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12V

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In the context of our fieldwork in the Egyptian desert, we previously discussed some of the problems that can affect electronic devices in a particularly harsh setting (McPherron and Dibble 2003). A related issue, and one that is just as important, is how to supply power to those devices when the nearest electric outlet is miles away. Our solution to this problem has been to develop a system that works off of regular car batteries. There are many advantages to batteries: they are relatively inexpensive, they store a lot of power, they are relatively portable, and both batteries and chargers are available all over the world. Moreover, with the recent rise in popularity of recreational vehicles and boating, a lot of products have been developed for use with the kind of power—12 volt DC—that car batteries supply. Here we will present some basics of how to use them in the field.

Understanding Electrical Power

One concept that is fundamental to understanding how to provide power to electronic devices is the direction of the current, which is either one-way (direct current, or DC, which has both negative and positive poles) or two-way (alternating current, or AC). For our purposes, we can say that DC current is the type provided by batteries, while AC current is what you find in common wall electrical receptacles. Most devices that consume a relatively greater amount of power, such as computers, printers, and so forth, work with AC; smaller devices often expect DC current. Also, with AC current, each change from one direction to the other and back again is called a cycle. Most alternating current is generated at 50 or 60 cycles per second, or hertz (Hz). When connecting devices to DC current, it is important to make sure that the polarity (negative or positive) is correct, just as you do when putting new batteries into an electronic device. Polarity with AC current is more complicated depending on whether it is 2-wire or whether there is an additional ground wire. As a general rule you should be consistent and not flip the two lead wires, but the consequences are typically less severe than in DC where it can easily result in damaged equipment.

There are three other important concepts that you should also understand, namely volts, amperes (amps), and watts, which work together. It is really very simple to understand them if you think of electricity as water running through a hose. With this analogy, the wire is represented by the hose itself, volts represent the force or pressure causing the water to flow, amps represent the speed or rate (current) of the flow, and watts represent how much water is used per unit of time, or the actual rate of power consumption. In this analogy, a battery is a water reservoir. The size of this reservoir equals the capacity of the battery. Volts, amps, and watts are all directly related to each other. In a DC system, multiplying amps by volts equals the number of watts. Thus, a device that uses 10 amps and runs on 115 volts consumes 1150 watts.

Electrical devices expect current with a specific voltage, and it is important to make sure that the power you supply conforms to the device's expectations. When using AC current in the US, the typical voltage is 110–120, running at 60 Hz. Many other countries use 220–240 VAC (volts AC), at 50 Hz. Different voltages are also common among DC appliances, with typical standards being 6, 12, or 24 VDC. Car batteries are usually 12 VDC, though some similar looking batteries, such as for motorcycles or golf carts, can be 6 VDC. For our purposes here we will assume a 12 VDC configuration.

Basics of Car Batteries

To some extent, all car batteries look and act the same. Because they are DC, they all have two connectors, usually at each end, with one of them marked Positive (+, and often color-coded in red) and the other Negative (–, often color-coded in black). When fully charged they will output between 13–14V, and when fully discharged the voltage will drop to about 11V, so the 12V can basically be understood as an average. There are some significant differences among different batteries, however, besides their voltages.

The first of these is their capacity, or how much energy they hold. Since there is a specified voltage, battery capacity is meas-

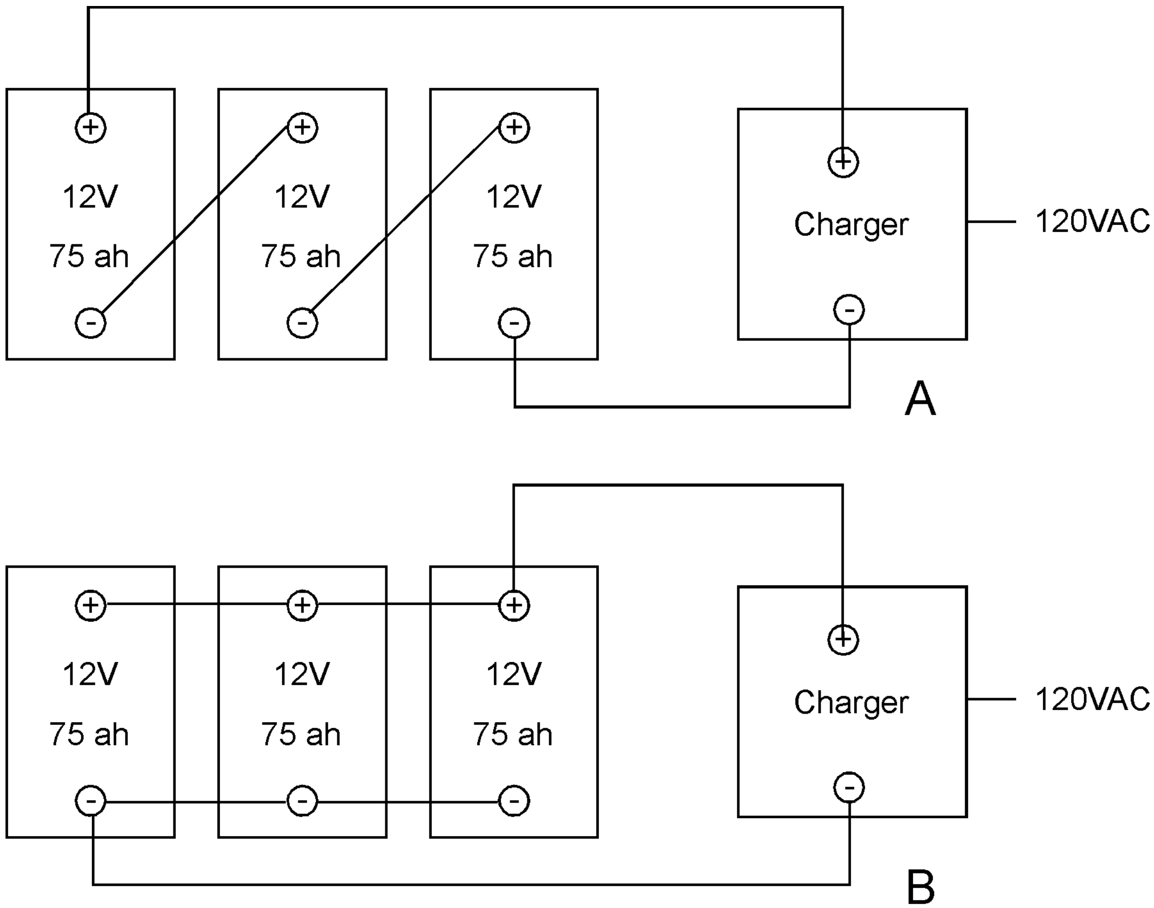

Figure 1. A. Three batteries wired in series, which results in 36 volt output, but with a total capacity of 75 amp-hours. B. Three batteries wired in parallel, which results in 12V output and a total capacity of 225 amp-hours.

ured in amp-hours; with a 100 amp-hour battery, you can ideally draw 1 amp over a period of 100 hours, or 10 amps over a period of 10 hours. Multiplying the number of amps by 12 (the number of volts) will give you the total number of watts a battery can provide. Batteries vary considerably in the capacities, but in general, the larger the capacity, the larger the battery.

The second consideration is whether they are sealed or unsealed, which refers to the presence or absence of small removable caps over the individual cells of the battery. If the battery is to be moved frequently, a sealed one might be an important consideration because the liquid sulphuric acid, which can cause severe burns, is less likely to leak. Dry-cell batteries, which are not typical for car batteries, are perhaps the best solution, though they are considerably more expensive than standard wet cell batteries, and, depending on where you are working, may not be easy to obtain locally.

There are many other considerations that could be taken into account when buying batteries, but they are not of major significance to archaeological uses. Most of them have to do with the useful life of the battery, since factors such as temperature, length of storage, total number of charge/discharge cycles, and degree of discharge all adversely affect how much use you will get. But in our experience, especially if they are used in fieldwork situations that take place over a limited number of weeks per year, it is often better just to assume that the batteries will function for only one or two seasons (it's the downtime during the off-season that does them the most harm), and therefore you may want to buy the cheapest possible.

It is possible to wire several batteries together and thereby change their characteristics. There are two simple methods: series and parallel (see Figure 1). Wiring two or more batteries in series, meaning that the positive pole of one is connected to the negative pole of the other, adds up the individual voltages of each battery, but keeps the total capacity equivalent to only one of the individual batteries. So, for example, wiring three 12 V, 75 amp-hour batteries in series creates a more powerful battery (36V), but it still provides this power at the same rate as a single battery (75 amp-hours). Parallel wiring, or connecting the batteries negative to negative and positive to positive, will keep the total voltage the same, but the total capacity will be equal to the sum of the capacities of the individual batteries. So, the same three 12 V, 75 amp-hour batteries wired in parallel would produce a power source that still outputs 12V but can provide this power at a much greater rate (225 amp-hours). Note that in each case the watts stay the same (2700 watts). Parallel wiring is an important way of getting the total capacity that you need while still keeping the sizes of your individual batteries within transport limits. Keep in mind that when connecting batteries you should use virtually identical batteries of the same age.

Charging Car Batteries

Of course, depending on how much current you are using, batteries will only last so long and so you have to consider how they will be charged in the field. Basically, charging a battery involves connecting it to a charger that produces more voltage than is in the battery itself, which then allows power to move from the charger to the battery. Thus, a charger might output 15 V to charge a 12 V battery; increasing the charger's output voltage results in a faster charge (though this is more harmful to the battery and can be very dangerous), while lower output voltages take longer to charge the battery and are generally better for the battery. To maximize your battery life, and to take the guesswork out of charging, one option is to get a multiphase charger that automatically decreases the output voltage as the battery gets closer to its maximum charge.

Charging is more complicated if multiple batteries are wired in series or parallel. In general, you still want to roughly match the voltage. So, if three 12V batteries are in series, you can charge them with 36V or just over, but if they are in parallel you should treat them as a single 12V battery. However, if you plan on charging multiple batteries, you should purchase a battery charger specially designed to do so as it will have extra options that allow it to be properly configured for different charging situations. As stated above, be sure to read the manual and take care to both set the charger correctly and attach the charger to the batteries correctly depending on their arrangement.

It is possible both to overly discharge and overly charge a battery, and you should take care to avoid either. To increase battery life, try to avoid discharging to a point less than 40 percent of the rated capacity. To see when you have reached that point you can measure the amount of voltage in your batteries using a voltmeter. Voltmeters with digital readouts accurate to at least a tenth of a volt are the best, and will give you a much better reading than ones with a needle gauge. A fully charged battery (with the measurement taken after disconnecting the charger and letting the battery discharge a bit) should produce about 12.7 V, and a battery that is discharged to 40 percent capacity should produce about 11.9 V.

Assuming that you do not have access to standard AC current, there are three alternatives for charging a battery: a generator, solar panels, or wind turbines. Generators are relatively inexpensive, can be purchased in any country, and run on locally available fuel, thus making them a good choice. Solar and wind are more expensive options and, of course, require environmental conditions suitable for their use. You do have to be sure that the power output by the power generator is greater than what you will be using, and so compare the total output wattage of the generator to the total wattage you will consume (see below).

What Can be Connected to a Car Battery?

The answer to this question is: virtually everything. Of course, the more power you consume, the more power you need to generate and store, so the goal should be to have enough power on hand to allow you to accomplish only what you really need. Remember too that some things are exceptional power consumers, while other items cost very little to run. And it is very important to maximize efficiency wherever possible.

Surprisingly, even though most electronic devices plug into standard AC outlets, many will also work on 12VDC. Among these is anything that can get power through the cigarette lighter plug in a car, including many different kinds of battery chargers for portable devices (such as cell phones, GPS units, and the like), computers that have cigarette lighter power adapters, and even portable electric coolers. To connect these to a car battery only requires that you purchase a 12V "female" cigarette lighter outlet that clamps onto the terminals of the battery, and then insert the "male" plug of the device into it. You can also buy 12V "power strips," which have one male plug and three or more female outlets, thus allowing you to connect several devices at once.

For devices that require AC current, the best option is to purchase a power inverter, which changes the 12VDC current from the battery to 120 (or 240) VAC, and which includes a standard 2 or 3 pin outlet exactly like the ones in your home. This is an easy solution, though not as efficient as a direct 12V connection, since the inverter wastes about 10-15 percent of the power coming through it. You also have to make sure that the inverter produces enough power to operate the maximum draw on it at any one time.

Figure 2. Power station for the ASPS project (Abydos, Egypt). To the right is a 12v battery charger that can be configured to charge up to five car batteries. To the left are a set of car batteries wired in parallel. A power inverter (the circular object in the upper left) is used to generate 220v for the power strips seen in the photo. The remaining items (IPaq computers, walkie-talkies, and rechargeable AA batteries) are charged directly from 12V.

Many devices, such as lights and pumps, can be wired directly to the battery. You need to use two wires—one for the negative and one for the positive—and for each of these wires connect one end to the proper pole of the device and connect the other end to an alligator clip that can clip onto the respective terminal of the battery. When joining two wires, remove a 1/4" of insulation on the each of the ends, and then connect them using a wire nut.

In all cases, you do not want to run excessive lengths of wire. Think back to the water in a hose analogy that was described earlier, though imagine that the hose has a number of small leaks in it. These leaks represent the natural resistance in the wire, which means that you lose more power with longer wires. However, how much you lose is also affected by how thick your wire is (thicker wire loses less power per foot than does thinner wire), and the percent of loss goes up exponentially with the amount of power going through the wire. Typically, if you use wire that is 14 AWG (approx. 1.5 mm in diameter, not counting the insulation), and you are pulling 2 amps, you start to lose more than 2 percent of your current once you exceed 20 feet in length. This means that you want to be careful in setting up your field situation so that your batteries are as close as possible to the devices they are connected to. Keep in mind too that 12V requires thicker wire to pass along the same amount of amps than would be needed for 120V, so you should use at least 12–14 AWG wire for most applications.

Adding up Your Power Needs

It is relatively simple to calculate your total power needs. Almost every electronic device is documented with how much power it consumes, and it is usually expressed either by total watts or amps. Keep in mind that if the consumption is given in amps, you must multiply this by the voltage to get the total watts. If you are going to use an inverter to power an AC device, then multiply the number of watts by 1.15 to take into account the loss of power in converting from DC to AC. Then multiply this by the number of hours per day that you will be using the device. Totaling these watt-hours for all of your devices will give you an overall total of your needs. You should then add an additional 20–30 percent because of losses due to overall inefficiency throughout your system.

To calculate your required battery capacity, you will need to decide how long between charging cycles. If it is daily, then

	Quantity	Amps	Volts	Watts per Unit	Total Watts	Inverter?	Corrected Watts	Daily Use (hrs)	Total Watt Hours per day
Shower Pump	1	2.5	12.0	30.0	30.0	no	30.0	0.5	15.0
CF Lights (continuous)	2	0.8	12.0	15.0	30.0	no	30.0	5	150.0
CF Lights (intermittent)	2	0.8	12.0	15.0	30.0	no	30.0	1	30.0
Big Laptop Computer	1	6.7	19.5	130.7	130.7	yes	150.2	6	901.5
Small Laptop Computer	1	2.5	16.0	40.0	40.0	no	40.0	6	240.0
GPS charger	3	0.2	5.0	0.8	2.3	no	2.3	8	18.0
Cell Phone charger	1	1.5	4.4	6.6	6.6	no	6.6	3	19.8

Note: CF = compact fluorescent

Total watt-hours per day	1374.3
Add 20% for inefficiency	274.9
Total capacity needed (watt-hours)	1649.1
Total capacity needed (amps-hours)	137.4
Amp-hours per battery	80
60% Available for use per battery	48
Total Batteries needed	**3**

divide the total watt-hours by .6 (representing a maximum discharge of 60 percent of capacity), which gives the rated capacity of the battery in watt-hours. Dividing that by 12 (the number of volts) gives you the total amp-hour rating. If this total required capacity exceeds the individual capacities of your available batteries, then divide the total amp-hours by the amp-hour rating of one battery to calculate the total number of batteries that, when wired in parallel, will yield the total required capacity.

In Table 1 above, most of the devices can run directly off of 12V, with the exception of the "big" laptop computer, which must be supplied with AC current through an inverter (12V chargers can be purchased separately for many brands of laptops and this is definitely worth investigating in this context). Notice too that some of the devices have voltages that are different from 12V—this is because the power supplies for them convert the voltage according to the needs of the device. So, when looking at the power supply to determine the power consumption, you might see something like this: OUTPUT: 16V = 2.5A, which computes to a total of 40 watts (16 volts times 2.5 amps).

One hidden and potentially complicating issue to the calculations listed here is that some modern electrical devices, especially computers, include special power sensors designed to protect them in cases where the power goes too high or low. What this means is that you may not be able to drain your car batteries to 40 percent of usable capacity before, for instance, a laptop power supply decides the power is unusable and shuts off. Power inverters are also subject to the same problem. Lights and electrical motors, on the other hand, are typically much better at accepting variable power: though too much power may pop a light or burn out a motor, low power typically results only in a dimmer light or a slower motor. On a related point, generators do not necessarily produce power that is stable enough for some equipment (for instance, desktop computers) and small fluctuations in the output from a generator can trip the power sensors. One solution is to use a power regulator, though these can be heavy and expensive. Another approach is to use the car batteries as the regulator. Thus, if you are having this problem when using a generator, connect the sensitive equipment to the car batteries (even if a power inverter is required) rather than directly to the generator.

It is easy to see from the table how power consumption adds up quickly, and so it is a good idea to conserve as much power as possible. Obviously lights and other devices should always be turned off when not in use, but the biggest power consumer will almost always be your computer. With laptops there are a number of ways to reduce their power consumption, including dimming the brightness of the screen, turning off wireless connectivity if it is not being used, and configuring their power management options to shut down completely the display, hard drive, and CPU when they are not used for a period of time. Simply putting them into standby mode, or shutting them down completely, when not in use will also save a considerable amount of power. If possible, it is a good idea to charge your computer directly from the generator when it is running, and then run it from its own battery power when the generator is shut down. This way you will not unnecessarily drain your main batteries.

Special Projects

1. LIGHTS. Electric lights can be a much safer alternative to kerosene lanterns and can be surprisingly efficient when working with 12VDC power. We all know how much power normal

Figure 3. The shower setup as described in the text.

incandescent lights use—a 60 watt light bulb consumes 60 watts. This is normally not considered to be a lot of power, but when running off of batteries, it can add up quickly. So, if we have one 100 amp-hour battery, then it has a total capacity of 1,200 watts, but remember that only 60 percent of that should be used before recharging. That leaves 720 watts for our light, which means that it can burn for 12 hours before we need to recharge the battery. Compact fluorescent lights are a much better alternative, since the equivalent amount of light can be produced with only 15 watts—using this bulb in the place of the incandescent one would allow us to go 48 hours before the battery should be recharged. An 18-LED unit may draw less than 200 milliamps, using 2.4 watts, allowing for 300 hours of use before recharging. We have not tested LEDs in the field yet, but the technology has been in use for flashlights and headlamps for several years. While such units are still relatively expensive, LED lights are expected to become even more efficient and more widely available in the future.

Watts refer to the amount of electricity used, but when calculating your lighting needs you should compare the amount of total light output by the bulb, as measured in lumens. An average 60 watt incandescent bulb produces 900 lumens of light, or about 15 lumens per watt. A 1.2 watt LED bulb, which is much more efficient (producing over 300 lumens per watt), may only output a total of 375 lumens, or about the same as a 25 watt incandescent. Thus, the total amount of light output per bulb can vary considerably and you will need to make sure you bring along a sufficient number (plus backups) for your needs.

Most 12V lights (including incandescent, compact fluorescent and LED lights) have "edison" screw-type mounts that can go into normal (and locally available) light fixtures. Keep in mind, however, that the bulbs themselves are different than normal AC types, even though they have identical mounts.

2. CAMP SHOWER. We've tried solar showers in the Egyptian desert where they should be ideally suited, but we came away less than enthusiastic about them. The main issue is that as soon as the sun sets the heat in the water is quickly lost. This last season we tried building our own hot showers. We heated water in large (50 liter) aluminum pots on propane burners, and then used a small electric pump to bring the hot water into the shower through a standard showerhead. All that is needed is a 12V submersible pump and a waterproof switch. Mount the switch inside the shower area, and connect one terminal of the switch to the positive wire coming from the battery and connect a wire from the other switch terminal to the positive terminal on the pump (the negative, or ground wire, can run directly from the pump to the negative battery terminal or other suitable ground). Then place the pump in the water, flip the switch in the shower, and enjoy a hot shower in the field. By restricting showers to a maximum of 60 seconds of running water (turn on water for 10 seconds to get wet, turn off water and soap up, then turn water on again for 50 seconds to rinse), each shower uses about 4 liters of water and only one-half watt of power.

Final Comments

None of what we have presented here is terribly complicated but there are lots of small issues that if not addressed can cause serious problems. Since most modern excavations are dependent on electrical devices, it is very important to find and solve potential issues before going into the field. We stress that, to the extent possible, all systems should be fully tested prior to going into the field. While this is obvious advice, it is amazingly easy to short cut the testing process, test parts independently of each other, to assume that new parts will work out of the box, and to discover in the field that key pieces are missing or do not work quite as predicted.

Even with testing, in a complicated system, some parts will likely not work at all, will not work like you expected them to, or will fail at some point. Again, if the project is dependent on this equipment working, you need to have backup solutions. For instance, even if you think the whole project can be done on 12V, bring a few extra power inverters so that if you have to, you can use standard 110/220 power. If you use multiple examples of the same piece of equipment (e.g., GPS units, digital cameras, laptops), try to buy exactly the same model so that parts, and particularly power supplies, are interchangeable. Where possible, buy equipment that works on standard batteries and not proprietary ones. For instance, buy digital cameras that work on AA batteries, and even if you plan on using rechargeable AAs have a supply of standard AAs just in case. If you have equipment that works on special batteries, like calipers, take extras with you. Don't count on purchasing nonstandard batteries where you do your fieldwork.

You will also need a good tool box. Stock it with pliers, wire cutters, extra wire, extra plugs, alligator clips, electrical tape, and a good digital volt meter. It is also a good idea to have a soldering iron. While the latter can be purchased to work on 12V, remember that you might need it to make your initial 12V system work; in that case, you might want to have one that works on standard 110/220V.

Finally, we need to note that electricity can be dangerous (though perhaps less dangerous than many other things archaeologists do routinely in the field), and it is best to be informed and proceed cautiously. Remember too that assessing the danger can be complex. The shock you receive after walking across a carpet and touching a metal doorknob can involve over 10,000 volts but the amperage is very low and the duration quite short. Alternatively, car batteries produce only 12 volts but enough power to cause serious injury depending on the context. In the example given above, the electrical switches in the showers are quite safe (even if the water-proofing fails) because the voltage used by the electrical motors is so low.

We also need to stress that working with lead-acid car batteries is dangerous. Above all, there is the real danger of spilling sulphuric acid on someone or something—in either case, the results will be bad. Batteries produce hydrogen gas, which can explode if exposed to a spark or flame, and they can explode if they are charged too quickly and gases are not allowed to vent. You can also create a bad spark by shorting the output terminals of a battery—always attach positive to positive first, then the negative to negative (and be sure to clearly mark your cables as to which is which), and connect the cables to the battery first and the device drawing power from them last, so to minimize the chance of a spark near the batteries. Always put the batteries in a well-ventilated area, wear safety glasses and protective clothing when working with them, and, above all, exercise caution.

Finally, care must be exercised before connecting power to many electrical devices—particularly computer equipment. Many of today's devices have sophisticated systems to protect them from bad power (say, for instance, the polarity of the DC source is reversed) but this is not always the case. Too much power (24V when 12V was required) can easily, irreversibly damage an electrical device. Be sure to always verify and test your work, preferably with a volt meter, prior to connecting devices, and never leave wires exposed, even temporarily, as they can easily come together and produce a short that could be both dangerous and harmful to the equipment.

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