with distilled water. This may do the trick.

Gel cell or AGM with white powder around its posts. What's happened here is you've overcharged the battery to the point that the pressure values have opened up and vented, drying out some of the goop and wrecking the battery. If you are really desperate and you are certain that the goop is dried out, you can try to force open the vents and refill the cells with distilled water. When you do this, you will ruin the values and have to treat the battery as a wet cell going forward – going through the charging and refilling routine with distilled water.

Gel cell or AGM with a black battery post. The battery likely has a leaking seal around the post. Sooner or later it will dry out and fail. To test the seal, brush a little soapy water around the post and the flex the battery case for that cell. If the soapy solution bubbles, you've got a bad seal.

If none of these signs are apparent and your battery just isn't putting out like it used to, you could simply have a battery that's dying of old age. A combination of shedding, shorts, sulphation, etc. Despite our best love and care, batteries don't live on forever.

As for problem children, I think the same steps would work well – think about it! Before signing off here, I've one last plea to make. If you've got a dead battery, please give it a proper burial. This means taking it to an automotive shop or battery shop to be recycled. There are a lot of nasty chemicals in batteries that our children will not want in their environment. Do please dispose of your dead battery through recycling.

For Additional Information – great sources for more information.

I'd like to leave you with a couple of great resources for battery information. There is a tremendous amount of information on the internet as well as some really good books that go into much more detail than I've presented here.

The Boatowner's Mechanical and Electrical Manual, Second Edition, Nigel Calder – a definitive masterpiece.

The 12 Volt Bible for Boats, Miner K. Brotherton

www.batterycouncil.org