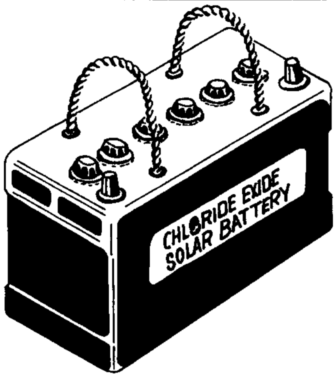
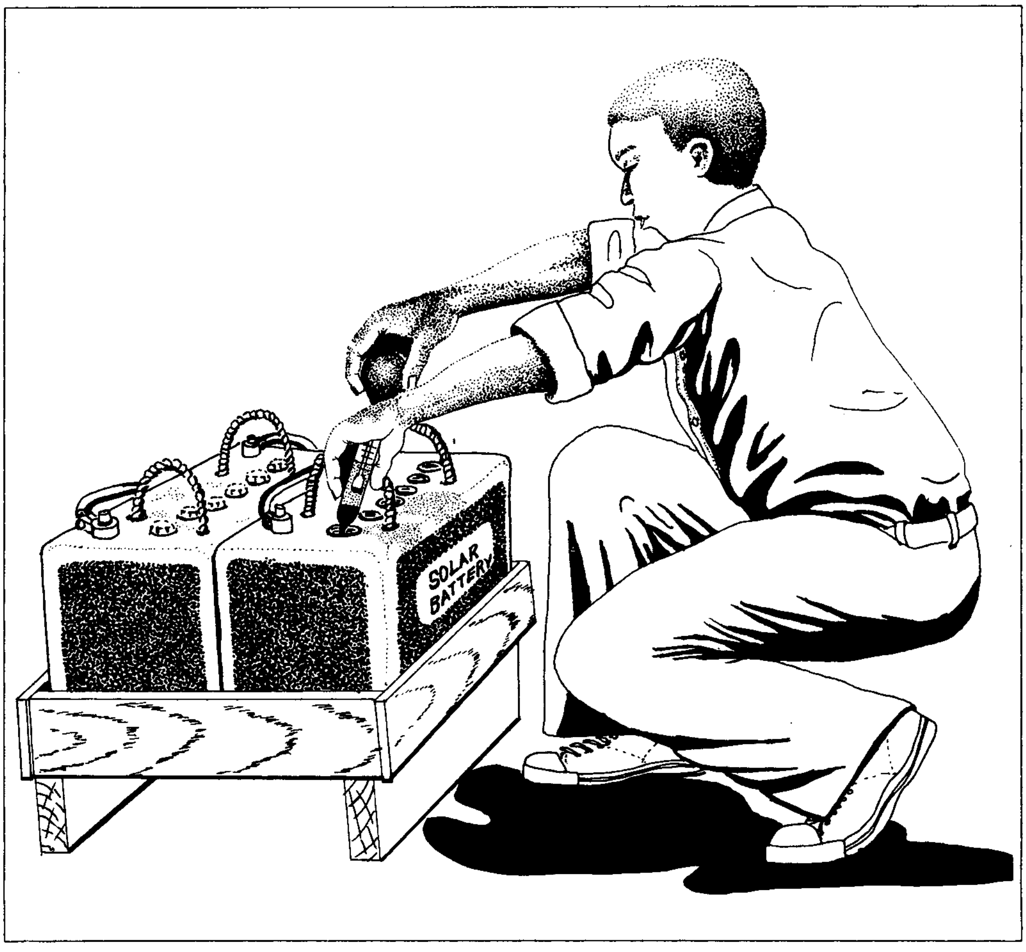
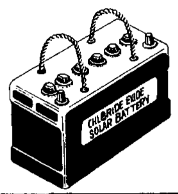


Chapter 4
Batteries

This chapter provides information about rechargeable batteries which are used for storing solar charge. Principles and operation of lead-acid and nickel-cadmium batteries are outlined. Battery concepts discussed include storage capacity in amp hours, charge and discharge, state of charge, cycle life, depth of discharge, and self discharge. The problems caused by deep discharge and overcharging of batteries are discussed in detail, and types of batteries available in East Africa are presented. The practice of battery management and maintenance is introduced (together with a description of the tools needed).





Batteries

Energy Storage Theory

Solar cell modules generate electricity *only when the sun is shining*. They do not store energy. If solar electric power is used to pump water into a storage tank, there is no need to store the energy from the modules because the pumped water is stored in a tank while the sun is shining. Unfortunately, this is not the case with solar electric lighting systems. Electric lights are required when the sun is *not* shining, so it is necessary to find a way to save the electric power generated during the day so that it is available at night.

A battery is like a tank for electric energy. It is impossible to remove more energy from the battery than was put in by charging.

The most obvious answer to this problem is to use *batteries*, which chemically store electric energy. Other proposed solutions to energy storage include flywheels (which store energy in rotating wheel-like masses), compressed air, and pumped water. Today these are neither practical nor economical for small systems. In fact, all of the stand-alone PV lighting and refrigeration systems installed in East Africa use some type of battery system to store their harvested solar energy.

Stated simply, a battery is like a tank for electric energy. The solar array collects solar energy, producing an electric charge as long as the sun is shining. The charge travels through wires into the battery where it is converted to stored chemical energy. Over the course of several days, a battery may 'fill' with stored energy like a water tank 'fills' with water collected from the roof top gutters.

Note that it is *impossible* to remove more energy from the battery than is put in by charging. As is the case with the tap of a water tank left open, if an appliance is left ON by accident, electricity will drain from the battery. Batteries operate like energy bank accounts. From the bank, as with batteries, you can never get something for nothing. You cannot take out more energy from a battery than was put in. Like a bank account as well, the long-term benefits from a battery are greatest when a large amount of energy is kept in the battery.

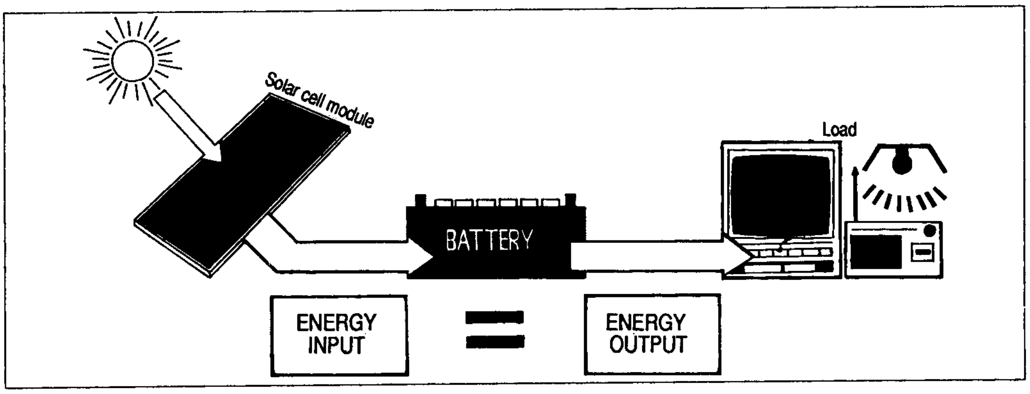


Figure 4.1 Energy input from the solar module must balance the energy output to the load.

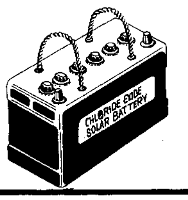
As a battery is charged, electric energy is stored as chemical energy within the battery cells.

Battery Principles and Operation

Batteries are groups of *electrochemical cells* (devices that convert chemical energy into electrical energy) connected in series. Battery cells should not be confused with solar cells, which operate according to completely different principles. Battery cells are composed of two *electrodes* (also called plates) immersed in *electrolyte* solution which produce an electric current when a circuit is formed between them. The current is caused by reversible chemical reactions between the electrodes and the electrolyte within the cell.

Some cells can only be used once (i.e. dry cells) while others can be recharged over and over again (these are called *accumulators* or *secondary batteries*). Because dry cells available in shops cannot be recharged, this chapter is concerned with rechargeable secondary batteries only.

As a battery is charged, electric energy is stored as chemical energy within the cells. When the battery is being *discharged* (i.e. when it is connected in circuit with a load), stored chemical energy is being removed from the battery and converted to electrical energy.



Batteries

Nicad batteries have some advantages that should be considered when planning small systems.

The two most common types of secondary battery systems on the world market today are *lead-acid* and *nickel-cadmium* batteries. In East Africa, lead-acid batteries are far more readily available than nickel-cadmium batteries (also called *nicad* batteries, for short), but nicads are used in a number of installations. Nicad and lead-acid batteries contain different types of electrodes and different electrolyte solutions.

As indicated by its name, the lead-acid battery operates on the basis of chemical reactions between a positive lead dioxide plate (PbO_2), a negative lead plate (Pb) and an electrolyte composed of sulphuric acid (H_2SO_4) with water (H_2O). When a battery is being charged, lead dioxide accumulates on the positive plate, spongy lead accumulates on the negative plate, and the relative amount of sulpuric acid in the electrolyte increases. When the battery is being discharged, lead sulphate ($PbSO_4$) accumulates on the negative plate, and the relative amount of water in the electrolyte increases (see chemical equation below). Each cell in a lead-acid battery has a voltage of about 2.0 volts.

Chemical Equation for Lead-Acid Battery Charge and Discharge:

$$\xleftarrow{\text{Charge}}$$
$$Pb + PbO_2 + 2H_2SO_4 \Leftrightarrow 2PbSO_4 + 2H_2O$$
$$\xrightarrow{\text{Discharge}}$$

Nicad batteries operate on the basis of similar chemical reactions between the positive nickel hydroxide electrode and the negative cadmium hydroxide electrode in a potassium hydroxide electrolyte. Each nicad cell has a voltage of about 1.3 volts.

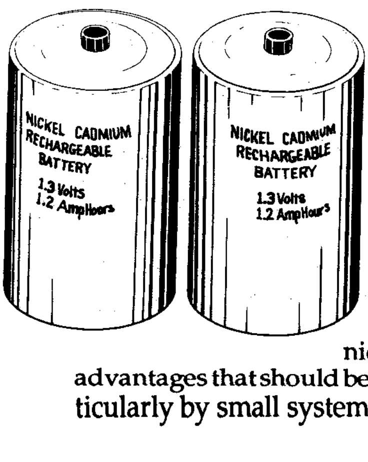


Figure 4.2
Rechargeable nickel-cadmium cells. Such cells can be connected with solar modules and used to power radios and torches.

Nicad Batteries
Nicad batteries are more expensive per unit of storage than lead-acid batteries; for this reason most installations choose lead-acid batteries. However, nicads have some advantages that should be considered, particularly by small system planners:

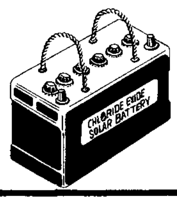
- Nicads are lighter and available in smaller sizes. Nicads, sized like dry cell batteries, can be used to power appliances such as radios, cassette players and torches.
- They can be completely *discharged* without damage to the cells, and they can be left for long periods in a low state of charge (see page 28). In very small systems without charge controllers, this is an important advantage.
- Nicads can be operated over a wider range of temperatures than lead-acid batteries.
- Nicad batteries require less maintenance than most lead-acid batteries, an important consideration at sites where the system maintenance is a problem.
- Finally, nicad batteries have a very long life compared to lead-acid types. Locally available 1.3 volt cells (packed like dry cells, see Figure 4.2) have a calender lifetime of between 3-4 years when used in solar electric systems. Larger nicad batteries may last longer than 10 years.

Assembly of nickel cadmium batteries has been carried out on a limited basis in East Africa (i.e. for Kenya Railways by Associated Battery Manufacturers, Nairobi). However, at present the demand for such batteries is far too low to justify the high cost of production. Furthermore, cadmium is a very poisonous chemical, and the environmental problems posed by large-scale manufacture and use of such batteries must also be solved before production begins.

Lead-acid Batteries
The discussions that follow in the next several sections concern lead-acid batteries. Where nicad batteries differ significantly from lead-acid batteries, the point is made.

Lead-acid Battery Hazards:

- **Lead-acid batteries contain corrosive sulphuric acid. If spilled, sulphuric acid will burn the skin or eyes; it will burn holes through clothes and furniture, and it will damage cement floors.**
- **If acid is splashed into the eyes, rinse the eye continuously for 10 minutes with clean water. Then take the affected person to the hospital for further treatment.**



The amount of energy that a battery can store is called its capacity, and is indicated in amp hours.

You should never use the full capacity of a lead-acid battery, as this will damage its plates.

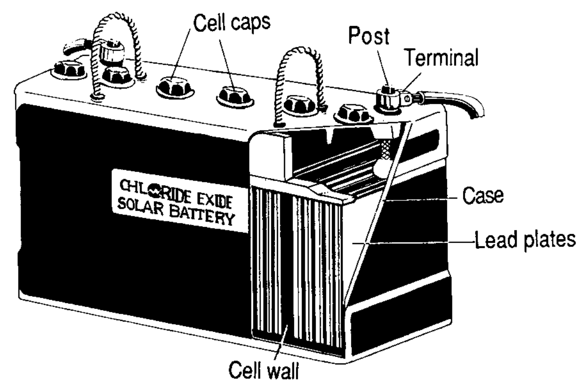


Figure 4.3 Parts of a lead-acid battery

- If acid gets splashed on skin wash immediately with plenty of water.
- If acid spills on the floor, rinse the floor with water, and pour "chapa mandazi" (bicarbonate of soda) on the acid.
- Batteries give off explosive hydrogen gas when they are being charged. This gas must be vented away from the battery to prevent explosions. Do not smoke or carry open flames in battery storage rooms.
- Batteries contain a large amount of energy. Make sure nothing can accidentally be placed across the terminals. If the terminals are shorted, they could cause a bad shock, or a fire.

There are many types of lead-acid batteries, which fall in two general categories: *deep discharge* and *shallow discharge*. Deep discharge batteries are preferred for solar electric systems because more energy can be taken out of deep discharge batteries than shallow discharge batteries without causing damage to the cells (these terms are explained on pages 28 and 29.

Shallow discharge batteries (i.e. automotive batteries) are designed to supply a large amount of power for a short duration; taking too much energy out of these batteries before recharging them is likely to damage the plates inside. If chosen for solar electric systems, shallow discharge batteries *must be managed very carefully*, or the results will be expensive and disastrous.

Shallow discharge automotive batteries are manufactured by Yuasa battery company in Dar es Salaam and by Uganda Batteries in Kampala. Both shallow and deep discharge batteries are manufactured in Nairobi by Associated Battery Manufacturers.

Rated Storage Capacity

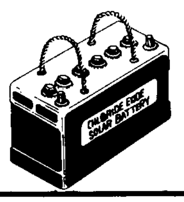
The amount of energy that a battery can store is called its *capacity*. A water tank, for example, with a capacity of 8000 litres can hold at *most* 8000 litres. Similarly, a battery can only store a fixed amount of electrical energy, typically marked on the side of the battery by the manufacturer.

The capacity of a battery is measured in *amp hours (Ah)*. This indicates the amount of energy that can be drawn from the battery before it is completely discharged (note that amp hours are *not* a measure of energy — to convert amp hours to energy in watt hours, multiply by the battery voltage). A battery of 100 Ah should ideally give a current of 2 amps for 50 hours (i.e. 2 amps times 50 hours equals 100 amp hours). The rated storage capacity, however, is a general guideline and not an exact measurement of the battery's size, as capacity changes with a battery's age and condition, and the rate at which power is drawn from it. If current is drawn from the battery at a high rate, its capacity is reduced.

Charge, Discharge and State of Charge

Charge current is the electric current supplied to and stored in a battery. As a water tank will take more or less time to fill depending on the rate at which water enters it, the amount of time required to completely charge a battery depends upon the size of the *current* at which it is being charged. Batteries can be charged by solar cell modules, by mains-power connected to a battery charger, or by diesel, petrol or automobile engines attached to a properly-sized alternator or generator.

The amount of charge a battery has received (Q, in amp hours) can be approximately determined by multiplying the charging current (I, in amps) by the amount of time the current has been left on (T, in hours):



Q (amount of charge in amp hours) = I (charging current in amps) x T (time in hours)

If this figure (Q) is multiplied by the battery voltage, then the energy supplied to the battery will be given in watt hours.

Of course, some energy is always lost in the charging and discharging process as heat. Depending on the type of battery and its age, the energy lost is between 10 and 30% for lead-acid batteries.

Several deep discharges will ruin or drastically shorten the life of a lead-acid automotive battery.

Batteries should not be charged at a current that is higher than one tenth of their rated capacity. Thus a 70 Ah battery should not be charged at a current of more than 7 amps. When batteries are charged at too high a current, the electrolyte level falls quickly because of gassing and the cells may be damaged. Low currents are more efficient than high currents for charging batteries.

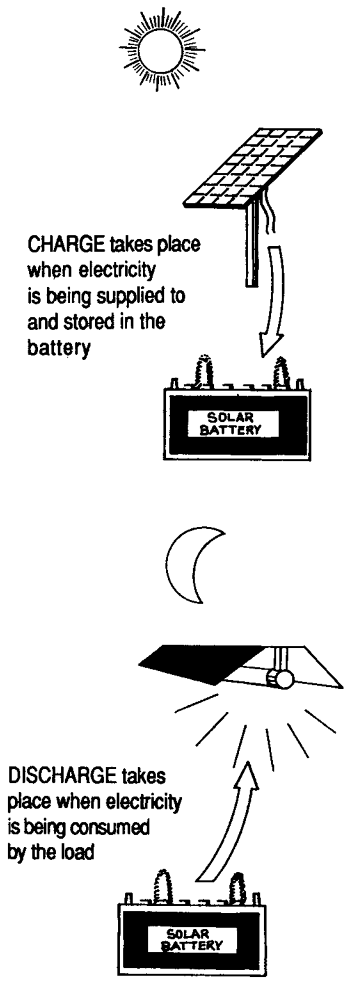


Figure 4.4
Charge, discharge and cycling. A cycle is one charge period followed by one discharge period

Most solar cell modules are designed to charge 12 volt batteries. In a 12 volt system, the *solar charge* from a 40 Wp module does not get much higher than 3 amps, which is well-suited for charging a 100 Ah battery.

Discharge is the state a battery is in when its energy is being used by a load (i.e. lights, radio or television). The *discharge current* is the rate at which current is drawn from the battery. The amount of energy removed from a battery over a period of time can be calculated (as charging energy was determined above) by multiplying the discharge current by the amount of time the load is used. For example, a lamp drawing 1.2 amps for four hours uses 4.8 amp hours of energy from the battery (1.2 amps x 4 hours = 4.8 amp hours).

State of charge is a measure of the energy remaining in the battery.

The *state of charge* is a measure of the energy remaining in the battery. It tells whether a battery is fully charged, half charged or completely discharged. With lead-acid batteries (but *not* with nicads) it is possible to measure state of charge using a hydrometer or voltmeter (see page 31). The cells of a fully charged battery have a state of charge of 100%, while those of a battery with one quarter of its capacity removed are at a 75% state of charge.

Cycle, Cycle Life and Depth of Discharge

A battery in a solar electric lighting system is charged each day by the solar cell module and then discharged by the load each night. Each charge period together with the following discharge period is called a *cycle*. For example, in one *cycle* a 100 Ah battery might be charged up to 95% state of charge during the day, and then discharged by lights and television to 75% state of charge that evening.

The *cycle life* of a battery is the number of cycles it is expected to last. Most batteries have a cycle life of several thousand cycles; nicads usually have longer cycle lives than lead-acid batteries. The *rated cycle life* of a battery (this should be specified by the manufacturer) is the number of cycles a battery is expected to last before its capac-

With small solar electric systems, deep discharging is a more common problem than over-charging.

Lead-acid batteries should not be left standing uncharged for long periods of time.

ity drops to 80% of its original rated capacity. The actual cycle life of a battery is shortened by deep discharges (see below), high temperature, and too much discharging at a high rate.

Depth of discharge (DOD) tells how much batteries are discharged in a cycle before they are charged again. Shallow cycle batteries should not be discharged below 80% state of charge on a regular basis. Deep cycle batteries should not regularly be discharged below 40% state of charge.

A *deep discharge* cycle is a cycle in which a battery is completely or almost completely discharged. This typically occurs during long cloudy periods, or when the load is much larger than the solar charge.

In East Africa, the most common cause of failure in solar lighting systems is abuse of batteries by deep discharge during cloudy weather. Small lighting systems often work well during sunny weather, but fail during the cloudy season. This is because there is not enough solar charge to meet the energy demands. If the battery is very low after a week or more of cloudy weather, it should immediately be charged by an alternative method. Meanwhile, the use of electricity should be reduced to protect the battery until the weather gets sunny again.

Self-discharge

If they are left standing uncharged, all batteries lose charge slowly by a process called *self-discharge*. This occurs because of reactions within the cells of the battery. For example, cars that have not been used for several months often do not start due to self-discharged batteries.

The rate at which batteries lose their charge depends on the temperature, the type of batteries, their age and condition. As batteries get older, their rate of self-discharge goes up. As well, dirty batteries (i.e. those with a high accumulation of acid mist on their surface) tend to have higher self-discharge rates. Warmer weather increases the rate of self-discharge. Normally, new batteries do not discharge more than 5% per month. However, in hot weather, old automotive lead-acid batteries may lose up to 40% of their capacity per month if they are not charged regularly.

To avoid high self-discharge rates:

- store the battery off the floor in a wooden battery box or non-metallic tray (see page 88);
- keep the top surface of the battery clean;
- keep the terminals clean and greased.

Lead-acid batteries left in a low state of charge for long periods lose some of their capacity due to *permanent* chemical changes in the plates (i.e. *sulphatation* of the plates). If a battery is left in a low state of charge for over a month, it may not accept its rated charge capacity, or it may not accept charge at all. (Note that nicad batteries *can* be left discharged for long periods without damage).

Overcharging and Charge Controllers

Batteries left on solar charge after they have been fully charged are said to be *overcharged*. If, for example, a 70 Ah battery at a 100% state of charge is still connected to a solar module on a sunny day, it will be *overcharged*. Small amounts of overcharging will not damage a battery (i.e. a 40 Wp module is unlikely to overcharge a 100 Ah battery), but continued overcharging of a battery causes a loss of electrolyte, damage to the plates, and a shortened lifespan.

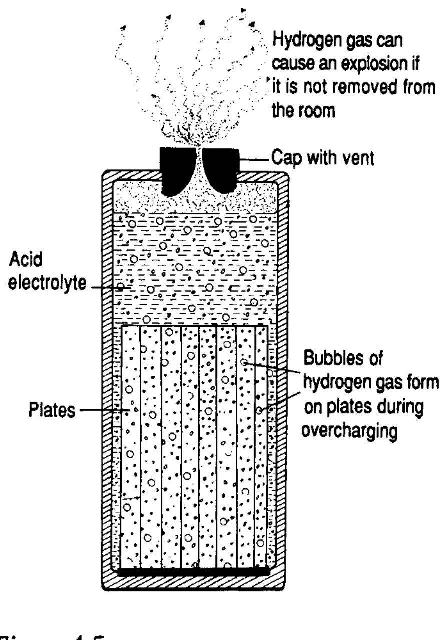
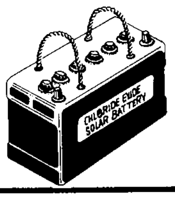


Figure 4.5
Gassing in a cell due to overcharge



Batteries

When a battery is being overcharged, it loses water by *gassing*. Since a fully charged battery can no longer hold solar charge from the module, the charge causes a chemical reaction which changes water in the electrolyte to hydrogen gas which escapes from the electrolyte as bubbles. Gassing causes two problems: First, the level of electrolyte in each cell goes down. Distilled water must be added to replace it. Secondly, explosive hydrogen gas is given off. To avoid the risk of explosion, this gas must be vented from the battery storage area.

In order to avoid damaging the battery by overcharging, several steps should be taken:

- a device called a *charge controller* may be connected between the battery and the solar module (see page 34). When the battery is fully charged, the charge regulator reduces the solar charge entering the battery to a *trickle*. This prevents water loss from the cells by gassing.
- the battery's state of charge should be checked regularly to determine whether it is being overcharged (see page 31).
- if a battery is being overcharged, the load should be left on longer, or, if there is no charge regulator, the solar charge should be disconnected when the battery is fully charged.

Types of Lead-acid Batteries

Automotive batteries are not the best choice of energy storage for solar electric lighting systems.

Automotive Batteries

Automotive batteries (also called Starting, Lighting and Ignition or SLI batteries) are shallow discharge lead acid batteries used mainly for starting car engines. They have a low self-discharge rate (1-4% per month when new) and they have a long cycle life with shallow cycling (i.e. if the battery is not taken below 80% SoC).

They are *not* the best choice of energy storage for solar electric lighting systems. However, since they are locally-manufactured, cheap and widely available in East Africa, many people do use automotive batteries for powering lights and televisions in rural areas. For those installing systems on limited budgets, 40 - 100 amp hour automotive batteries may be practical options.

If automotive batteries are chosen, special care should be taken to ensure they last as long as possible. They should not be used below 80% state of charge (i.e. only 20% of their capacity should be removed per cycle). Furthermore, during cloudy weather, they should be carefully maintained and taken for charging in town if necessary.

Lead Antimony (Motive) Batteries

Lead antimony batteries are deep discharge batteries which were originally designed to power electric vehicles. Antimony is added to the positive plate, enabling the battery to withstand deep discharges of between 50 and 80%. Lead antimony batteries have higher self discharge rates, however, and require more frequent additions of distilled water.

Example: ABM Solar Battery
Associated Battery Manufacturers, Kenya Ltd., (ABM) in Nairobi manufactures 12 volt lead antimony batteries for use in small solar electric systems. The batteries, available in 70 and 100 amp hour capacities, have been specially developed for solar electric uses. Their features include the following:

- A good cycle life. Cycle life should be between 1000 to 2000 cycles (i.e. between 3-6 years) if the batteries are not deep discharged too often.
- A low self-discharge rate of between 2 and 4% per month.
- A large electrolyte reservoir to prevent damage from excess gassing and to minimise the need to add de-ionised water.
- Much better tolerance of deep discharge than automotive batteries. The battery will last long under daily discharge of 40%. Still, a daily discharge of 10% gives the longest life.

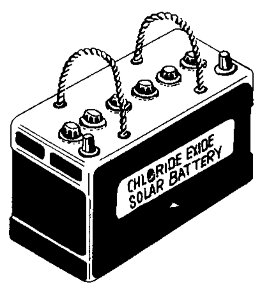
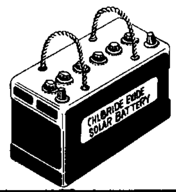


Figure 4.6 ABM solar battery



Captive Electrolyte (Gel) Batteries

Captive electrolyte batteries use a non-liquid electrolyte to eliminate the problems of water loss through gassing. Sealed at the factory, they do not leak or spill, so they are easily transported and require less maintenance. They can withstand deep discharges, and have a good cycle life (i.e. 2 years when cycled to 50% SoC and 3 years when cycled to 25% SoC at 25°C). They have a low self discharge rate.

Captive electrolyte have poor performance characteristics at high temperatures, so they should not be used in hot sites. They are among the most expensive type of battery.

Measuring State of Charge

Beware of battery acid when measuring the state of charge. Wear old clothes, and keep plenty of water nearby to rinse spilled acid.

The state of charge is checked to determine whether the battery is being discharged too much, and to determine whether there are any bad cells. Each battery in a solar electric system should have its state of charge checked at least once a month. Heavily used small systems should have battery state of charge checked once per week during cloudy weather.

When measuring state of charge, check the electrolyte level in each cell to make sure that it has not fallen too low due to gassing.

As mentioned above, it is possible to measure the state of charge (SoC) of a lead-acid battery using either a *hydrometer* (a tool which measures the thickness of sulphuric acid) or a *voltmeter*.

Hydrometers are more accurate than voltmeters. They measure the *density*, or the weight per unit volume of the sulphuric acid electrolyte in a cell (this is also called the *specific gravity*), which is directly related to the state of charge of the battery. As lead-acid batteries are discharged, the sulphuric acid within each cell is converted to water, which has a lower density than sulphuric acid. As the cell is discharged, the electrolyte becomes less dense and the battery's state of charge decreases.

Hydrometers

Typical hydrometers contain a floating scale with specific gravity readings. Use the hydrometer as follows:

1. Draw sulphuric acid up into the hydrometer from the battery cell by squeezing the bulb while the nozzle of the hydrometer is placed in the cell (see Figure 4.7).

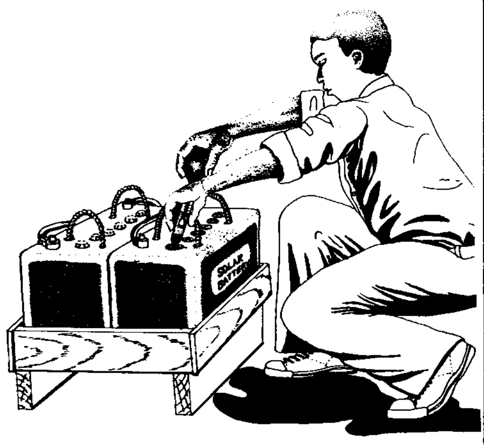


Figure 4.7 Using a hydrometer

2. The scale floats at a level that varies according to the density of the acid, and the state of charge of the cell.
3. Read the specific gravity of the cell from the scale floating in the acid (see Figure 4.8). Sometimes the hydrometer scale does not give the specific gravity, but only tells whether the battery is in a low, medium or high state of charge.
4. Consult a state of charge vs. specific gravity table or graph to determine the SoC (i.e. for ABM solar batteries, see below).

The arrow and dotted lines in Figure 4.9 show that if the specific gravity reading is 1205 with an ABM solar battery, the state of charge is about 80%.

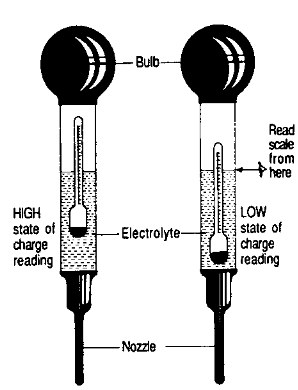


Figure 4.8 Reading a hydrometer

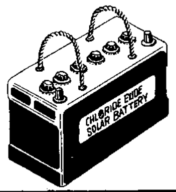


Table 4.1 What the Hydrometer Readings Mean with ABM Battery

Specific Gravity (grams/litre)	Stage of Charge	Action to be taken
1210 and above	Good	None. Battery cell is fully charged.
1160 - 1210	Fair	The cell needs charging. Reduce use of lights and appliance
1110 - 1160	Poor	The cell is almost flat. Do not use load until battery is charged.
Below 1110	Flat	The cell is flat. Take for recharging at a petrol station.

Figure 4.9
Using specific gravity to measure the ABM "Solar" battery's SoC

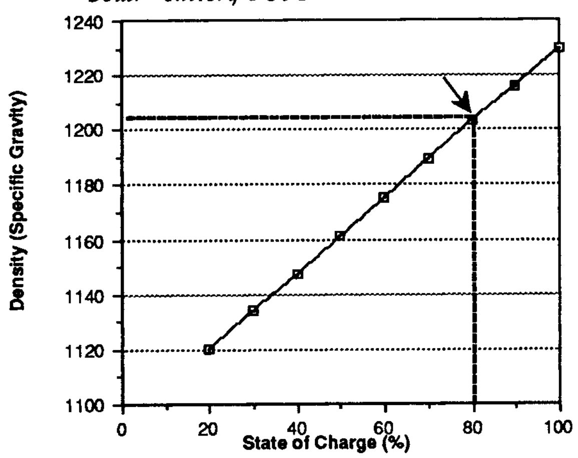


Table 4.2
State of Charge for ABM Solar Battery

State of charge (%)	Specific Gravity (grams/litre, 25°C)	Open circuit voltage (volts)
100	1230	12.74
90	1216	12.62
80	1203	12.50
70	1189	12.36
60	1175	12.25
50	1161	12.13
40	1147	12.00
30	1134	11.87
20	1120	11.75
10	n/a	11.64
0	n/a	11.51

Battery state of charge can be measured with voltmeters or hydrometers.

Voltmeters

Voltmeters are also used to measure a battery's state of charge. As the state of charge of a lead-acid battery decreases, its voltage also decreases. An ABM solar battery at 100% state of charge, for example, has a voltage of about 12.7 volts; when discharged to 50% SoC its voltage will be about 12.1 volts (see Table 4.2). The actual reading varies with the type of battery and the temperature.

To measure a battery's state of charge with a voltmeter:

1. Disconnect the battery from the load and solar charge. If the battery was being charged (or discharged), wait 20 minutes to allow the cell voltages to stabilise *before taking a measurement*. If you measure right away, the reading will be inaccurate.

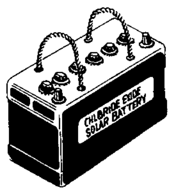
2. Connect the voltmeter's leads to the positive and negative terminals of the battery. Read the voltage on the voltmeter and compare it to the reading on a state of charge table that is appropriate to your battery (i.e. Table 4.2).

Bad Cells

Sometimes, a battery may have a *bad cell*. This means that, although the other cells in the battery are still working, one cell has stopped functioning properly (possibly due to a short circuit in the plates). When a battery's voltage is low (i.e. about 10.5 volts or less), but the state of charge in most of its cells is high, the battery probably has a bad cell. To check for a bad cell, measure the state of charge of each of the cells in the battery individually using a hydrometer.

If a hydrometer is not available, you can still check a battery in a *low* state of charge for bad cells. To do this, remove the caps of all the cells and short the terminals with an insulated wire. If a cell is bad, it will bubble furiously and produce a disagreeable smell.

It is possible to rebuild bad cells; certain *fundis* have set up businesses charging batteries and repairing bad cells. However, you should first check the work of such *fundis* before paying money to have a battery repaired. Quite often with old batteries, the repair job will only last several weeks before another cell goes bad in the battery. It is often more economical to



purchase a new battery rather than repair a single bad cell.

Replacing Batteries

Depending on its type and the way it is treated, a battery in a solar lighting system should last between two and ten years. When the battery is dead, it needs to be replaced. When they finish their cycle life, batteries no longer hold a charge. At this time, the cells may have different state of charge readings.

Typically, one or more cells will fail before the others, so it is a good idea to occasionally check for bad cells in old batteries. Repairing very old batteries is usually futile, because they are likely to fail again. Battery manufacturers buy the cases of old batteries for recycling.

Never put an old second hand battery in parallel with a new one.

If a system has more than one battery in parallel, the batteries should be of the same age and condition. Putting a new battery in parallel together with an old battery will prevent the new battery from getting fully charged.

Maintaining Batteries

Batteries will last for a long time (from 2-10 years depending on the type) if they are properly installed, maintained and managed. They should be located in well-ventilated rooms (i.e. where air can circulate).

Do not add tap water, sulphuric acid, battery tonics or any other impure solutions to the cells.

Tasks involved in maintaining and managing batteries include:

- Regular checking of state of charge to ensure that the battery is performing well. Keeping state of charge records may help to detect when a battery is getting too old to use, or when a cell has gone bad.
- Checking electrolyte levels in each cell. Replacing water lost during gassing with *de-ionised* water. The plates should always be below the level of the electrolyte to avoid damage to the battery. De-ionised water, which is available at battery shops, is used instead of tap water because it does not contain any impurities which could damage the cells. Rainwater or home-made distilled water may be added to replace lost electrolyte (see page 93).
- Cleaning the top of the battery. This avoids high rates of self-discharge caused by electrical conduction through acid mist accumulating on top of the battery.
- Cleaning terminals and contacts. Cleaning the terminals ensures a good electrical contact with the solar array and load. Application of petroleum jelly or grease to the terminals prevents them from becoming corroded.
- Giving the battery occasional *equalizing charges* to mix up the electrolyte. Equalising charges are charges well above the normal "full" charge which cause the electrolyte in the cells to bubble and get mixed up. These charges can be done in town, preferably in the cloudy season when the solar radiation is low.

Alternatives to Solar Charging

Systems should be designed so that the module is large enough to keep batteries in a high state of charge *even in cloudy weather*. However, because of the high expense of modules, and because of the lengthy cloudy periods in some areas, small lighting systems sometimes do not receive enough solar charge to meet the load requirements. In such cases, the users should protect the battery from deep discharge by charging it with an alternative method:

- *Charging with a battery charger:* The battery can be taken to town for charging. In many small towns, petrol stations or *jua kali* industries operate battery chargers from mains, and top batteries up for a small fee.
- *Charging from a car's alternator:* Batteries can also be charged from the alternator of a car. This is done by replacing the battery in the car with the solar battery and, *either* running the engine when the car is stationary for enough time to bring the battery to a high state of charge, *or* driving the car on a journey with the solar battery in the place of the other battery.
- *Charging with a bicycle generator:* Nicad cells can be charged with a bicycle generator. The generators available for bicycles produce a current of less than one amp at about four volts, and an hour or two of easy pedalling should bring a pair of nicad cells to full charge. In cloudy weather, a bicycle can thus be used to charge nicads as a supplement to small modules. Using a transformer, small (below 50 Ah) 6 and 12 volt batteries can also be charged.