INTRODUCTION TO
LEAD ACID BATTERIES

Introductory Note: *Much of the perceived confusion among battery users of all types, and in particular for power sports enthusiasts, is largely due to the wide variety of construction methods used in making lead acid batteries. Although for the most part, the electro- chemical workings of these differently constructed lead acid batteries is very similar, manufacturers recommend that these batteries be used in different applications and that they be charged by slightly different methods.*

Table of Contents:

What is a battery?

A battery is a device that stores energy. The way that it stores energy is by holding different electro-chemically active materials together is such a fashion so that they can generate and store free electrons (electrical potential energy) for long periods of time and only deliver that energy when the battery user demands it.

The inherent properties of the electro-chemically active materials allow them to store energy chemically and then release that energy electrically as a bi-product of a chemical reaction. If we skip the explanation of how a battery is "brought to life", and jump in at a point where the battery has already experienced several discharges and recharges, then we can say that the battery actually stores electrical charge. The production of the electrical charge came about as a bi-product of a chemical reaction. You might want to think of this as being similar to the way that gasoline stores its energy chemically and then releases that energy thermally as a bi-product of a chemical reaction.

Since electrical charge has a polarity, the individual charges will try to travel towards the polarity that is opposite of its own polarity. Opposite polarities attract and like polarities repel. Remember also that a battery contains both a positive and a negative terminal. So the electric charge is sitting, waiting to move when a proper conductive path exists to allow the charge motion, or the electric current to flow. The trick to making a battery deliver its electrical energy is to provide an electrically conductive path that connects the terminals of the battery to an appliance that requires a certain amount of electrical current to operate.

This is a very important point for safety. The amount of energy that a battery stores is fairly substantial. The amount of energy delivered by a battery is only limited by its capacity and the resistance to electrical current flow that exists across the battery terminals. If there is nothing connected to the battery terminals, then the resistance to electrical current flow is infinite, or at least very, very large. Therefore, no electrical current will flow outside the battery between its terminals. This is an OPEN circuit condition.

If only a wire, or cable, or a metal screwdriver lay across the battery terminals, then the resistance to electrical current flow is essentially zero, or at least very, very small. Therefore, an extremely large electrical current will flow outside the battery between its terminals, through essentially a zero resistance connection. This is called a SHORT CIRCUIT condition, and IT IS VERY, VERY DANGEROUS. A typical automotive engine start battery with the ability to deliver 650 cold cranking amps, may very well have the capacity to deliver in excess of 2000 amperes into a short circuit connection. That much electrical current generates a tremendous amount of heat. In the case of a lead acid battery, there is also an extreme risk of explosion and fire. Forensic scientists and engineers, some of whom actually do have a sense of humor, prefer to use the term “rapid disassembly”. In fairness to the battery manufacturers, there are many styles of lead acid battery construction that will minimize or even eliminate the risk of explosion during a short circuit. Still, in general, bad things happen when a battery is short-circuited.

What exactly is in a battery?

Battery must have a case that is electrically insulated and mechanically strong enough to support the weight of its component parts. All batteries are composed of individual cells. A cell might be considered the smallest unit of a battery that is capable of generating a voltage and performing the functions of a battery on its own. Many combinations of chemical compounds can be put together to create an electric charge generating battery cell. Once the electric charge is generated, it must have a conductive path to escape to the outside world. Those conductive paths are provided by the grids and the electrodes. In the strictest sense of the word, the grids are actually part of the electrodes, because an electrically conductive welding process mechanically bonds them.

The individual battery cells are composed of plates and insulators. The plates are composed of the conductive grid and the active material. There are two polarities of plate, both positive and negative. One pair of opposite polarity plates is sandwiched around some type of insulator, called a separator. The composition of the separator varies. For the AGM battery, this separator is some type of poly-fiber **Glass Matte** material, hence the letters **GM**. This combination is called a couple. Depending on the Amp-Hour rating of the cell, the plates will be physically larger to deliver more Amp-Hours or a greater number of smaller plates could be put in a cell to have the same effect.

The last piece of the puzzle is the electrolyte. This is a source of free electrons; actually the captive electrons within the electrolyte are waiting to be liberated as a result of a chemical reaction. In the AGM style battery, the bulk of the electrolyte is **Absorbed** in the separator material, hence the letter **A**. So **AGM** stands for **Absorbed Glass Matte**.

What's in a Lead Acid Battery?

Since we are most interested in lead-acid batteries, let's talk about that one. In a lead acid battery, the electrodes and grids are made from lead. Usually there is some other additive mixed in with the lead, like calcium to give it mechanical strength. The polarity of the plate is determined by the active material that is placed in physical contact with the grid. The active material is some formulation of lead oxides. Every battery manufacturer has its own proprietary formulation, usually optimized for one performance characteristic or another. The electrolyte is sulfuric acid. Hence the name "Lead-Acid".

The basic lead acid battery chemistry has been the workhorse of the automotive engine start and traction vehicle industries for a long, long time. When used in engine start applications, the batteries are referred to by the acronym SLI, which stands for Starting Lighting & Ignition. Even with all the new, exotic developments in battery technology within the last decade, lead acid still offers one of the most economic alternatives for many applications.

What can a battery do?

A battery can do one or more of three things.

First, and most common in the minds of the general public, is to start an engine. Here, the battery delivers a short burst of high amplitude electric current to energize the starter motor that turns the crankshaft on an internal combustion engine. In general, these types of batteries are called SLI, which stands for Starting Lighting & Ignition.

Second, the battery can sit for months or years in a stand-by mode waiting to provide back up power when there is a power outage from the utility company. When the battery supplies its power as a backup, it may discharge completely or only very slightly. Then it is recharged when the power comes back on, and then it again sits idle for long periods of time. Actually, this application is very common, particularly now with the literal explosion (not to be confused with rapid disassembly) of new applications within the telecommunications industry.

Third, the battery can deliver the majority of its capacity repeatedly, possibly on a daily basis. This is called a deep-cycle application. Typical examples of this type of use are electric vehicles: cars, busses, golf carts, bicycles, and scooters; industrial applications like electric forklifts (also an electric vehicle); and marine applications like running trolling motors. Deep cycle applications where the battery supplies electric power to portable equipment include medical equipment like EKG machines and respiratory monitors, electronic test and data collection equipment used in industrial settings, telecommunications equipment and a wide range of other types of equipment.

Repetitive deep-cycle discharges are, in all likelihood, the most strenuous application for a battery. Very often, the recharge power requirements for this type of use are extreme, particularly in the eyes of those who have to pay for the battery charging equipment. A good rule of thumb to gauge the price that consumers would have to pay for charging equipment is that on average, for equipment with reasonable electronic control, one would expect to pay about $1.00 per watt. For chargers with more sophisticated electronic controls and display devices, the price can be as high as $3.00 to $3.50 per watt.

The electric vehicle (EV) applications are the most strenuous on the battery pack. In some respects, the EV application is like a combination of engine start and deep cycle. The current draw from the battery pack could be very high, at several hundred amps when the vehicle begins to move from a dead stop, during acceleration, and climbing hills. Other times, the current draw may be steady at a much lower value, possibly less than 50 amps when the vehicle is coasting or traveling at a steady speed.

Most batteries do 1 of these 3 things very well, either engine start, standby, or deep cycle. Occasionally, a battery can perform 2 of these functions well. Usually engine start and stand-by are the applications that can be handled by a single battery style. Although there has been much research and development in the last 10 years to optimize battery performance for EV applications, it is very rare that any battery style can do all 3 things equally well.

What are the different types of lead acid batteries?

(These explanations are somewhat simplified)

Flooded: This is the traditional engine start and traction style battery. The liquid electrolyte is free to move in the cell compartment. The user has access to the individual cells and can add distilled water as the battery dries out.

Sealed: This term can refer to a number of different constructions, including only a slight modification to the Flooded style. In that case, even though the user does not have access to the cell compartments, the internal structure is still basically the same as a Flooded battery. The only difference is that the manufacturer has ensured that a sufficient amount of acid is the battery to sustain the chemical reaction under normal use throughout the battery warranty period. Other types of lead acid batteries are also sealed, as explained below.

VRLA: This stands for Valve Regulated Lead Acid battery. This is also a Sealed battery. The valve regulating mechanism allows for a safe escape of hydrogen and oxygen gasses during charging.

AGM: As stated earlier, the Absorbed Glass Matte construction allows the electrolyte to be suspended in close proximity with the plate's active material. In theory, this enhances both the discharge and recharge efficiency. Actually, the AGM batteries are a variant of Sealed VRLA batteries. This particular style has recently become very popular in many engine start and power sports applications.

Note: *It is not uncommon for the marketing folk of the industry to exercise a bit of literary license in the description of various Lead Acid batteries performance characteristics. The creative marketer, although meaning well while sculpting a recognizable niche in the all-too-often drab and unappealing market landscape will occasionally coin a phrase that not only catches on but also generates a bit of confusion. One such phrase is* ***"Drycell™ Batteries"****. That description is an extension of the performance characteristics of a very high quality AGM battery line, intended to emphasize the minimal amount of free acid (virtually none) that will leak in the event that the battery wall is ruptured. The unfortunate confusion results from conflicts with the required warning verbiage dictated by Underwriter's Laboratory standard UL-1236 for battery chargers used in engine start applications. That wording, from subparagraph 47.4.11 h) is:* ***"... Do not use battery charger for charging dry-cell batteries that are commonly used with home appliances..."*** *What is not obvious to the average end user is that the intent of the UL-1236 warning, written in June, 1994 is to avoid attempting to recharge primary, non-rechargeable cells, like D, C, AA, alkaline cells that are used in things like flashlights, cameras, etc. There are rechargeable battery types available in those sizes, for those same household appliance applications, but for the most part, the chemistry of the cell is not lead-acid. The technical staff at Deltran has had numerous inquiries about the compatibility of Battery Tender® battery chargers with "Drycell™ Batteries". Once the battery brand name is identified to be the sealed, AGM, lead acid type, then there is no concern over compatibility with Deltran chargers.*

GEL: The gel cell is similar to the AGM style because the electrolyte is suspended, but different because technically the AGM battery is still considered to be a wet cell. The electrolyte in a GEL cell has a silica additive that causes it to set up or stiffen, first like Jell-O, then after subsequent discharge/charge cycles more like peanut brittle. Micro cracks form in the gelled electrolyte that provide paths for the oxygen recombination reactions between the positive and negative plates. The recharge voltages on this type of cell are lower than the other styles of lead acid battery. This is probably the most sensitive cell in terms of adverse reactions to over-voltage charging.

Note: *It is very common for individuals to use the term "GEL Cell" when referring to sealed, maintenance free batteries, much like one would use "Kleenex" when referring to facial tissue or "Xerox machine" when referring to a copy machine. Be very careful when specifying a charger.* ***More often than not, what someone thinks to be a Gel Cell is really a sealed, maintenance free, GRT, probably AGM style battery.***

Maintenance Free: This term is very generic and refers to basically all of the battery types except flooded batteries that have accessible individual cells so that the end user can add water. Since any sealed construction prevents the user from adding water to the individual cells, then by default it becomes maintenance free.

The following table summarizes typical applications and charge voltage ranges for different styles of Lead Acid Batteries. These are just very general guidelines. Again, it is very important to check with the battery manufacturer to verify what specific charging requirements they recommend for your application.

Lead Acid Battery Type Summary					
Type:	**Typical Application***			**Typical Absorption Voltage Range:**	**Typical Float Voltage Range:**
	SLI	DC	SP		
Flooded	X	X	x	14.2V to 14.5V	13.2V to 13.5V
Sealed	X	X	x	14.2V to 14.5V	13.2V to 13.5V
VRLA	x	x	X	14.2V to 14.5V	13.2V to 13.5V
AGM[$]	x	X	X	14.4V to 15.0V	13.2V to 13.8V
GEL		x	X	14.0V to 14.2V	13.2V to 13.4V

SLI = Starting, Lighting, Ignition; DC = Deep Cycle, SP = Standby Power
Capital X = much use, Small Case x = some use.

*Besides those listed, all battery types can be used in all applications. More AGM batteries are now being used in SLI applications, particularly in motorcycles and sports watercraft, while flooded and sealed lead acid batteries are still most commonly used, particularly for automotive SLI.

[$]Notice the wide range of absorption and float voltages for the AGM battery.

Table 1 Lead Acid Battery Type Summary

Time Required to Charge a Battery:

Let's take a moment and talk about two of the fundamental electric quantities, Amps and Coulombs. A battery stores charge (Coulombs), and an electric current (Amps) is made up of charge that is moving. Let's ask a very important question: **How long will it take to charge a battery?** ***This question is so important that it is repeated in the section titled Frequently Asked Questions.*** If you look at the battery specifications and ratings, you won't find Coulombs listed anywhere. What you probably will find is Amp-Hours. Let's look at that term. Amps times Hours = (Coulombs per second) times 3600 seconds (in 1 Hour). So, 1 Amp-Hour = 3600 Coulombs. That's still sort of confusing. The main thing to remember is that Amp-Hours and Coulombs are both units that describe an amount of electric charge.

Let's try something else. Suppose I have a 50 Amp-Hour battery. That's a fairly typical size for an automotive engine start type battery. Now let's say I have a 10 Amp charger. If it's a good charger (like the Battery Tender® products), it will deliver close to 10 amps for as long as it takes to get the battery voltage up to its recharge level. **So how long will it take to actually charge the battery?**
We can make a pretty good guess by just dividing two numbers:

(Battery Capacity) / (Charger Current) = Time

(Amp-Hours) / (Amps) = Hours

for this example:

(50 Amp-Hours) divided by (10 Amps) = 5 Hours.

So we would estimate that it will take a good 10 Amp charger about 5 Hours to recharge a 50 Amp-Hour battery. **Actually this rough estimate usually tells us how long it takes to recharge the battery to about 80% of its capacity.** It turns out that it will probably take an equal amount of time, or another 5 hours to recharge the last 20% of the battery capacity. Keep in mind also that many of the 10 Amp chargers on the market today are what we call taper chargers. They typically sell for $25.00 to $40.00 retail. With those types of chargers the charge times that we just calculated probably need to be doubled.

TABLE OF CONTENTS

SERIES AND PARALLEL BATTERY PACKS

It is important to discuss this topic because when more than one battery is connected together the resulting battery pack will have either a different voltage or a different amp hour capacity (or both) when compared to a single battery.

SERIES CONNECTIONS:

Let's begin in Figure 1 with a simple box model showing the positive and negative terminals to represent the physical battery. We'll use this to relate to the physical connections between the batteries that you would use to construct a battery pack.

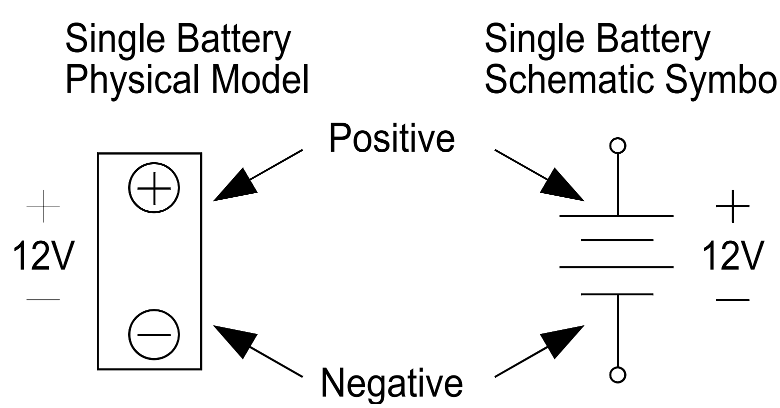


Figure 1 Single Battery Physical Model & Schematic Symbol

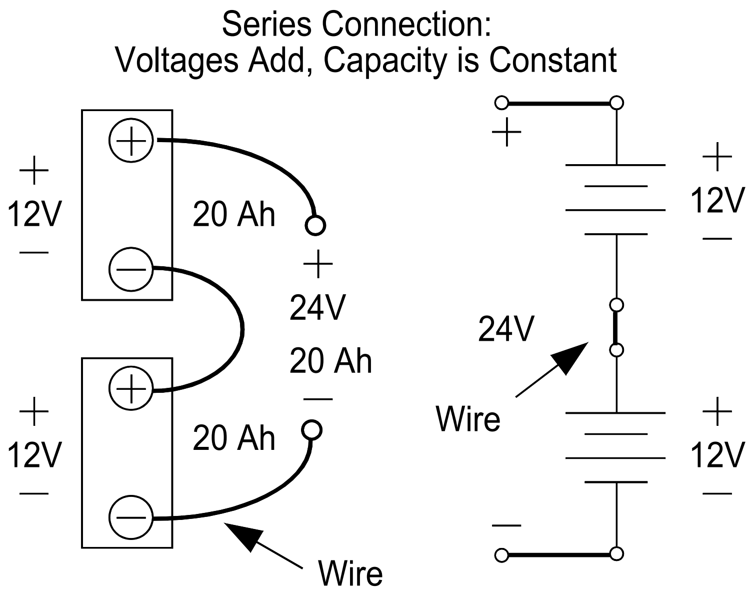


Figure 2 Batteries Connected in Series

Figure 2 shows two 12-volt batteries connected in series. The important things to note about a series connection are: 1) The battery voltages add together to determine the battery pack voltage. In this example the resulting pack voltage is 24 volts. 2) The capacity of the battery pack is the same as that of an individual battery. This assumes that the capacities of the individual batteries are the same. In fact, this is a must. Do not mix and match different size batteries in the same battery pack.

PARALLEL CONNECTIONS:

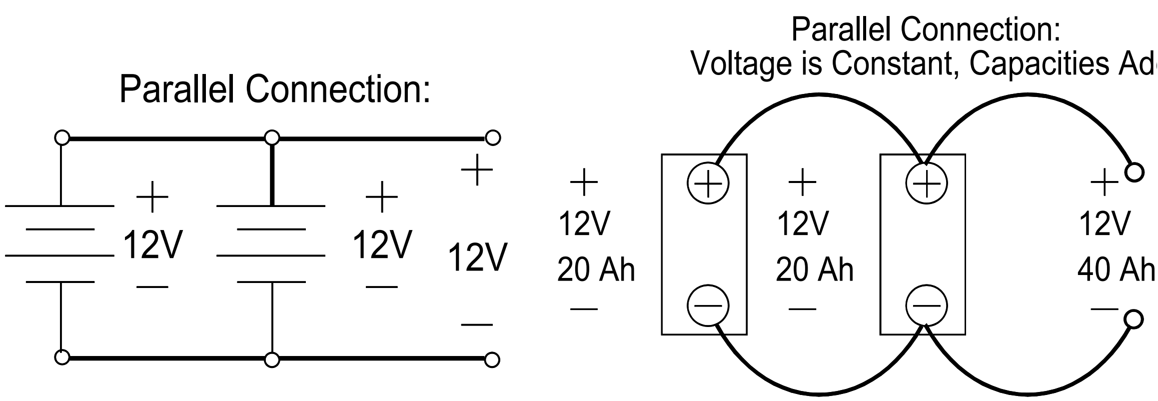


Figure 3 Batteries Connected in Parallel

Figure 3 shows two 12-volt batteries connected in parallel. The important things to note about a parallel connection are: 1) The battery pack voltage is the same as the voltage of the individual battery. This assumes that the individual battery voltages are the same. In fact, this is an absolute must. **Do not mix and match different battery voltages in the same battery pack.** In this example the battery pack voltage is 12 volts which is exactly the same as each of the individual 12-volt batteries. 2) The capacity of the battery pack is the sum of the capacities of the individual batteries. Again, make sure that all of the batteries are the same size, that is that they have the same amp-hour capacity.

SERIES / PARALLEL CONNECTIONS:

There are many ways to connect a group of batteries in both series and parallel at the same time. This is common practice in many battery power appliances, particularly in electric vehicles and large UPS systems where the battery packs require large voltages and amp-hour capacities. It is not uncommon to have battery packs with several hundred volts and several hundred amp-hours.

Just to get an idea of how these connections can be made, we'll look at two examples, with 4 batteries each, using 12 volt, 20 Ah batteries. In each of the examples, the 4 batteries are identified as A, B, C, and D.
Example 1, shown in Figure 4, has 2 pairs of series connected batteries joined in a single parallel connection. In this type of arrangement, we refer to each pair of series connected batteries as a "string". Batteries A and C are in series. Batteries B and D are in series. The string A and C is in parallel with the string B and D. Notice that the total battery pack voltage is 24 volts and that the total battery pack capacity is 40 amp-hours.

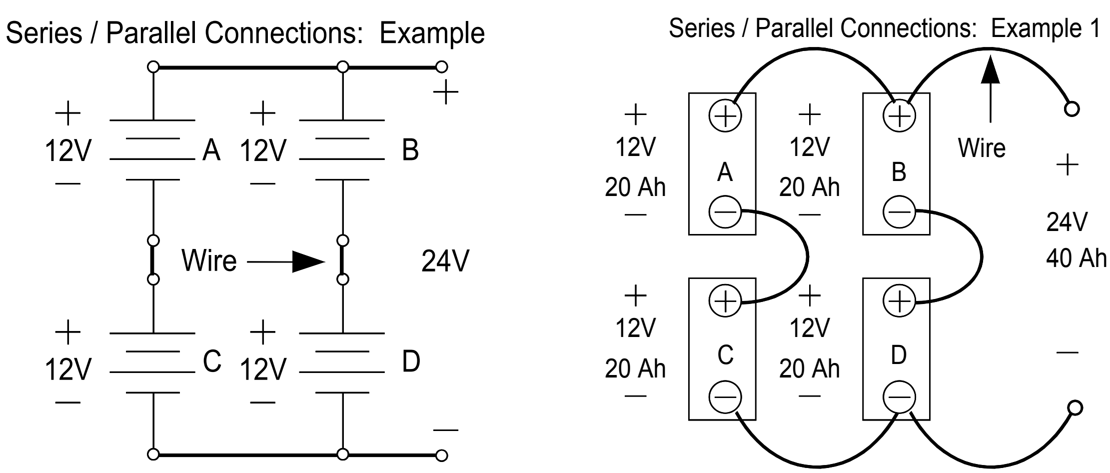
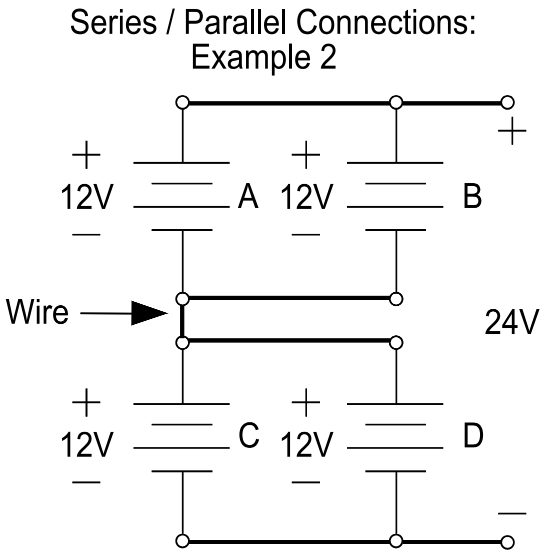


Figure 4 Batteries Connected in Series / Parallel: Example 1

Example 2, shown in Figure 5, has 2 pairs of parallel-connected batteries joined in a single series connection. Batteries A and B are in parallel. Batteries C and D are in parallel. The parallel combination A and B is in series with the parallel combination C and D. Again, the total battery pack voltage is 24 volts and that the total battery pack capacity is 40 amp-hours.



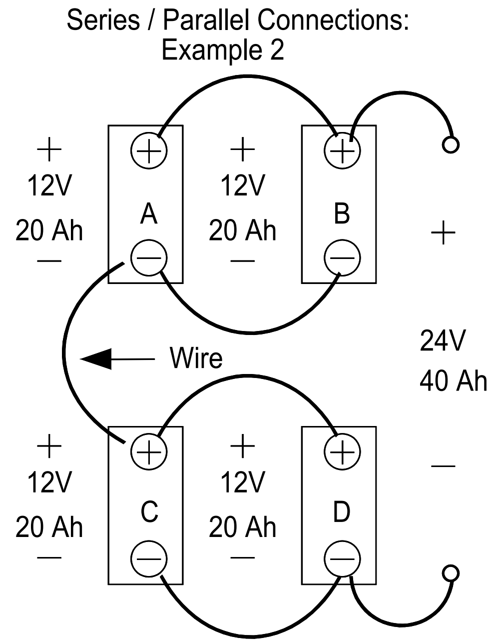


Figure 5 Batteries Connected in Series / Parallel: Example 2

CONNECTING BATTERY CHARGERS TO SERIES AND PARALLEL BATTERY PACKS

Note: *The following diagrams show some ways to connect Deltran battery chargers to various battery packs connected in series and parallel.*

One Battery, One Charger, One Voltage

Positive to Positive, Negative to Negative, Voltages are the Same

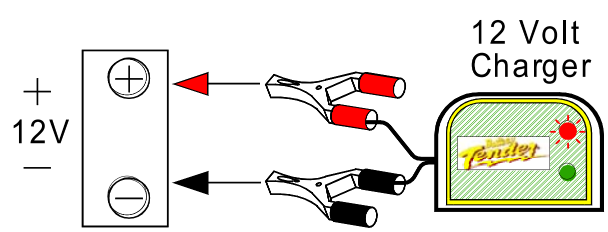


Figure 6 One Battery, One Charger

Figure 6 shows the most basic connection between a battery charger and a single battery. The positive charger output (red) connects to the positive battery post. The negative charger output (black) connects to the negative battery post. Always remember: 1) positive connects to positive and negative connects to negative 2) the charger and the battery must have the same voltage.

Two Batteries in Series, Two Chargers

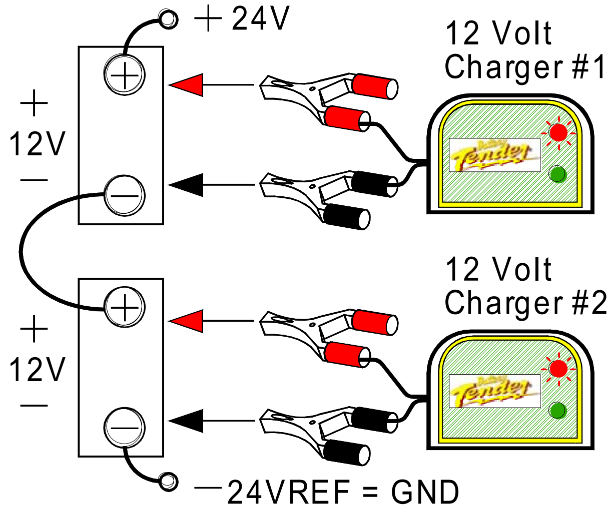


Figure 7 Two Batteries in Series, Two Chargers

Figure 7 shows two 12 Volt batteries connected in series. The resulting battery pack voltage is 24 volts. As you can see, each battery is connected to a single 12-volt charger. This is probably the best way to ensure that each battery is completely recharged to its full capacity after each time that the battery pack is discharged. This eliminates most of the problems associated with cycling batteries connected in series strings.

Two Batteries in Series, One Charger

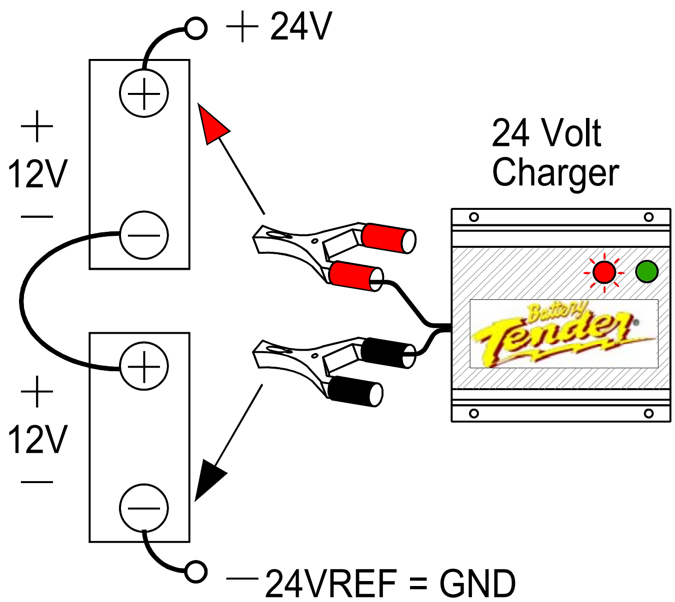


Figure 8 Two Batteries in Series, One Charger

Two Batteries in Parallel, One Charger

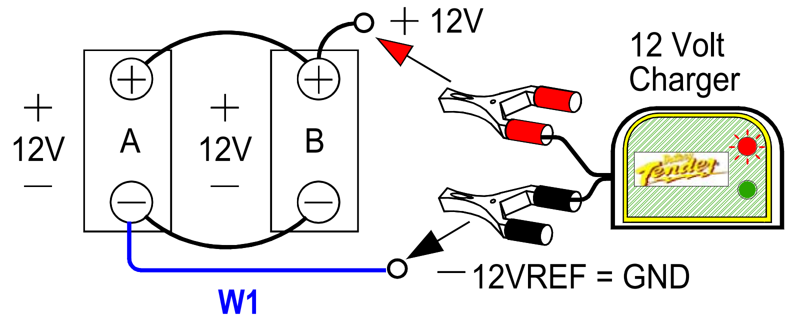


Figure 9 Two Batteries in Parallel, One Charger

Batteries connected in series strings can also be recharged by a single charger having the same nominal charging voltage output as the nominal battery pack voltage. In Figure 8, a single 24-volt charger is connected to a 24-volt battery pack.

In Figure 9 we see a pair of 12-volt batteries connected in parallel. This 12-volt battery pack is connected to a single 12-volt charger. Note the blue wire designated W1. The purpose of this wire is to balance the voltage drop evenly across both batteries and each wire during charging. This is not critical for lower current chargers, but when you start to get into the 10 amp and above range, the voltage differential can be significant. The blue wire W1 must be connected to the opposite end of the battery pack as the black wire at the top of the battery pack

When batteries are connected in parallel, only use one charger. Do not connect a charger to each battery, unless you break the electrical connection between the batteries. The reason is that the chargers will very likely complete one or more their charging subroutines (charge modes or stages) at different times. That means that each charger would be trying to bring the battery pack to a different voltage level. Depending on how the chargers are configured to prevent a reverse polarity connection, the charger with the lower voltage output could possibly draw current from the charger with the higher voltage output, or even from the battery pack that it is trying to charge. If the chargers' reverse polarity protection mechanism includes a solid state, unidirectional, voltage controlled, current switch (like a diode), then this is not a big problem.

Four Batteries in Series / Parallel (Example 1), Two Chargers

THIS ARRANGEMENT IS ABSOLUTELY NOT RECOMMENDED!

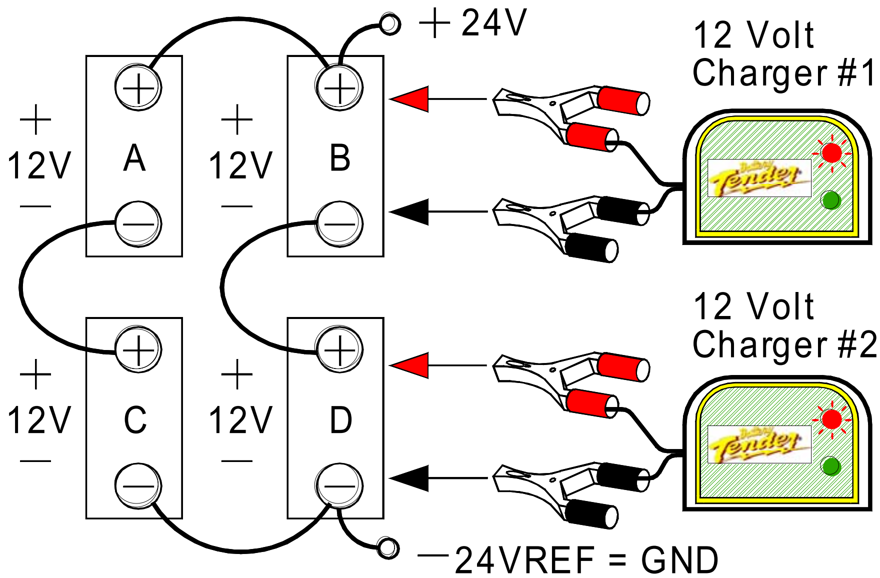


Figure 10 Four Batteries in Series / Parallel (Example 1), Two Chargers

Figure 10 is not the best arrangement for recharging this type of series/parallel battery pack. At first glance it appears that batteries B and D are both receiving the full attention of chargers #1 and #2 respectively, while batteries A and C receive no recharge current. What actually happens is that all 4 batteries get charged, but probably not evenly. Depending on the cable and contact resistances, batteries A and C may only be charged as much as 0.5 or 0.75 volts less than batteries B and D. **AGAIN, THE ARRANGEMENT SHOWN IN Figure 10 IS ABSOLUTELY NOT RECOMMENDED!**

Four Batteries in Series / Parallel (Example 1), One Charger

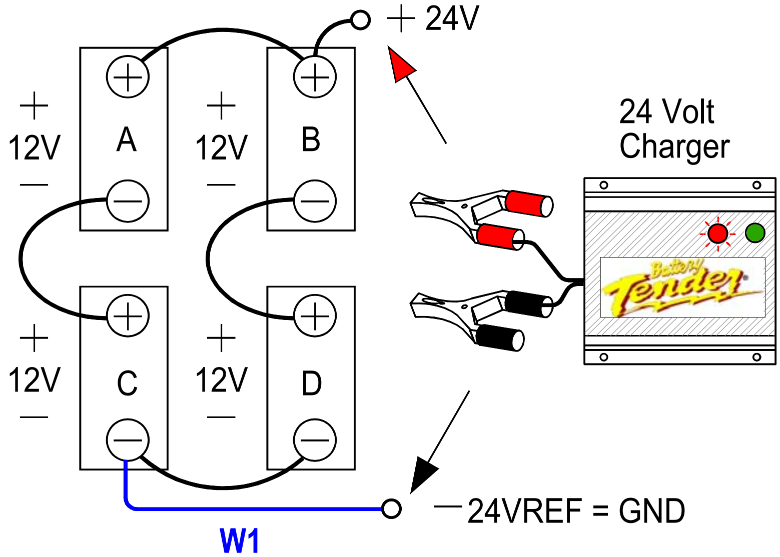


Figure 11 Four Batteries in Series / Parallel (Example 1), One Charger

The diagram shown in Figure 11 is an acceptable way to charge a combination series / parallel battery pack. This method is definitely better than the arrangement shown in Figure 10 because the imbalance in individual battery voltages is not as much of a concern. There are some intricate details of charging algorithms that are specifically optimized to account for and eliminate the individual battery voltage imbalance in large series strings. Even without those special charging features, the single 24-volt charger in this arrangement does a better job than two 12-volt chargers would. Again, the blue wire designated W1 serves the same charge voltage drop imbalance function that it did in Figure 9.

Figure 12 again shows two 12 volt chargers connected to a series / parallel battery pack. But this battery pack is configured like example 2 in the previous section. What you have is two sets of two batteries each connected in parallel. Then those two parallel-connected sets of batteries are connected in series by a single wire connection. In this case, it is perfectly acceptable to use a single charger for each of the parallel-connected sets of batteries without worrying about the voltage imbalance discussed with respect to example 1. Recall that example 1 shown in Figure 4 had two sets of two batteries, first connected in series, then each series connected in parallel by 2 wire connections.

For those mathematics buffs that are into topology and n-dimensional spaces, etc., one might consider the fact that there is one more piece of wire connecting the batteries in example 2 (5 pieces of wire total) compared to only 4 pieces of wire in example 1. That one extra connection makes the difference between being able to use two 12-volt chargers effectively instead of having to use one 24-volt charger. In some larger systems, these types of considerations could have an impact on both economics and system reliability.

Four Batteries in Series / Parallel (Example 2), Two Chargers

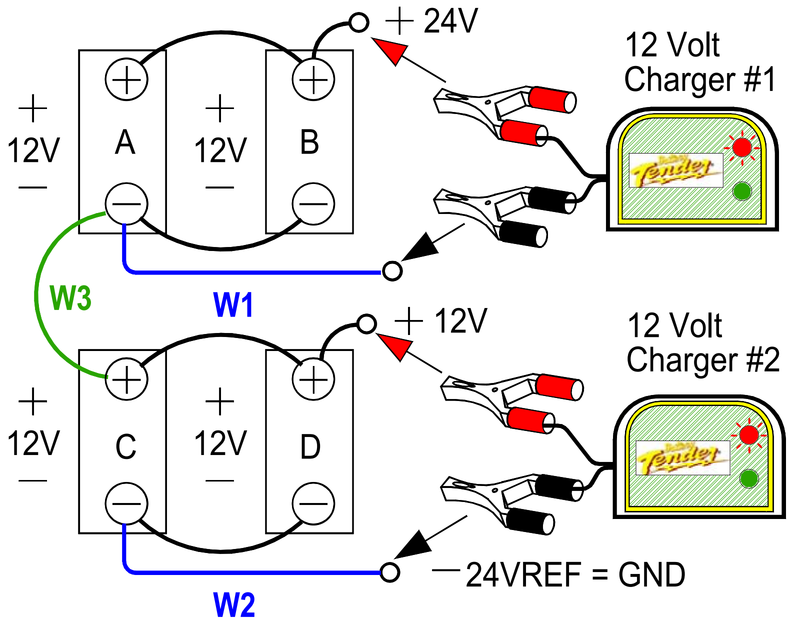


Figure 12 Four Batteries in Series / Parallel (Example 2), Two Chargers

Figure 13 shows the same 24 volt, 4 battery, series / parallel battery pack arrangement as in example 2, but with a single 24 volt battery charger. Because of the differences between the physical, electrical connections in the battery packs when comparing example 1 and 2, in one case it is acceptable to use either two 12-volt batteries or a single 24-volt battery. In the other case it is not acceptable.

If you ever have any doubts about the electrical connections between batteries and charging equipment, contact the battery and / or the battery charger manufacturer and make sure that you are making the connections correctly. That information can potentially save a lot of money and frustration.

Four Batteries in Series / Parallel (Example 2), One Charger

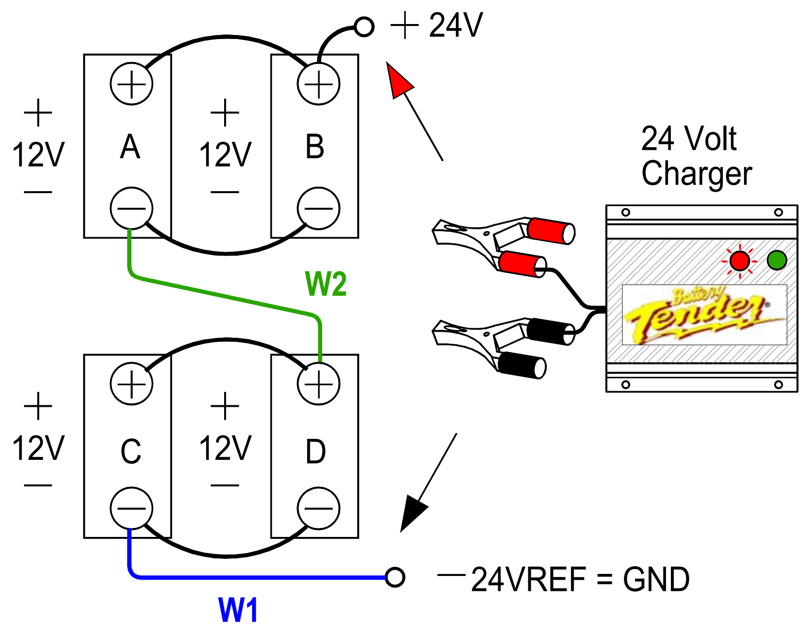


Figure 13 Four Batteries in Series / Parallel (Example 2), One Charger

Just one more comment about voltage imbalance while charging current is being applied. Figure 13 shows two wires highlighted, the blue one designated W1 and the green one designated W2. Interestingly enough, if the connection at battery D positive terminal is moved to battery C positive terminal, without changing the connection at battery A negative terminal, then a voltage imbalance will exist. Do a thought experiment. Take a pencil and trace the path of the charge current from the output, positive terminal of the 24 volt charger, through the wires, and the batteries, through W1 and back to the output, negative terminal of the 24 volt charger.

Now go back to Figure 12 and look at the green wire designated W3. With 2 independent chargers connected, the blue wires W1 & W2 correct the voltage imbalance that would exist in the individual, parallel connected battery packs. The green wire W3 does absolutely nothing in terms of charging the batteries. In fact, it can simply be removed because NO CURRENT flows through it while the two groups of batteries are being charged.