



BATTERIES AND CHARGERS CONNECTED IN SERIES & PARALLEL

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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.

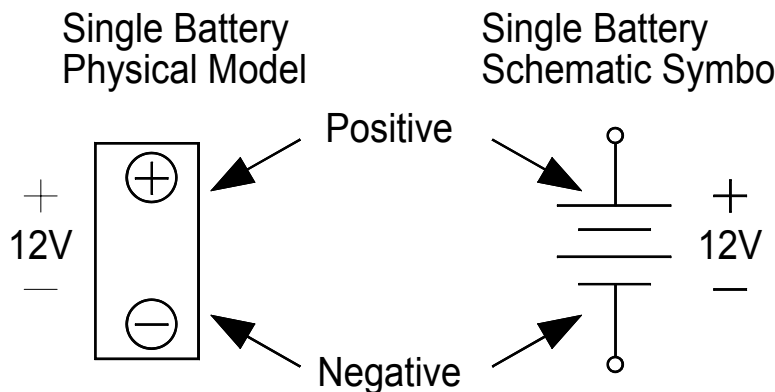


Figure 1 Single Battery Physical Model & Schematic Symbol



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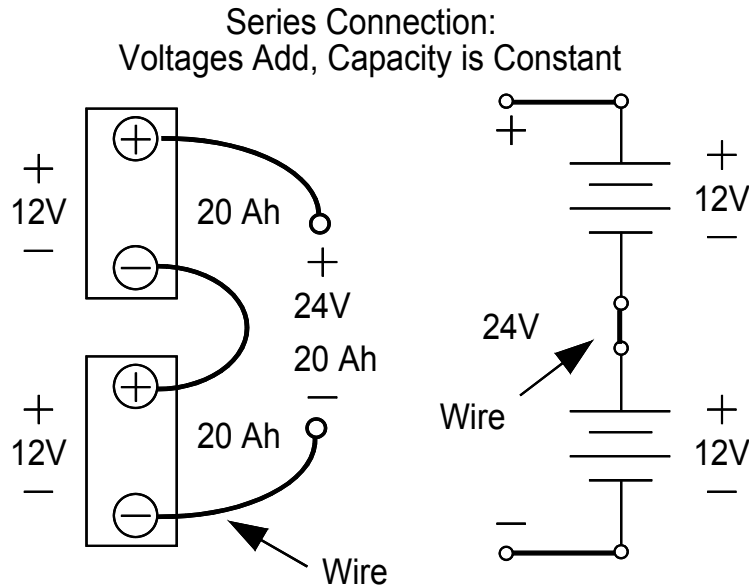


Figure 2 Batteries Connected in Series

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:

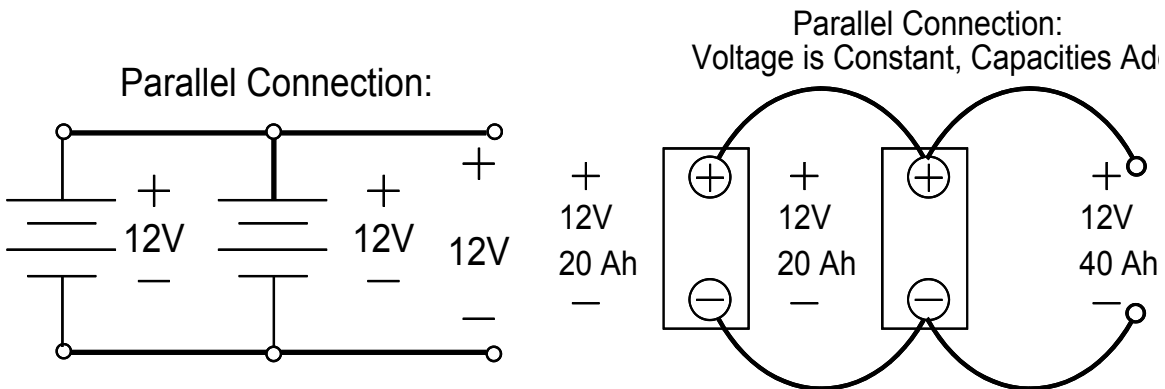


Figure 3 Batteries Connected in Parallel

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



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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.

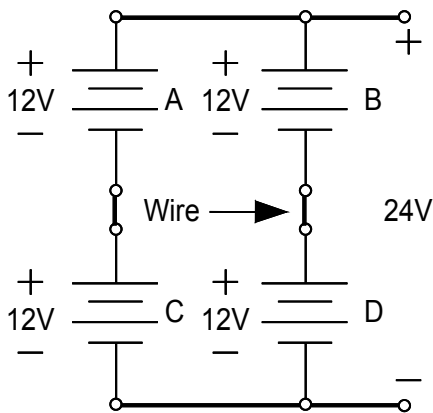
SERIES / PARALLEL CONNECTIONS:

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.

Series / Parallel Connections: Example



Series / Parallel Connections: Example 1

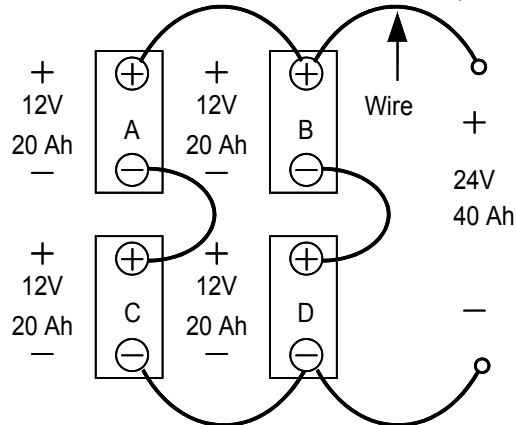


Figure 4 Batteries Connected in Series / Parallel: Example 1

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.



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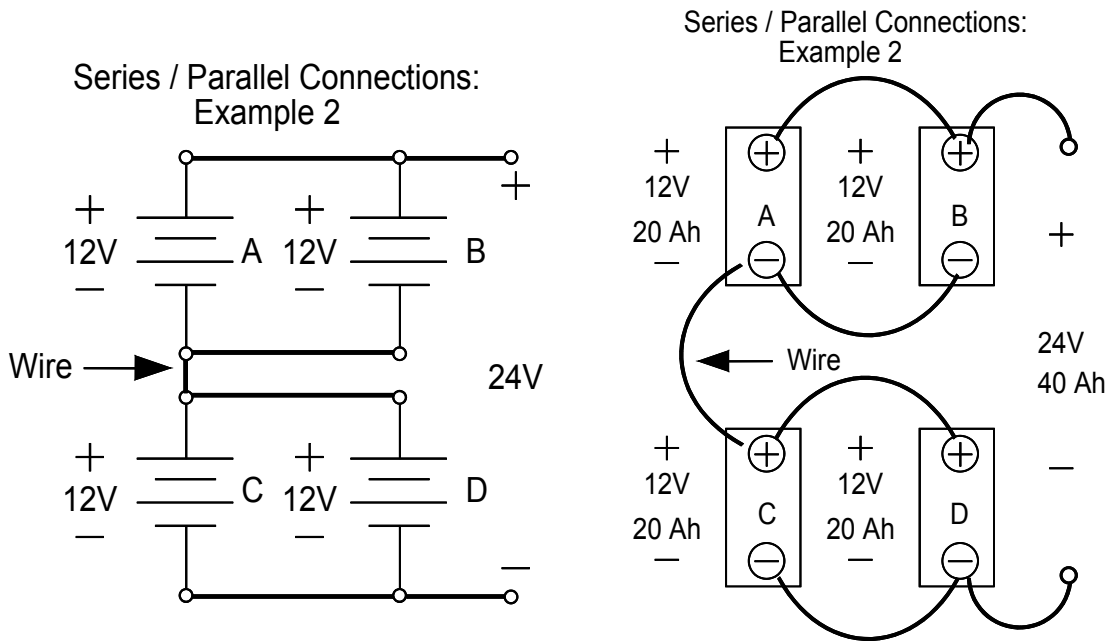


Figure 5 Batteries Connected in Series / Parallel: Example 2

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**

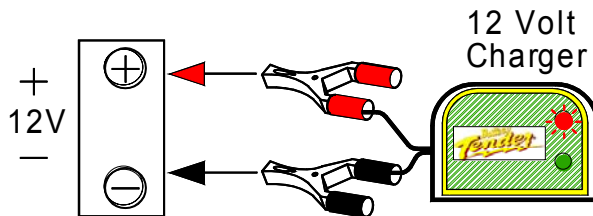


Figure 6 One Battery, One Charger

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.



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Two Batteries in Series, Two Chargers

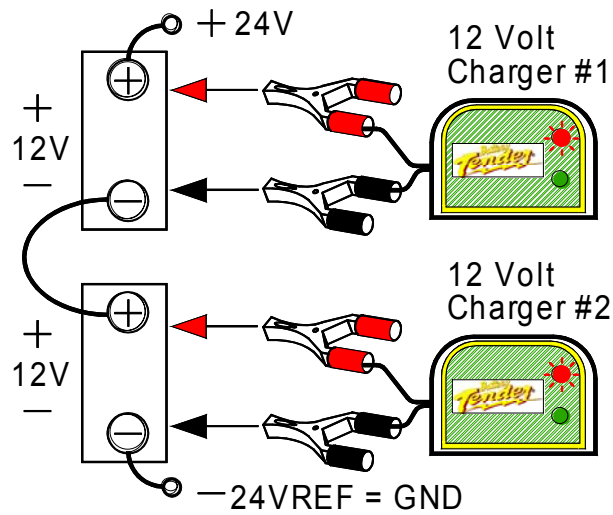


Figure 7 Two Batteries in Series, Two Chargers

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

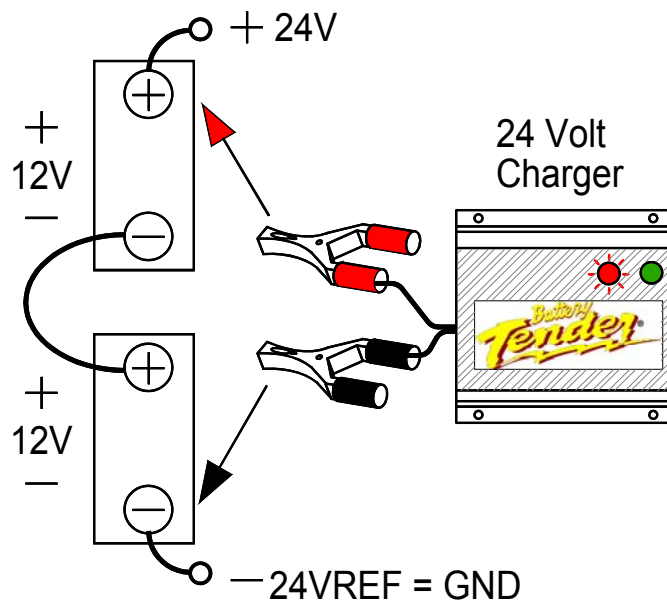


Figure 8 Two Batteries in Series, One Charger



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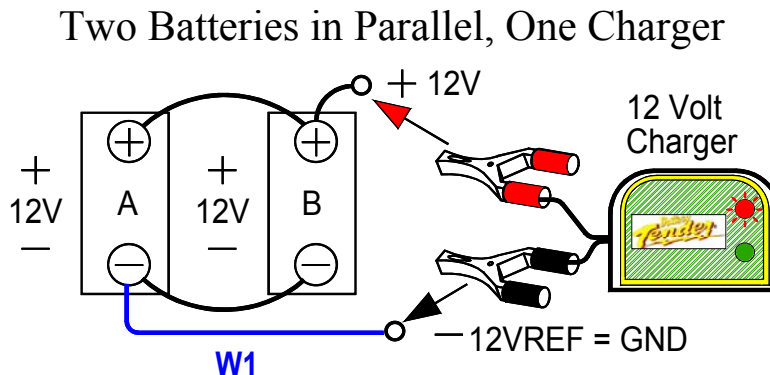


Figure 9 Two Batteries in Parallel, One Charger

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.



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Four Batteries in Series / Parallel (Example 1), Two Chargers
THIS ARRANGEMENT IS ABSOLUTELY NOT RECOMMENDED!

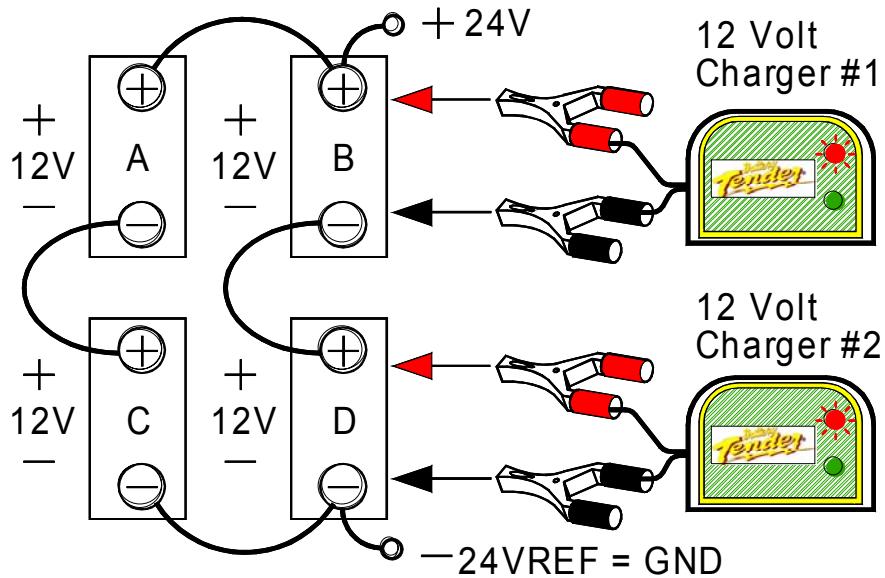


Figure 10 Four Batteries in Series / Parallel (Example 1), Two Chargers

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!**



BATTERIES AND CHARGERS CONNECTED IN SERIES & PARALLEL

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

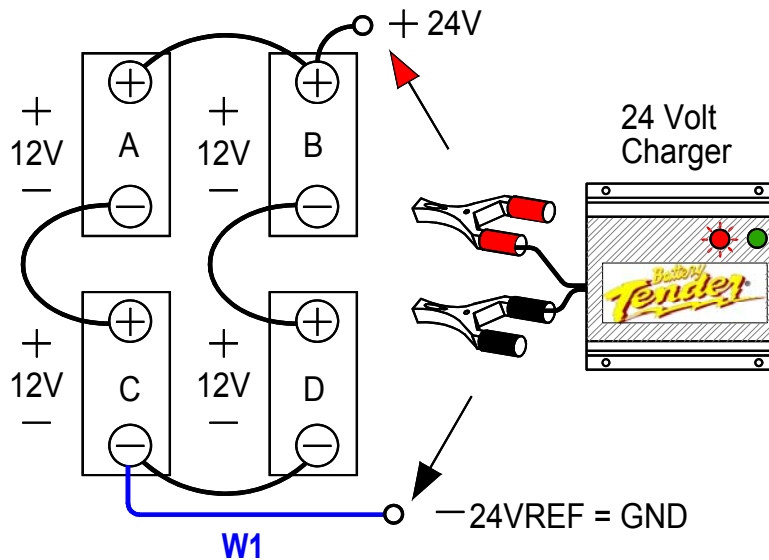


Figure 11 Four Batteries in Series / Parallel (Example 1), One Charger

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



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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

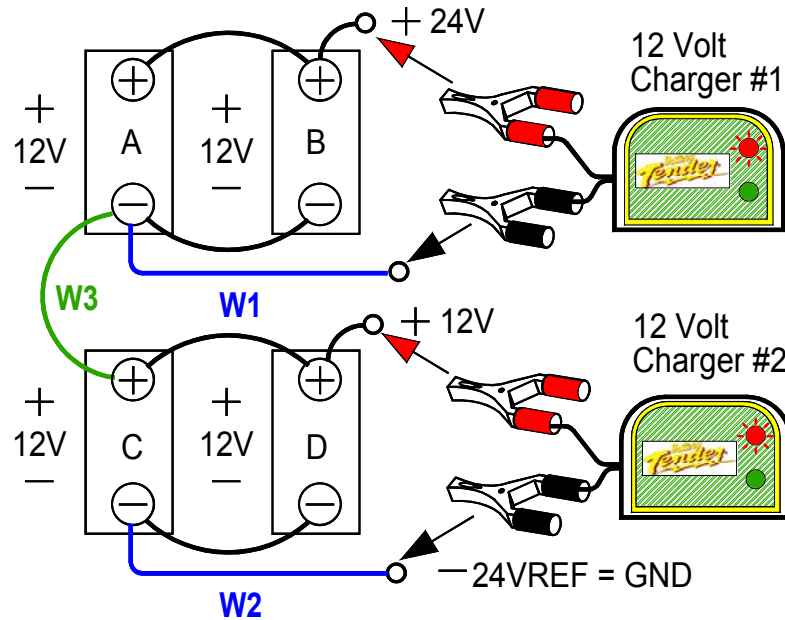


Figure 12 Four Batteries in Series / Parallel (Example 2), Two Chargers

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.



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

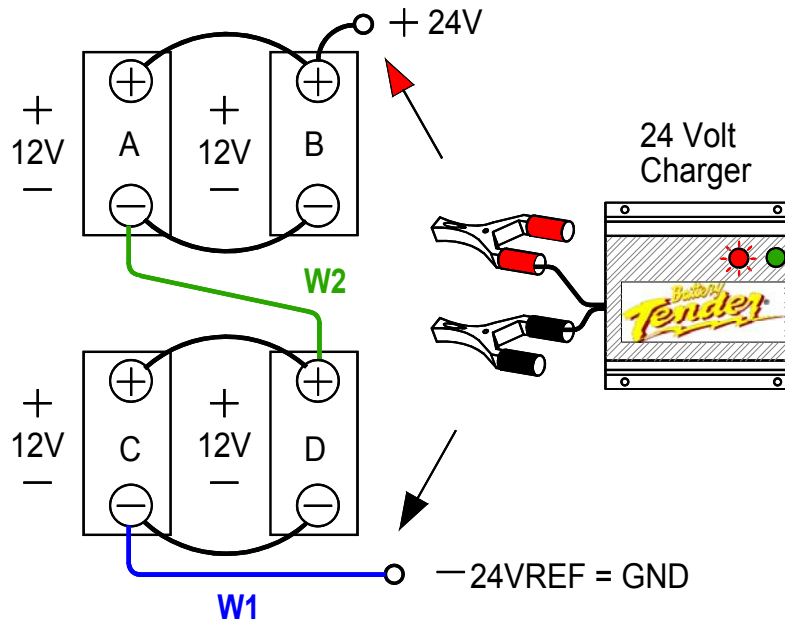


Figure 13 Four Batteries in Series / Parallel (Example 2), One Charger

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.