How to Build a SOLAR CELL That Really Works!

by Walt Noon

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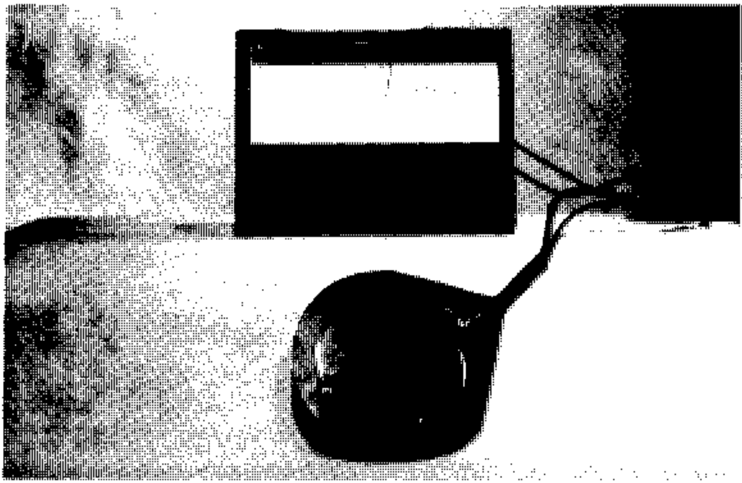


Fabrication of a modern solar cell is a very complicated and delicate process. In most cases, a large silicon ingot is grown from a small crystal in an extremely clean and sterile environment. Any dust or particle contamination even down to the atomic level during the growing process can completely ruin the ingot. Impurities must typically be kept to one part per billion.

The growing process itself is slow, and the very pure materials required are extremely costly. Because of this, a single ingot which is later sliced into thin cells approximately 0.05 centimeters thick often costs thousands of dollars to produce.

This fact coupled with the general inefficiency (7-14% typically) of even these modern cells has kept the price of photoelectric cells too high to be competitive with other sources of power.

Someday, lower cost production techniques together with higher efficiency will make widespread use of clean, renewable solar energy possible. Until the day when solar cells are so common that they are taken for granted, the idea of deriving electricity directly from sunlight will continue to intrigue the inventor and experimenter.

It has been said that if even 1% of the Sahara desert were covered with the modern cells just described, it would more than supply our worlds current energy needs.

In this article I will briefly outline some of the processes and materials that are now being researched for converting of solar energy into electrical energy, and I will show several little known processes for building your own solar cells completely from scratch.

Keep in mind that the cells and processes described are experimental.

You should have no trouble building the cells that will be described in the following pages. Be cautious. Use good judgement and common sense in handling the chemicals and heating processes described. You'll find that a simple solar cell can be constructed by a persistent student, a cell that will make an outstanding science fair project.

The electrical output from the homemade cells described in this article will be well below that of modern commercial cells, but the materials cost is also very low. Often a cell can be literally produced for pennies! The loss in efficiency is probably more than made up in the reduction of their price.

A small, carefully made solar cell of approximately 2 1/2" diameter will produce around 5 milliamperes of current in direct sunlight. This is enough to drive a sensitive light meter or extremely sensitive relay. Banks of these cells have even been used to run small electric motor.

In attempting the processes that follow, be patient. Expect a few failures in the beginning. A few ruined cells are normal. You will soon find that you can consistently build your own good quality solar cells in no time at all.

Experiment with the procedures described. You may stumble onto a method of producing even more efficient cells than I have. Just be sure to be very careful. The chemicals described can be dangerous if abused or mishandled.

There are an estimated 80 trillion kilowatts of solar electrical energy available in the northern hemisphere. Capture some of it!

Chemicals That Have Photoelectric Properties

There are a number of elements and chemical compounds that can be used to produce photoelectric power. They include titanium, selenium, thorium, cuprous oxide, and metals of the alkali group including sodium, potassium, rubidium, lithium, cesium and francium.

Although you may find any of these interesting to experiment with, most will produce only a very weak electrical current – a current that can be difficult to measure much less do useful work.

The two best substances for a homemade cell are, in my opinion, selenium and cuprous oxide.

Selenium was extensively used in the production of commercial solar cells before silicon. Although it can be a somewhat difficult to find a supplier and it is a toxic heavy metal, it is relatively inexpensive and can often be found in old model radio sets where it was used in the rectifier of the power supply.

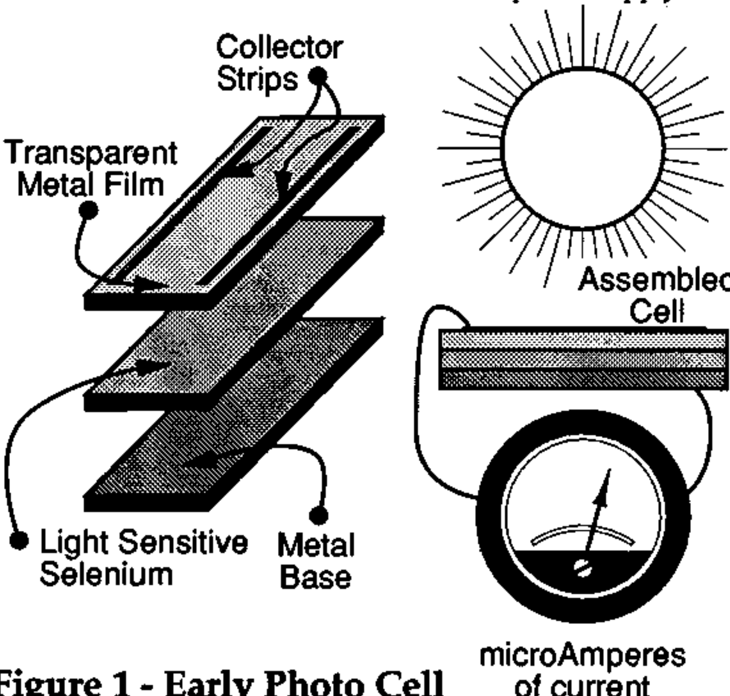


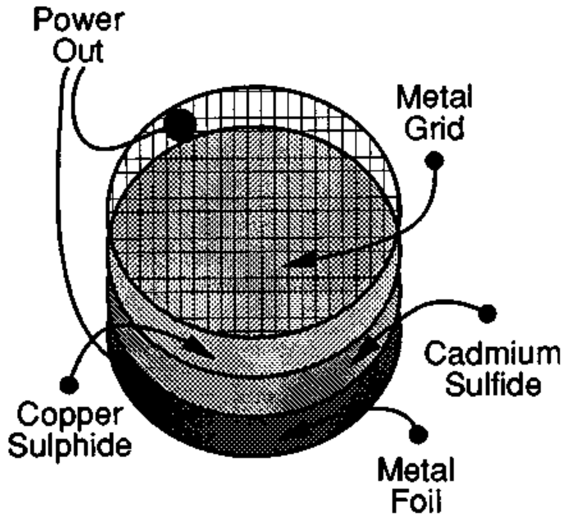
Figure 1 - Early Photo Cell

Figure 1 shows how selenium is used in a commercial photoelectric cell. A selenium photocell is made from a metal plate (usually iron) with one side being covered with a layer of selenium. A very thin layer of silver or gold is spattered over the selenium layer forming a layer of current-carrying material that allows light to pass through it. This layer is called a transparent electrode. A metal electrode called a collector rests on the gold or silver near its edge.

Wires are attached to the collector and the iron plate to deliver the electric current to the load. Although not as great an output as more modern cells, a selenium photocell can produce as much as eight milliamperes for each square inch of surface area exposed to bright sunlight.

Cadmium Sulfide

Cadmium sulfide is probably the most promising low-cost solar cell second only to silicon. A cadmium sulfide photocell is shown in figure 2.



If you have an interest in electronics, you will undoubtedly recognize cadmium sulfide (the common "CDS" cell) as the material used in light detecting circuits. Although inventors have realized for some time that a number of materials such as cadmium sulfide change their electrical resistance in the presence of light, it has only been in fairly recent times that it was realized they could also be used to generate power.

The most important attribute of cadmium sulfide is that it could be mass-produced efficiently using a thin-film procedure wherein very thin layers of its photosensitive components are evaporated onto a base metal.

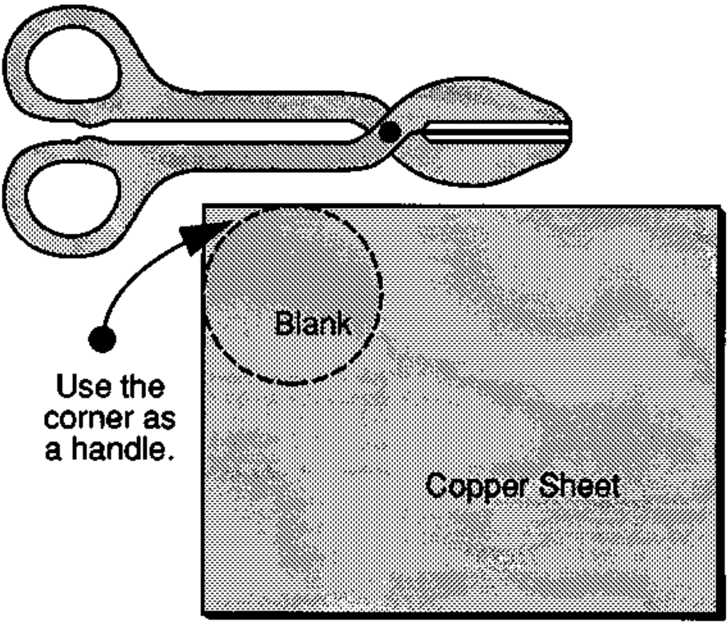
Cadmium cells are also fairly efficient (3-5% typical) making them a good rival for amorphous silicon cells.

The major draw backs at this time still remains cost, and a much shorter lifetime than silicon cells.

An Experimental Cell With Cuprous Oxide

The best cell by far for the experimenter to make is a cell made with cuprous oxide (Cu_20). Copper actually has two oxides, a red oxide called cuprous oxide, and a black oxide called cupric oxide (CuO).

The dark red cuprous oxide has photoelectric properties but black cupric oxide does not. The black oxide that forms on the outside of your cell must be removed because it is opaque and will not allow light to reach the cell's active surface.



Building a Cell

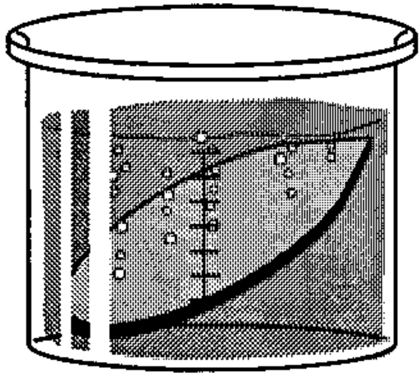
Step 1. First, cut a piece of pure sheet copper into the size and shape you wish for your cell. Although .025 inch thick copper was used for the cells described here, just about any thickness will do.

Copper is a soft metal and may be cut with tin snips or even with an old pair of scissors, although the scissors may be ruined for any other use.

A circular cell with a diameter of 2 1/2 inches is typical for my needs. You will find that you may be limited to a smaller cell by the heat source you will use later. You may want to build a much larger cell.

As you cut the copper, be sure to leave a "handle" so that you may grip the cell with pliers without marring the cell's active surface.

Step 2. At this point, the surface of the cell must be made extremely clean. Prepare a solution of nitric acid by carefully mixing 20 parts nitric acid and 80 parts distilled water. Remember to wear protective goggles or other suitable eye protection and to work in a well ventilated area whenever you work with chemicals.



The scoured disk is cleaned with acid.

IMPORTANT! ALWAYS ADD ACID TO WATER!
NEVER ADD WATER TO ACID!

Begin by carefully polishing the face of the cell with a fine grade of steel wool until it shines brightly. Then place the cell shiny side up in the solution of nitric acid.

Soon, tiny bubbles will form on the copper disk. Stir the solution occasionally. When the disk seems shiny and well cleaned, remove and rinse it under running water.

Make certain never to allow your skin to touch the acid, and that no acid remains on the cell.

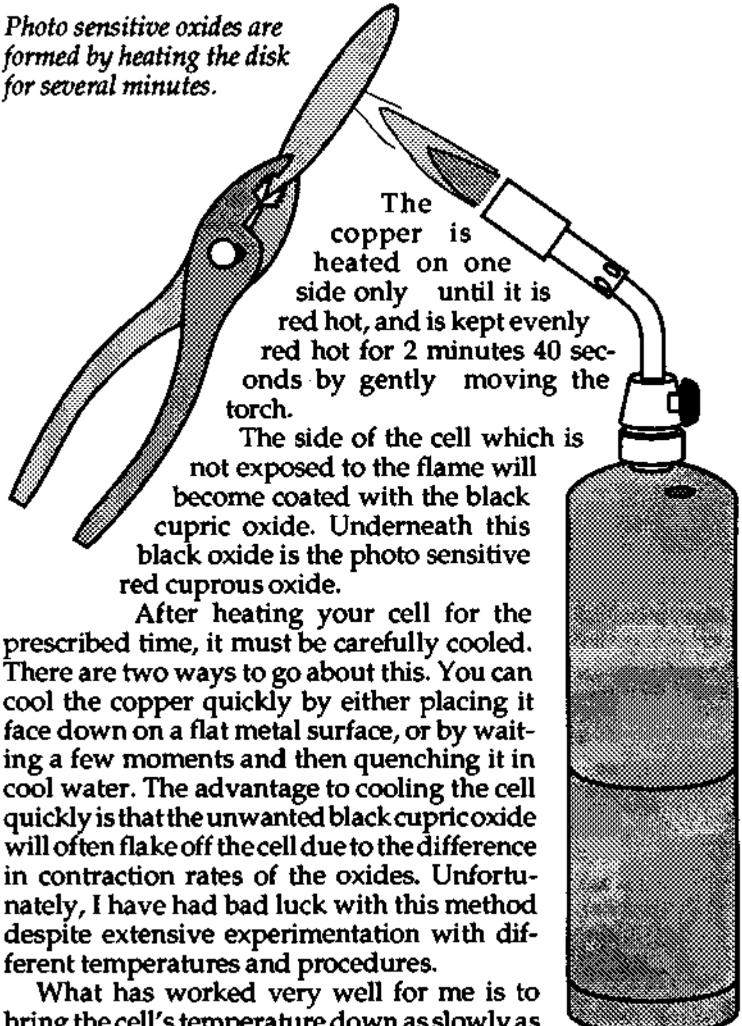
The cell will sometimes work without the acid cleaning if it is simply well polished by the steel wool. However, I strongly recommend the acid cleaning.

Nitric acid and the other chemicals mentioned in the text can be easily ordered from a number of mail-order chemical houses such as found in the classified section of magazines such as *Popular Science.* You will also find sources mentioned later in this publication.

Step 3. Cuprous oxide is now formed on the disk by heating it over a Bunsen burner, or propane torch. A gas stove can be used, but results may be unpredictable.

The time the disk must be heated varies greatly depending on the heat of the torch, and the thickness and size of the copper piece. Using a standard propane torch from the hardware store and a disk of the described size, I found 2 minutes and 40 seconds to be ideal. If you heat it too long, you run the risk of burning off the oxides. Heating for too short a time may prevent the oxides from forming fully.

Photo sensitive oxides are formed by heating the disk for several minutes.



The copper is heated on one side only until it is red hot, and is kept evenly red hot for 2 minutes 40 seconds by gently moving the torch.

The side of the cell which is not exposed to the flame will become coated with the black cupric oxide. Underneath this black oxide is the photo sensitive red cuprous oxide.

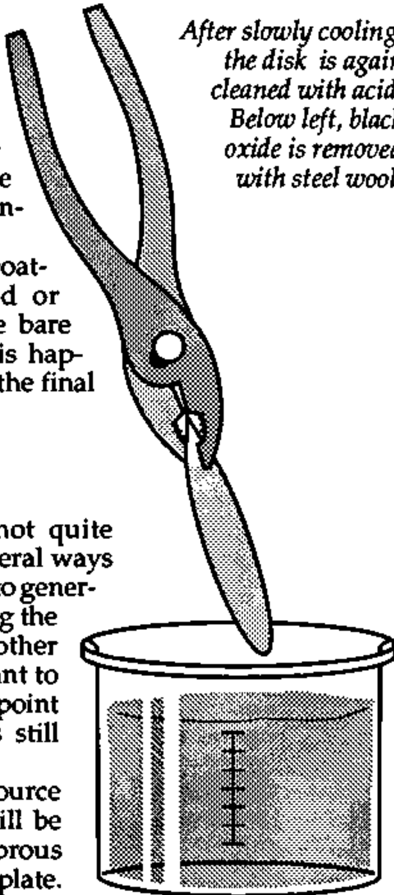
After heating your cell for the prescribed time, it must be carefully cooled. There are two ways to go about this. You can cool the copper quickly by either placing it face down on a flat metal surface, or by waiting a few moments and then quenching it in cool water. The advantage to cooling the cell quickly is that the unwanted black cupric oxide will often flake off the cell due to the difference in contraction rates of the oxides. Unfortunately, I have had bad luck with this method despite extensive experimentation with different temperatures and procedures.

What has worked very well for me is to bring the cell's temperature down as slowly as possible making sure the black oxide does not crack at all. Once completely cool, the cell is immersed in the nitric acid bath. You must wait while the acid begins to dissolve the black oxide. Then you remove and rinse the cell.

A very weak solution of sodium cyanide can also be used with good results. However, you should be extremely careful when using it. Cyanide is an extremely poisonous chemical, and if accidentally mixed with an acid can create deadly fumes.

At this point the black oxide covering the cell can be rubbed away with steel wool and a little elbow grease. After all of the black oxide has been removed, your cell should have a uniform coating of deep red on one side. Don't worry if the very outside edges of your cell don't have the coating, this is due to uneven cooling and is normal.

Keep in mind that the red coating must not be scratched or scraped away to reveal the bare copper plate beneath. If this happens the cell might short in the final step and not work at all.

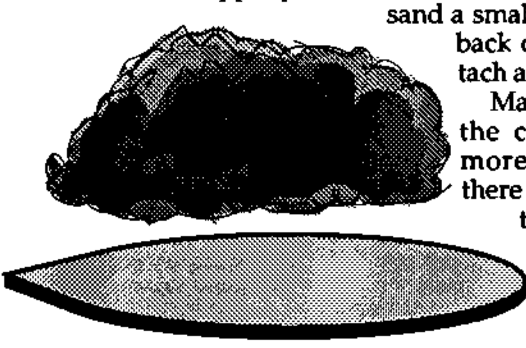


After slowly cooling, the disk is again cleaned with acid. Below left, black oxide is removed with steel wool.

Testing

Although your cell is not quite complete, there are now several ways that you can test it and use it to generate power. If you are building the cell for a science fair or other demonstration, you may want to stop and use the cell at this point while the cuprous oxide is still visible.

If you hold the cell near a source of bright light, a current will be generated between the cuprous oxide coating and the copper plate. The copper will form the positive terminal and the cuprous oxide the negative, respectively. Making contact with the copper portion of the disk is very easy. Simply sand a small bare spot on the back of the cell and attach a wire.



Making contact with the cuprous oxide is more difficult since there is enough resistance in this material that simply attaching a wire will not work.

One excellent

method of making efficient contact with this large surface area is by attaching a wire grid to it. A better way is to apply a very thin layer of silver or gold called a transparent electrode which will be described in detail later.

An easily fabricated but temporary transparent electrode can be made from salt water. A soloution of salt or acid will conduct electricity and also pass light to the cell. Drip a small amount of salt water on to the center of the cell. Make sure that the water rests only on the cuprous oxide and does not touch any of the cell's copper surface.

Next, attach one wire from a galvanometer, digital voltmeter or other very sensitive meter directly to some exposed portion of the cell's copper surface. Usually the back or the edges have some exposed copper. Touch the other meter lead to the surface of the water. The meter will spring to life.

Next, bring a bright source of light such as a 100 watt bulb near the cell. The meter should show a slightly smaller voltage as the light approaches. Your cell is changing some of the light into electricity but is having to counteract the current generated by the saltwater, hence the drop in voltage. The salt water actually acts as an electrolyte and with the oxide generates its own current just as a small battery would.

Another way that you can test your cell is by making a wire electrode for the surface. This is done simply by coiling some 30 gauge silver-plated wire as shown in figure 7 and by holding it against the cuprous oxide surface with a sheet of glass. A good trick is to coil the wire around a cone shaped dowel or other object first in order to make good, even spirals. Make sure that the wire touches the cuprous oxide only, and none of the bare copper.

By simply attaching one wire of your sensitive meter (a digital voltmeter works best) to the silver wire, and one to the cell's exposed copper, you will be able to register a small current when a light is brought near.

In this form, the cell can be operated indefinitely and makes an excellent display.

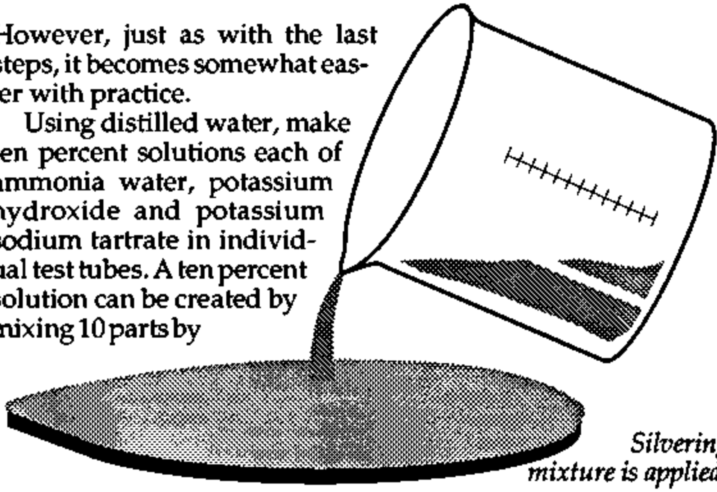
Making The Silvering Solution

The final step in making your own solar cell will be to make a permanent transparent electrode. When properly applied, this will give your cell a beautiful semi-mirrored finish and allow you to make electrical contact with the whole cuprous oxide face of the cell.

This step is probably the trickiest in the production of the cell.

However, just as with the last steps, it becomes somewhat easier with practice.

Using distilled water, make ten percent solutions each of ammonia water, potassium hydroxide and potassium sodium tartrate in individual test tubes. A ten percent solution can be created by mixing 10 parts by



Silvering mixture is applied.

weight of solute in 90 parts of water. Keep in mind that the test tubes can become warm or even hot when the water is first added, so be sure to use Pyrex glass test tubes. Also, make certain you have ample ventilation when mixing the ammonia solution.

Dissolve in 1 oz. water a single crystal of silver nitrate. The crystal should be somewhat larger than the head of a match. Begin adding drops of the ammonia solution to the dissolved silver nitrate until the water first becomes brown, and then just begins to clear.

Add a drop of potassium hydroxide to this solution. The solution will discolor somewhat. Then again begin adding drops of ammonia water until the solution just begins to clear. The solution should remain somewhat cloudy. Too much ammonia in the solution can dissolve the cuprous oxide coating and can damage or ruin the cell.

Stir the mixture while adding a single drop of the potassium sodium tartrate solution.

The mixture is now ready and should be used immediately.

Applying The Solution

Temperature and variations in the chemical mixture can dramatically change the time required to complete the silvering process. The best way to complete this step is by simple visual examination of the process as it proceeds.

With the cell on a flat surface, begin by carefully pouring the silvering mixture on to the center of the cell. Remember to avoid letting this mixture contact any exposed copper. A good trick is to cover with paint or lacquer any exposed copper surfaces on the face of the cell.

Continue pouring until the liquid has covered as much of the surface as you wish it too. If all exposed copper on the surface has been properly protected with the lacquer, you can actually pour the solution until it comes right to the edge. Since water has an affinity for itself called "cohesion", it won't spill over the edge.

Very soon, a thin film of silver will begin to form over the cell's surface. The liquid should be poured off when the red oxide is still slightly visible beneath the silver. The cell should then be cleaned and polished with a ball of cotton. If you have difficulty judging this process, keep in mind that it is probably better to allow the silvering process to go a little too long rather than not long enough since some of the silver coating can be polished away.

You should now have a smooth silver coating through which the red oxide is barely visible.

Completing the Cell

Contact is now easily made to the cuprous oxide face of the cell by means of a ring of lead or silver-coated wire which is slightly smaller in diameter than the disk itself. With the ring held firmly against the disk, a protective coating of thin lacquer can be applied. Make certain the lacquer does not come between the wire and the disk.

With wires attached to the disk's copper back and the lead or silver ring, the cell is complete. The disk can now be housed behind glass, mounted to a sheet of plastic, cast in a clear resin or housed in any other enclosure you desire!

Other Cells, Experiments and Ideas

Even though the output of the homemade cell is small, with a little imagination there are many valuable uses to which it can be put.

There are many different ways that a cell can be assembled, each with different merits as far ease of assembly, permanence and output efficiency. Feel free to experiment.

The magic of watching something as delicate as a sunbeam move an electrical relay or drive a circuit is always fascinating!

An Electric Eye

Because it generates its own power, a photoelectric cell can make an excellent electric eye. By electrically attaching your cell or group of cells to a sensitive moving coil of wire such as that of a galvanometer it is possible to use the pointer needle and metal stops of the galvanometer as a highly sensitive relay switch. When light shines on your cell, the resulting current will move the needle, close the switch, and complete the circuit. This might also be tried with a very sensitive panel meter.

Because a galvanometer is such a delicate instrument, using it as a relay is somewhat impractical. A better method is to use the generated current to control the conduction of a transistor (a solid state switch) which in turn controls another device.

If you wish to use your electric eye out of doors, it can be placed at the back of a length black tubing so it will not be falsely triggered by sunlight. You can then shine whatever light source you intend to use directly into the tube to trigger the cell.

A Light Meter

A photocell can also make an excellent light meter since it can often power a sensitive meter directly, and will never require batteries. The cell(s) should simply be wired directly to a meter of sufficient sensitivity, and both built into the same enclosure.

If you wish to calibrate the meter, there are a number of ways this can be done. The first is to simply mark your own scale above the meter's while comparing its readings to those of one used by photographers. Because the output of the cell is small, you may find that movements in the meter are also small and markings are very close together.

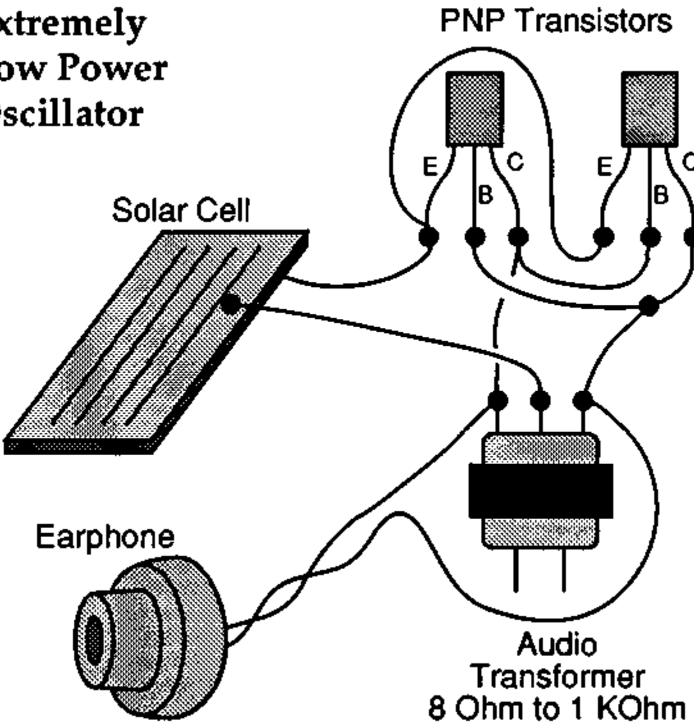
The second calibration method is to precisely vary the light coming into the meter. This can be done by holding a large white card in front of the meter so as to reflect light into the cell from an electric light source. Make a small mark on your meter's scale at the point it indicates. Next, fold the card in half keeping the card at the same distance. The light will be reduced 50% and another mark made. Repeat this procedure until a reading is no longer possible.

How To Kill A Rabbit

Actually, I don't like to kill rabbits, but I almost did by mistake. I don't recommend it unless you have sadistic interests. It can however be interesting in small doses.

What I am referring to is simply a solar powered high frequency audio oscillator. The schematic shown in figure 4 shows the circuit assembly of a very simple oscillator which requires a

Extremely Low Power Oscillator



minimum of current to operate. A set of solar cells, three silicon cells or a greater number of homemade cells, power the oscillator which puts out a high frequency squeal right at the upper edge of the human audio spectrum. It is small enough to be hidden and amazingly annoying after any period of time. Being solar powered it can run indefinitely in daylight.

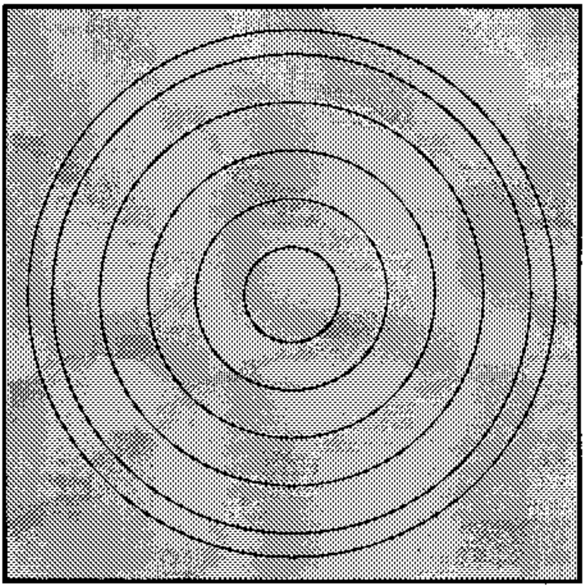
"But what was that about the rabbit?" you ask. It appears that rabbits and perhaps other animals do not tolerate the sound very well. This was evidenced by a pet rabbit that was temporarily being kept in my room.

Not even considering that the sound made by the circuit could be dangerous, I left the oscillator on a dark shelf one evening and returned the following afternoon. During the day enough sunlight had crept into the room to power the circuit and annoy everyone in the household who could not identify where the terrible squeal was coming from. The rabbit was found lying on the bottom of his cage.

In removing the rabbit's limp body from the cage (he seemed dead in every way), I noticed he could still move slightly and, happily, he recovered shortly after the oscillator was removed from the room.

Although terrorizing rabbits is hardly a humane application for this oscillator, perhaps a solar oscillator in the garden could be valuable in protecting plants from pests if it were far enough from people.

If nothing else, turning sunlight into sound is an interesting experiment.



Fresnel Lens Top View

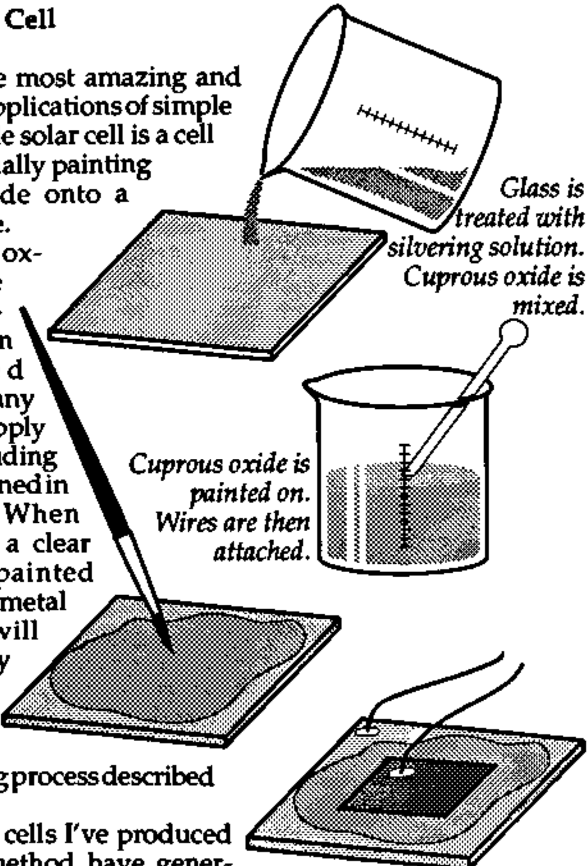
Fresnel Lens Cross Section

A Fresnel Lens "Concentrator"

A good way to improve the efficiency of any cell is to collect and focus more light on it with a lens, and the most common lens for this application is the Fresnel lens. In effect, the Fresnel lens is a standard large magnifying flattened into a thin sheet of plastic which makes it much lighter and cheaper.

Such lenses are available in sizes ranging from small magnifiers available for less that $2.00 in camera shops to disks several feet across. In direct sunlight one of these large disks can produce enough heat to cook a meal or solder metal!

A Painted Cell



One of the most amazing and interesting applications of simple cuprous oxide solar cell is a cell made by actually painting cuprous oxide onto a metal surface.

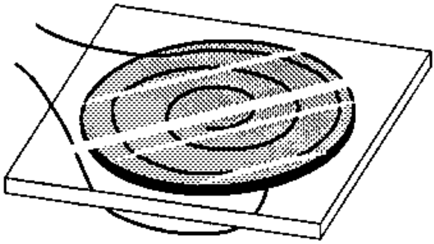
Cuprous oxide may be purchased inexpensively in powdered form from many chemical supply houses including those mentioned in the text. When mixed with a clear resin and painted thinly on a metal surface it will take on many of the properties of a cell made by the heating process described earlier.

So far the cells I've produced using this method have generated only very small amounts of power. Perhaps better resins and techniques could make this the fastest, lowest cost cell to fabricate. What would be lost in efficiency could be made up in greater surface area.

Final Notes and a Simple Cell

I don't know if the construction of a photoelectric cell such as those described in this article is worthwhile versus purchasing commercial cells when you take into consideration their low efficiency and the time it takes to fabricate them. But I do know

Cell Protected by Cover Glass



that they are a great deal of fun to experiment with. And there is something very satisfying in being able to fabricate a device that is generally considered to be too technical for the layman.

With the list of photoelectric materials and processes described you should have no problem making a great variety of cells of your own design. Commercial cells are readily available. Many times it is faster and easier to use them on projects requiring very large amounts of power.

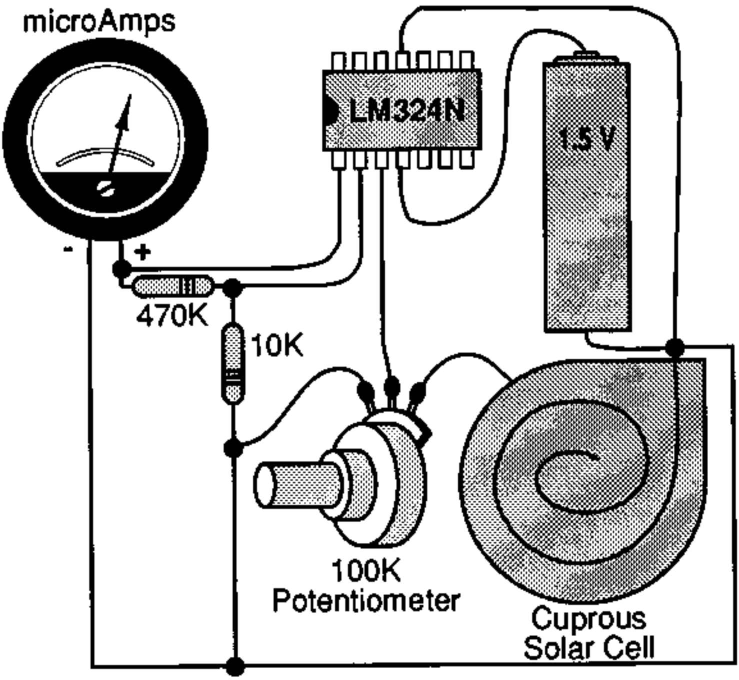
If you find that you have difficulty getting power from a cell, check first to see if it has been "shorted out" by the silvering solution. This is by far the most common reason that a cell will not work. To make this check, attach the leads coming from the cell to a digital volt meter. Set your meter to look for a resistance between the leads. You should find some resistance. If the resistance is zero, the silvering solution has made contact with the copper backing at some point on the face, and the cell has been shorted out.

One possible way to salvage such a cell is to cut the cell into smaller cells and test them individually. Usually you will find at least some segments will work.

Another point that I would like to stress is the usefulness of a digital volt meter for these experiments. Because the outputs measured are often so small, especially with your first cells or with experimental cells, having a sensitive instrument such as a digital volt meter can save you the frustration of wondering whether or not a cell is functioning properly.

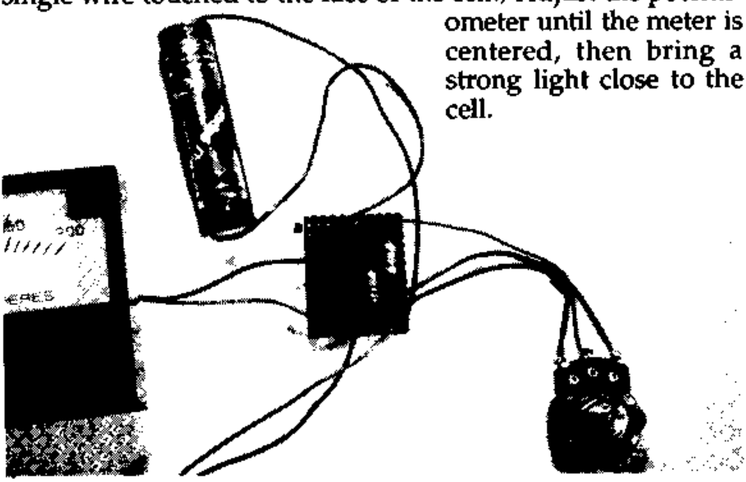
An experiment you might like to try is to use metalized film products such as Mylar for your transparent electrode. I recently purchased for under $3.00 an "emergency blanket" made from such a film. I have been wondering how well it might perform as a painted cell substrate. If a thin film of cuprous oxide could be applied, in a similar manner, behind the aluminum film already on the blanket, what a battery that might make!

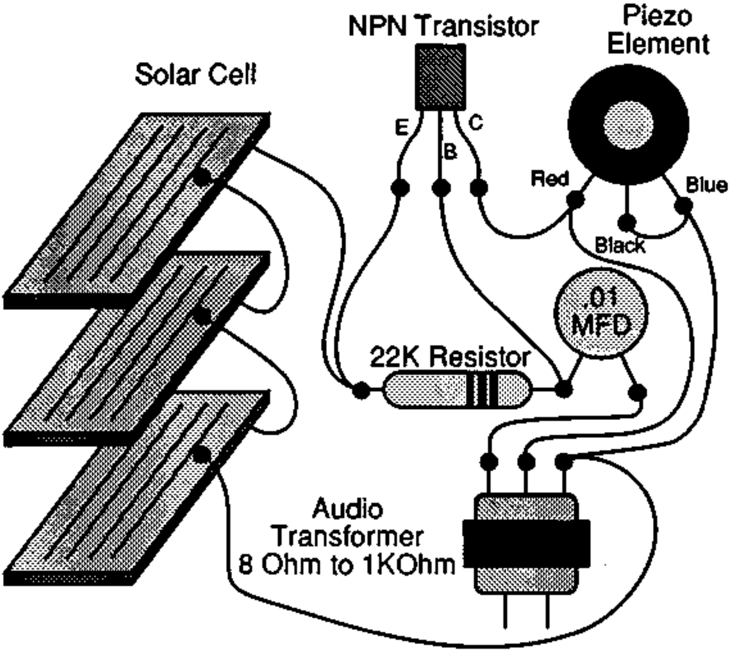
With that estimated 80 trillion kilowatts of electrical energy available in the northern hemisphere, there is certainly plenty of power waiting to be tapped. I wish you the best of luck in your experiments with it!



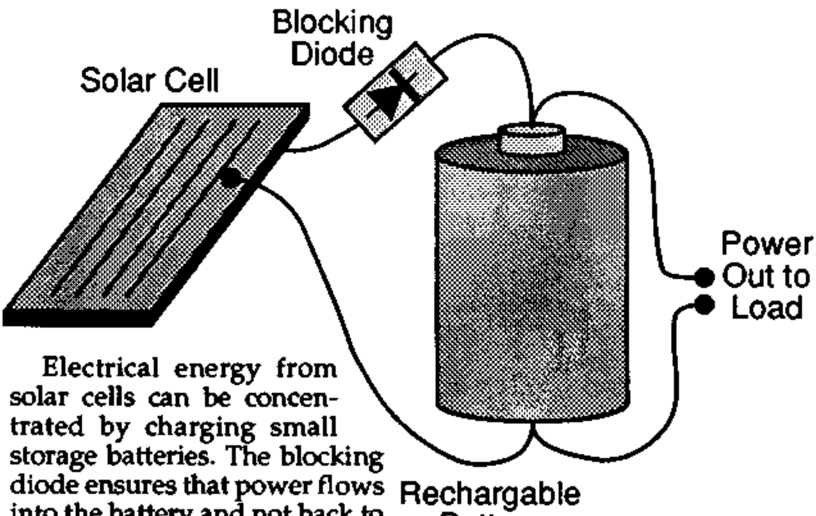
Meter Amplifier

If you don't have a digital meter, here is a very simple circuit you can use to test your cells. This circuit is so sensitive it will read voltages from cells that have not yet been silvered. (From a single wire touched to the face of the cell!) Adjust the potentiometer until the meter is centered, then bring a strong light close to the cell.





Solar Powered Oscillator



Electrical energy from solar cells can be concentrated by charging small storage batteries. The blocking diode ensures that power flows into the battery and not back to the cell.

MATERIALS SOURCES

For silvering and other chemicals:

Chem-Labs
1060 Ortega Way, Unit C
Placentia, CA
92670

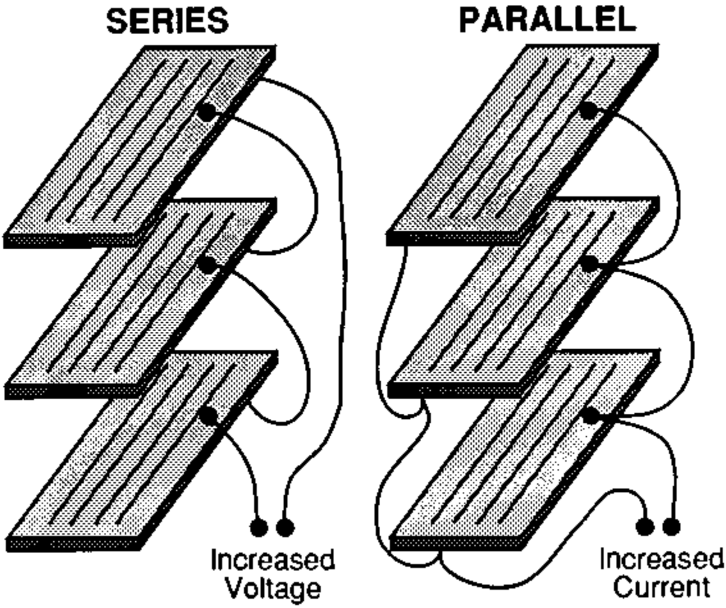
For sheet copper – Found in most hobby stores. Copper used in this article was K&S #259

K&S Engineering
Chicago, IL
60638

For large Fresnel lens and other optics:

Edmund Scientific Co.
101 East Gloucester Pike
Barrington, New Jersey
08007

Chemicals needed:
Ammonia
Potassium Nitrate
Potassium Sodium Tartrate
Silver Nitrate
NitricAcid



Connecting cells into batteries