GB OPERATING INSTRUCTIONS

Version 05/14

GB Rechargeable Batteries and Charging Technology

Understanding and Using

Item No. 553893

Table of Contents

GB

Page

1. Becoming familiar with the components of the learning package

Pieces	Component	Specification
1	Plug board	SYB 46, 270 contacts
1	Solar module	
1	USB plug with cable and ends for the plug board	
1	Transistor	2N3904
1	Transistor	2N3906
1	Schottky diode, blue	BAT 42
2	Silicon diodes	1N4001
1	LED, red	5 mm
1	LED, orange	5 mm
1	Flashing LED, red	5 mm
1	Carbon resistor	1 W
8	Carbon resistors	¼ W
1	Electrolytic capacitor	1,000 µF, 10 V
1	Battery holder with wire	Mignon, AA
4	Plug pins	
2	Alligator cable, red and black	
1	Jumper wire	1.0 m

1.1 The Experimenting Board

The experimenting board, also called a lab plug board or simply plug board, permits setting up the experiments without using a soldering gun. It comprises of contact springs inside that are connected to each other in a row system. The electronic components and connection wires can be plugged into the contacts repeatedly and thus permit circuit setup without soldering or screwing. Connection wires diagonally cut off with a wire cutter can be pushed in most easily.

The plug board enclosed with the learning package has a total of 270 contacts in the 2.54-mm grid. The 230 contacts in the middle area are connected by vertical strips in rows of 5 each.

At the edges of the wide side, there is one row each with 20 contact points that are horizontally connected with a rail. These „upper“ and „lower“ rows are well suitable as power supply rails.

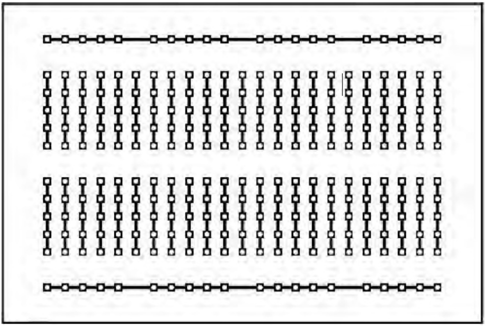


Fig. 001: The plug board – the power supply rails at the top and bottom

1.2 USB Connection Cable

The USB connection cable of the learning package has a USB A plug on one side and a pin plug for the plug board on the other side. This permits connecting the 5 V (Volt) power supply of a USB source (USB mains plug) to the plug board.

Important!

When connecting the pin plug to the plug board, always observe polarity! The red cable to the pin plug is the plus pole, the black is the minus pole.

Fig. 002: USB connection cable, connection assignment of the plug:
1 = GND, 2 = D+, 3 = D-, 4 = +5 V

Important note on use of the USB power supply

It is urgently recommended to use a simple USB mains unit for the following experiments (e.g. for a mobile phone) with 5 V voltage and at least 500 mA (milliampere) power output.

The USB power supply for the experiments could come from the computer‘s USB socket, but this is urgently advised against!

The reason: Basically, high power devices at the computer USB socket may have a current consumption of 500 mA, low power devices one of up to 100 mA. Unfortunately, not all USB sockets (depending on computer type) are short-circuit protected! Often, there is only one fuse soldered in at the socket, sometimes also the corresponding resistor. Some devices have a fuse that will reset on its own, in others it must be replaced after a short circuit.

There are also mobile computer systems where the USB socket emits a reduced voltage and a reduced current.

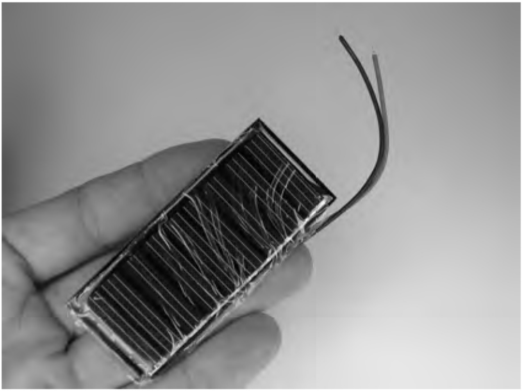
1.3 Solar Module

The enclosed solar module comprises several polycrystalline solar cells. The silicon material, put together from several crystals, is contaminated by deliberate doping so that there will be a negative and a positive layer.

At the top, the N-layer (negatively doped) is coated dark blue for better light absorption. The lower layer is the P-layer.

Incoming light will put the electrons in motion and there will be a voltage between the two described layers. We can use this voltage and the flowing current.

A single crystalline silicon solar cell will reach approx. 0.5 V per cell. The current depends on the cell size.

a)


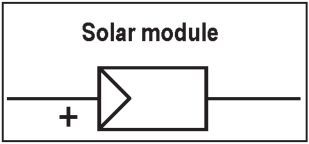
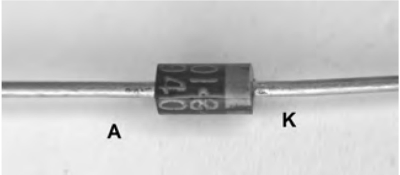
b)


Fig. 003: a) Solar module with protective film, b) Circuit symbol

1.4 Diodes

A diode only permits current to flow in one direction. They are therefore used to rectify alternating voltages and block undesired polarity in direct voltage. The function of a diode can be imagined as a kind of check valve (as in water installations) in regular operation.

a) 

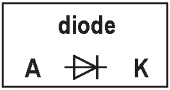
b) 

Fig. 004: a) Silicon diode type 1N 4001; the cathode of the diode can be recognised by the printed-on dash. The other connection wire is the anode. The technical current direction goes from the anode to the cathode. b) Circuit symbol of the diode

In passage direction (circuit symbol arrow), considerable current starts flowing in the silicon diode, such as the 1N 4001, only from a voltage of approx. 0.6–0.7 V or 700 mV (millivolt) onwards.

a) 

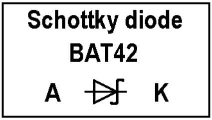
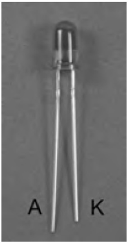
b) 

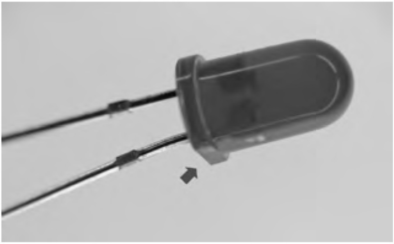
Fig. 005: a) Schottky diode, b) its circuit symbol

In photovoltaic systems, low-loss Schottky diodes are usually used in two ways: As blocking diodes and as bypass diodes. The blocking diodes prevent the rechargeable battery from discharging through the photovoltaic modules if there is no sunlight. The bypass diodes protect solar cells and the panel from possible damage that may be caused by partial shading.

1.5 Light Emitter Diodes

The LED (light emitting diode) has another property in addition to those of a regular diode: It lights up when voltage is applied. LEDs should usually always be operated with a dropping resistor for current limitation. Red LEDs require the lowest voltage (1.8 V). Then there are yellow, green, blue and last white LEDs with the highest voltage (up to 3.6 V).

a)


b)


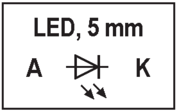
c)


Fig. 006: a) Connection assignments of the light-emitting diodes: the anode (+) with longer connection wire (left) and the cathode (–), b) additionally marked by a flattening at the housing. c) The circuit symbol of the LED

In addition to the »normal« LEDs, there are also special versions such as a flashing LED. The flashing LED can be recognised by the small black drop within the red housing. This dot contains tiny electronics in the form of an integrated circuit that makes the LED flash - once the right voltage is applied.

1.6 Transistors

Transistors are active components that are used in electronic applications to switch and amplify current and voltage.

The bipolar transistors contained in the learning package have the type designations 2N 3904 and 2N 3906. These are complementary small-power transistors that are suitable for a maximum operating voltage of 30 V and a current of up to 200 mA. Complementary means that they are a matching transistor pair of an NPN and a PNP transistor. The designations »N« and »P« stand for the negative and positive semi-conductor layers in the transistor. If you are not very familiar with these terms yet, you will understand their functions from the practical experiments later.

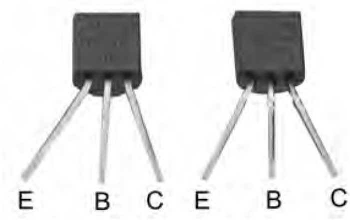


Fig. 007: Transistor connections.

E = Emitter, B = Basis, C = Collector

How the transistor works

A small current applied to the basis-emitter section can control a large current on the collector-emitter section. I.e. if a low basis current is flowing (positive in NPN transistors, negative in PNP transistors), the transistor will conduct the current from the collector to the emitter or vice versa. If no current is flowing through the basis or if the basis connection is with negative (NPN) or positive potential (PNP), the transistor will block.

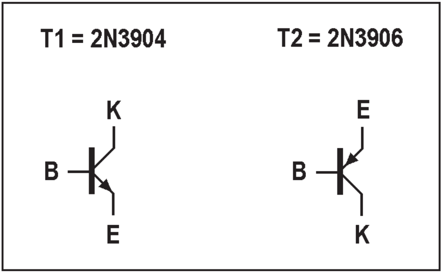
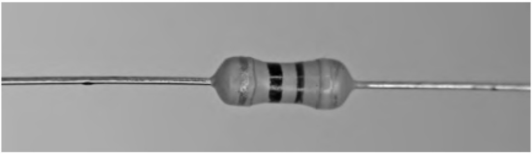


Fig. 008: Circuit symbols for NPN and PNP transistors.

1.7 Resistors

A resistor is a passive element in electrical and electronic circuits. Its main task is reduction of the flowing current to sensible values (also see chapter »Light-Emitting Diodes«).

The best-known resistor build is the cylindrical ceramics carrier with axial connection wires.

a) 

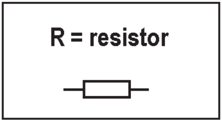
b) 

Fig. 009: a) Resistor, b) Circuit symbol

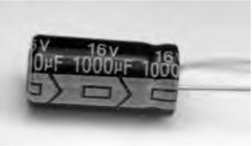
The resistor values are encoded and printed on as coloured rings. The learning package contains carbon layer resistors with the following values and colour rings according to the table:

Amount	Resis-tance	1st ring 1st number	2nd ring 2nd number	3rd ring Multiplier	4th ring Tolerance
1	1.2 Ω	Brown	Red	Gold	Gold
1	1.5 Ω	Brown	Green	Gold	Gold
1	10 Ω	Brown	Black	Black	Gold
1	100 Ω	Brown	Black	Brown	Gold
3	1 kΩ	Brown	Black	Red	Gold
1	2.2 kΩ	Red	Red	Red	Gold
1	100 kΩ	Brown	Black	Yellow	Gold

1.8 Electrolytic Capacitors

Electrolytic capacitors (elcos) have a high capacity as compared to regular capacitors. Due to the electrolyte, an electrolytic capacitor is polarity-dependent and the connections are marked with a plus and a minus pole. If a component is connected »swapped« for an extended period of time, this will destroy the electrolyte of the capacitor. The printed-on maximum voltage indication should not be exceeded. Else, the insulation layer may be destroyed.

μ always is the millionth part of the basic unit. μF means micro farad.

a) 

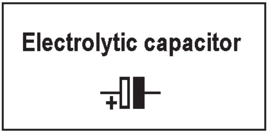
b) 

Fig. 010: a) Electrolytic capacitor. The minus pole is marked by a light-coloured dash at the housing. b) The circuit symbol of the electrolytic capacitor

1.9 Battery Holder

The battery holder is used to hold the rechargeable battery in the AA-mignon format. The battery holder can also be used for the AAA-micro format if the spring at the minus pole connection is elongated a little.

a)

b)

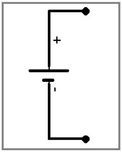


Fig. 011: a) Battery holder; b) Circuit symbol of the battery

1.10 Experimenting Cable

Use the red and black experimenting cables at the ends of which alligator terminals are connected to quickly and simply electrically connect parts to the circuit and to each other – without soldering gun and screwdriver. It is sensible to use the red connection cables for the plus pole and the black ones for the minus pole.

Fig. 012: Experimenting cable with alligator clamps

1.11 Jumper Wire

Wire bridges can be made of the enclosed jumper wire. For this, estimate or measure the approximate length of the wire jumper (plus the length for the wire ends that are to be pushed into the plug-in contacts). The ends must be stripped on approx. 8 mm then. Connection wires that were cut off with a wire cutter can be plugged more easily. The wire jumpers produced once can be reused as often as desired.

2. Use of the USB-Cable

The enclosed USB cable should be connected to a 5-V-USB plug-in mains adapter as it is used for charging mobile phones. Generally, connection to the USB output of a PC is possible, but advised against. The reason: At accidental short circuit when setting up the circuit, the current limitation in the computer (usually in the form of a resistor) may be destroyed.

2.1 Connecting the USB Cable to the Plug Board

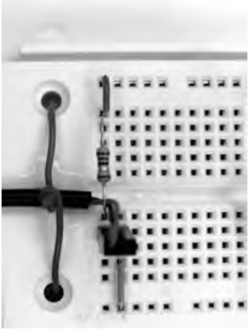
Test setup: Plug board, cable with USB-A plugs and pins, resistor 1 kΩ, resistor 1.5 Ω, red LED

> The USB cable can remain connected to the plug board for the following charging experiments.

Plug the pin plug of the USB cable into the contacts of the plug board. Observe that the plus pole of the pin plug leads to the upper current supply rail. Then connect the pin connected to the red cable to the plus pole strip and the pin of the black cable to the minus pole strip with the enclosed jumper wire (see figure). The protective resistor at 1.5 Ω serves as a short-circuit protection in any case.

a)

b)



c)

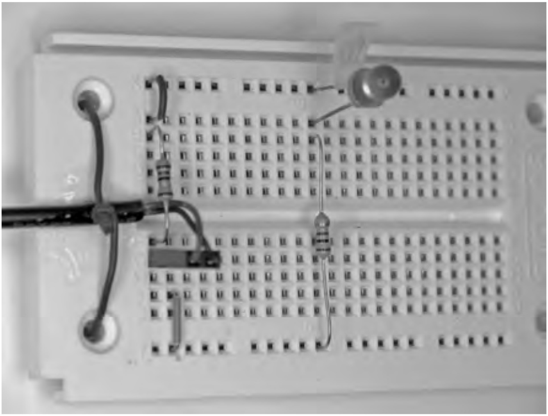


Fig. 013: a) and b): Connect pin plugs to the plug board; connect the 1.5Ω protection resistance to the plus pole. c): Add the LED and the 1kΩ resistor.

In the next step, plug in the red LED. Observe that the longer connection wire reaches the plus pole. Additionally push the 1 kΩ resistor into the plug board. If the USB plug is now connected to the USB power source, the LED should light up.

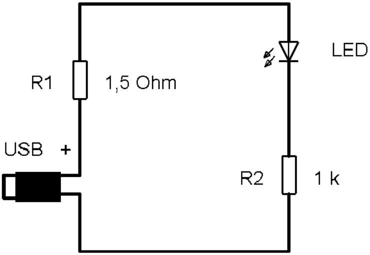


Fig. 014: Circuit diagram with USB connection and red LED

3. Storing Energy

The principle of energy storage with electrical current that cannot be perceived with our senses can be compared and explained with a principle that we can observe in water: A water container is filled with water from a tap. The water can be taken out again at a later time.

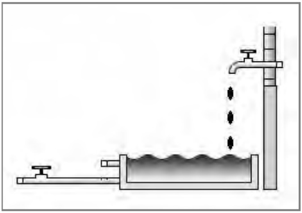


Fig. 015: Principle of energy storage, illustrated by a water tank

The »energy storage« has different forms in the electronic world. The learning package contains an electrolytic capacitor. The storage effect can be illustrated well with this. The benefit of the capacitor storage is in its very long service life. As compared to the rechargeable battery, the storage capacity is low, which has the benefit for experiments that the principle of storage happens in a short period that can be observed well. Comparison: The water tap fills only a small jar. That is much faster than to fill a larger pool.

3.1 Energy Storage with the Electrolytic Capacitor

Test setup: Plug board, cable with USB-A plugs and pins, resistor 1 kΩ, red LED, electrolytic capacitor, 1,000 µF

The preceding setup is expanded by the electrolytic capacitor. The connection wires of the electrolytic capacitor point to the plus pole rail of the plug board with their plus poles. If the electrolytic capacitor is plugged in correctly, plug the USB plug into the USB plug-in mains adapter. The LED lights up. Disconnect the USB plug from the USB source. The red LED will continue to be lit for a short time although the power supply has been interrupted. The power is interim-stored in the electrolytic capacitor.

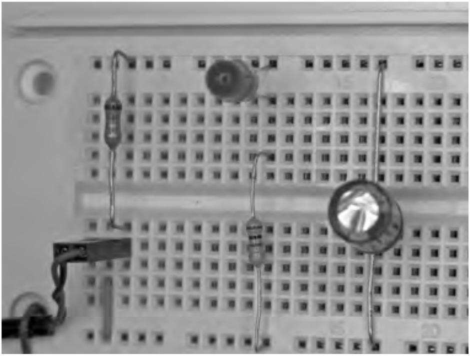


Fig. 016: Plug board with storage electrolytic capacitor

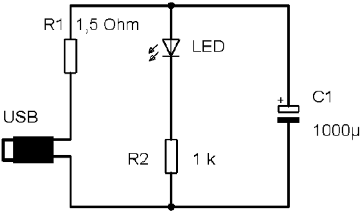


Fig. 017: Circuit diagram

4. Familiarising Yourself with Battery Types

The most common battery types used in everyday life:

1. Lead batteries (lead acid, lead gel), e.g. starter battery in the car.
2. Nickel cadmium (NiCd; no longer being sold), often used in cordless screwdrivers.
3. Nickel metal hydride (NiMH)
4. Nickel zinc (NiZn; new on the market)
5. Lithium (Li) in very different designs

The lead battery is familiar from cars as „starter battery". This battery type is cost-efficient, long-term stable but heavy. Referring to its weight it only has a low energy content. Lead is a heavy metal. Old rechargeable batteries must be returned and are then recycled.

Battery types 2 to 5 are the object of the following experiments. Although the nickel-cadmium battery is no longer sold, the long service life of this battery type means that there are still many of it in use.

The experiments practically explain the different charging procedures and what to observe during them.

5. First Step with the Solar Module

Experimenting setup: Solar module, alligator clamps, 2 red LEDs

The learning package includes two red LEDs that are hardly distinguishable from the outside. To find out which one is the flashing LED and which one the „regular" one, you can perform the following simple experiment with the alligator cables and the solar module: Connect the alligator cable and clamps to the connection wires of the solar module, red to red and black to black. Then connect the red alligator clamp to the longer connection wire of one of the red LEDs and the black one to the shorter connection wire. If light falls onto the solar module, you can see that the connected LED either flashes or stays lit.

Fig. 018: Experimenting setup with alligator clamps

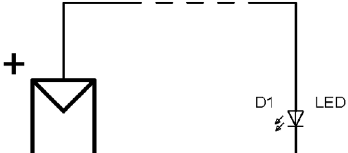


Fig. 019: Circuit diagram, on the left the symbol for the solar module

Usually, LEDs should be operated with a dropping resistor. Since the solar module will only deliver a limited current and this is a short-term experiment, you can make an exception to find out which one is the permanently lit LED and which one the flashing LED. The flashing LED is then marked with a piece of adhesive tape for the further experiments.

Fig. 020: Marked flashing LED

6. Charging Rechargeable Batteries with the USB Source

USB is a standard in the computer area and widely distributed. Electronic devices, computer accessories, such as external hard discs, but also small lamps, fans, etc. can be operated with it.

Most mobile phone providers now offer micro USB as the standard device socket for the charging contact.

The USB standard in the computer is set up so that the devices will first start in Low Power-Mode (100 mA or 150 mA) and request a higher current before they switch to regular mode.

The different applications mean that mains units with a 5-V-USB current source are very common. The current supplied by the mains unit is usually at 500 to 2,000 mA. This kind of USB mains unit is well suitable for the other charging experiments.

Fig. 021: USB mains unit

The USB source is great for charging experiments with smaller rechargeable battery cells. Use requires electronic circuits that consider the special charging conduct of the respective rechargeable battery types, though.

Fig. 022: USB-cell-NiMH, mignon cell with integrated USB adapter

Fig. 023: Compact USB-charger for AA and AAA rechargeable batteries of types NiMH and NiCd

7. Charging NiMH and NiCd Rechargeable Batteries

Test setup: Plug board, cable with USB-A plug, resistor 100 Ω, LED orange, battery holder, rechargeable battery AA or AAA, if present: Multimeter

The rechargeable batteries, such as the NiMH rechargeable batteries and the NiCd rechargeable batteries, are alternatives to disposable batteries. The last rechargeable battery type listed is no longer sold.

Nickel metal hydride rechargeable batteries are currently the most common rechargeable battery type. They are available in various formats. In turn, the most frequently used formats would be mignon (AA) and micro (AAA). Both can be inserted and used in the battery holder of this learning package.

The battery types are mostly unproblematic when charging and in application. Sometimes, the low cell voltage of 1.2 V as compared to the system voltage of disposable batteries at 1.5 V, is a problem in practice.

Although the rechargeable battery type nickel cadmium is no longer sold, many of these rechargeable batteries are still in use. Cadmium is toxic, which is why sale of this rechargeable battery type is forbidden and has ceased. At the same time, NiCd rechargeable batteries are very robust and will work without problems for a long time if they are properly charged and used.

Below, a simple continuous charging circuit (charge maintenance) from the USB source for NiMH and NiCd rechargeable battery cells is explained. The LED indicates the charging function while also regulating the charge current to approx. 20 mA (with the rechargeable battery flat). The »fuller« the rechargeable battery is charged, the lower will the charging current be and the less will the LED light up.

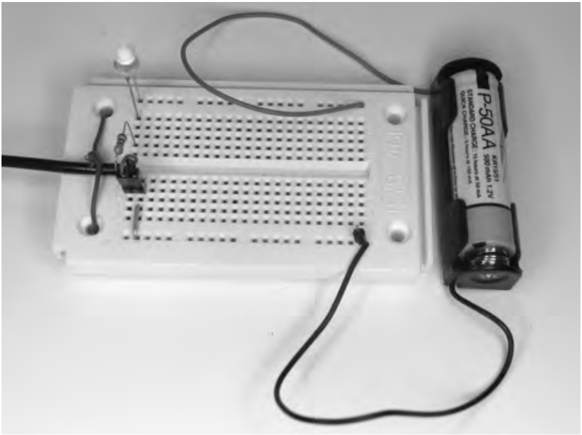


Fig. 024: Setup plug board; a mignon rechargeable battery is being charged.

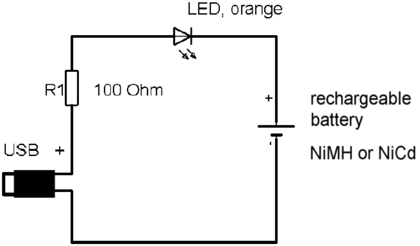


Fig. 025: Circuit diagram

Additional test (with a multimeter): Wire the multimeter in the milliampere range in series with the rechargeable battery. You can then read the current charging current, see figure 026.

Fig. 026: Measuring setup

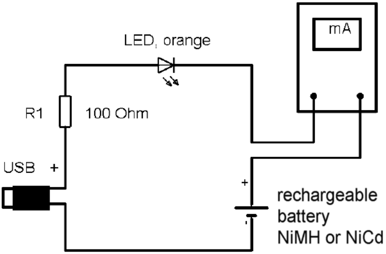


Fig. 027: Circuit diagram

A multimeter can be used to check the charging current and, of course, measure the rechargeable battery voltage. To measure the rechargeable battery voltage, connect the cables of the multimeter right to the battery holder (in parallel to the rechargeable battery).

8. Constant Current Charging

Test setup: USB cable, plug board, 1 resistor 1.5 Ω, 2 resistors 1 kΩ, 1 resistor 1.2 Ω, LED orange, Schottky diode BAT 42, battery holder, rechargeable battery mignon AA or micro AAA

Constant current charging is a wide-spread way of charging rechargeable batteries in simple chargers. Depending on the battery capacity, the flat rechargeable battery is charged for a defined time with constant current.

Fig. 028: Charging recommendation for one rechargeable battery: Constant current charge

The charging recommendation printed on the rechargeable battery indicates the period and current at which it is to be charged. At a simple constant current charge of a rechargeable battery, it is the common practice to charge it at 1/10 of the current of the capacity indication for 14 hours.

Example

Battery capacity: 800 mAh, charging current: 80 mA, charging time: 14 hours. When the 14 hours of charging time are over, there is the option of time-controlled electronics switching to maintenance charge. The charge maintenance can take place with 1/20 of the battery capacity or less, i.e. at 40 mA or less.

There are also chargers with thermal monitoring and deactivation (e.g. in rechargeable batteries of low-cost cordless screwdrivers). This works best with NiCd rechargeable batteries, since they convert the energy flowing in from the charger into heat when fully charged. Thus, the electronics can understand that the rechargeable battery is now fully charged.

In simple mains chargers the charge current limitation of the constant current charge is implemented by a resistor that is inserted between the mains unit and the rechargeable battery and controls the charging current.

The resistor R1 is calculated with the formula: R = U/I. R is the resistance in Ohm, U the voltage in volt and I the current in ampere. R1 should be sized so that the charging current is suitable for the rechargeable battery.

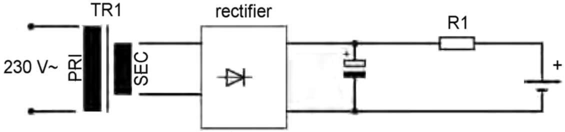


Fig. 029: Principle circuit diagram constant current charger; R1 is the resistor relevant for the charging current.

The charging method with constant current is very simple but has a few disadvantages: The rechargeable battery should be fully discharged and the charging current should be about C/10 of the rechargeable battery capacity to balance out inaccuracies by slight but harmless overcharging. If the rechargeable battery is quick-charge-capable, the charging current may be higher if the charging time is accordingly shorter as well.

Older NiCd rechargeable batteries may suffer from a memory effect if the rechargeable battery has not been fully discharged.

Memory Effect

If not the entire capacity is used after discharging the rechargeable battery and the rechargeable battery is only partially discharged and then charged again, the rechargeable battery will „remember“ this condition and only provide this amount to the consumer the next time it is discharged.
The charged battery then loses more and more useful capacity in the course of its service life, since the cadmium cathode forms crystals that reduce the rechargeable battery output.

The memory effect can be „deleted“ by deliberate deep discharge. Modern rechargeable batteries only rarely show this problem.

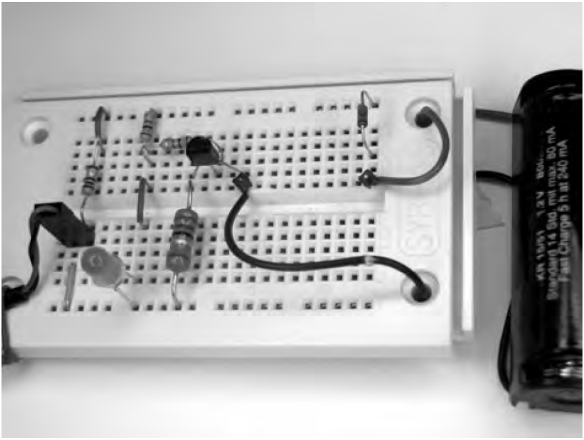


Fig. 030: Plug board setup: Charging with constant current

The voltage distributor, comprising of R2 and D2, as well as the basic resistor R4, can be changed as well. This changes the constant charging current. You can thus first experiment with R4, i.e. replace the 1 kΩ-resistor (R4) with the 2.2 kΩ-resistor of the learning package, to get a lower charging current for the rechargeable battery.

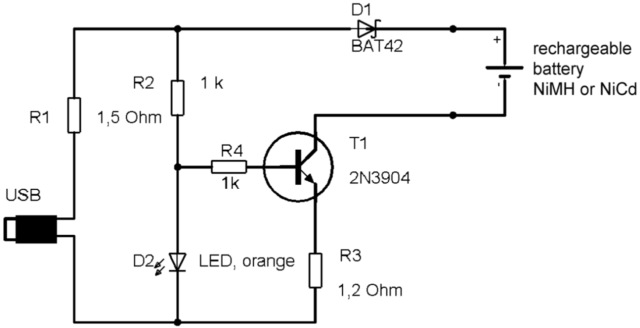


Fig. 031: Circuit diagram of the constant current charger

9. Impulse Charging

Test setup: USB cable, plug board, flashing LED, LED orange, diode 1N 4001, transistor T1 2N3904, transistor T2 N3906, resistor 10 Ω, 2 resistors 1 kΩ, battery holder, rechargeable battery AA mignon or AAA micro

Impulse charging mostly prevents the memory effect even in older rechargeable battery cells. Short current surges will charge the rechargeable battery cell. The rechargeable battery is charged faster or more slowly depending on wiring. Older rechargeable batteries may also be regenerated.

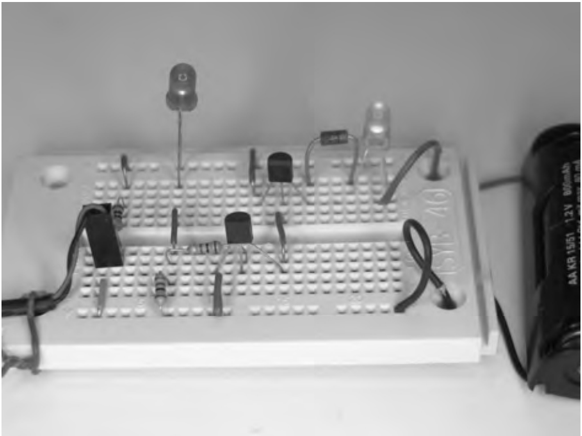


Fig. 032: Test setup for impulse charging; both transistors are plugged in so that the type designation can be read by the observer. The upper transistor is T2 (2N3906), the left LED is a flashing LED.

The flashing LED and the resistor R2 together form a voltage distributor. The LED emits impulses to the basis of transistor T1. T1 Controls the basis input of transistor T2 via the collector-emitter section. It releases the current flow to the rechargeable battery as longitudinal transistor. The orange LED shows by its flashing brightness whether and how much current is flowing to the rechargeable battery.

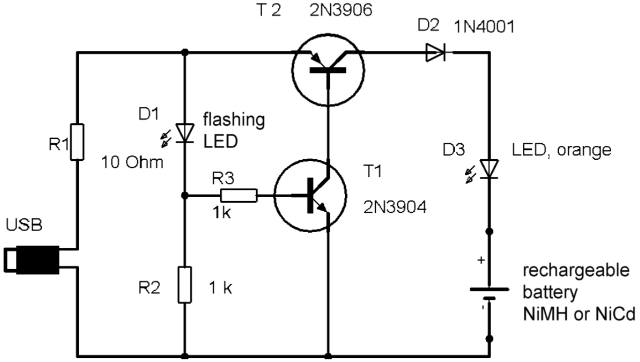


Fig. 033: Circuit diagram impulse charging

If a multimeter is at hand, the pulsating and rising rechargeable battery voltage can be observed. If the diode D2 is bridged, charging is faster (more charging current), but at the expense of the orange LED‘s service life.

Fig. 034: Setup for measuring impulse charging with a multimeter

10. Charging a Nickel Zinc Cell

Test setup: USB-cable, plug board, red LED, orange LED, resistor 100 Ω, battery holder, NiZn rechargeable battery AA mignon or AAA micro.

The nickel zinc cell (NiZn) is a very old and also more recent development on the rechargeable battery market. The benefit of this cell type is a higher cell voltage of approx. 1.6 V. Thus, it is better to replace disposable batteries (1.5 V). Specifically in electronic devices intended for only one or two battery cells, the NiMh-cells are frequently below the required operating voltage too quickly. This prevents the capacity from being used fully.

Fig. 035: Professional charger nickel-zinc, for AA and AAA cells

It is interesting that the capacity in the NiZn rechargeable battery is not indicated in milliampere, but in milliwatt hour.

The voltage of a freshly charged NiZn-cell is at approx. 1.8 V and the discharge end voltage, depending on current load, at about 1.2 V. Since the cell type is still rather new, there is little experience with the cycle number yet.

Rechargeable battery cycles means the number of times the rechargeable battery cell can be completely charged and discharged before it is rendered useless.

The required charging technology for the NiZn rechargeable batteries is generally simple and similar to the charging technology of lead rechargeable batteries. Processor-controlled chargers offer a higher safety standard and better charge efficiency with more options for charging and discharging technology.

The charging principle

Charging takes place with a current limitation that is about 0.5 to 1 times the rechargeable battery capacity (0.7 A to 1.5 A in the AA type). The charging end voltage, i.e. the voltage when the rechargeable battery is fully charged, is approx. 1.9 V. At the same time, the charging current reduces to less than 0.05 C (in the AA cell 75 mA) at the end of charging.

The specific energy density is approx. 50 Wh/kg, which is about the same as for the NiCd rechargeable batteries, but less than in the NiMh- and the Li rechargeable battery.

C means the capacity of the rechargeable battery, usually in milliampere hours (mAh).

A simple experimental USB charger with which the NiZn rechargeable battery cell can be charged as shown in fig. 036 as a plug board setup. The smaller AAA micro rechargeable battery with 550 mAh is used as a rechargeable battery cell.

It is important for the circuit setup for a simple charger that the charging end voltage is stabilised/limited to max. 1.9 V. If the current used for charging is lower, this is unproblematic and charging merely takes longer. For many rechargeable battery types, a gentler charge (at a lower current) is rather of benefit and contributes to a higher number of charging cycles. Quick-chargers charge rechargeable batteries in the shortest time possible.

On rechargeable battery packaging and the rechargeable battery housings of the NiZn rechargeable batteries there is the charging recommendation:

AA Mignon: 12–15 hours at 150 mA, quick-charge capable

AAA micro: 12–15 hours at 55 mA, quick-charge capable

At the pre-set charging circuit, the charging end voltage is implemented with the orange LED. This LED shows the charging status at the same time. When the rechargeable battery is empty, the LED will not light up. If it has a bigger charge, it lights up brightly. The current is controlled by the resistor R1 and the red LED.

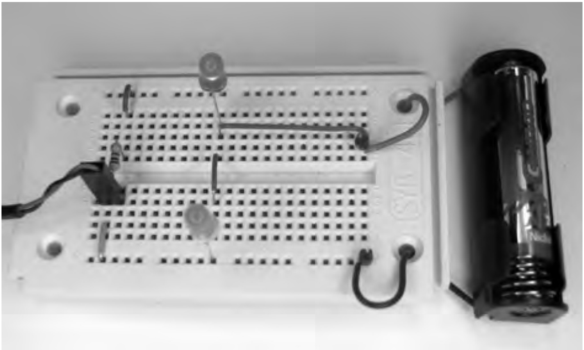


Fig. 036: Plug board setup, charging circuit NiZn rechargeable battery

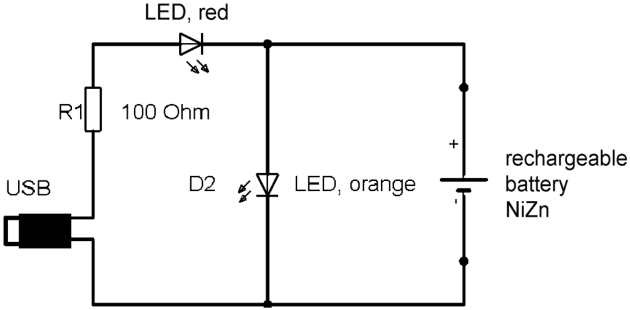


Fig. 037: Circuit diagram

The self-discharge of the NiZn cells takes place independently of the ambience temperature, according to experience in the area of approx. 5 – 7%.

11. Charging Lithium Rechargeable Batteries

Test setup: USB-cable, plug board, red LED, 2 diodes 1N 4001, resistor 1 kΩ, cable with alligator clamps red and black, lithium rechargeable battery.

Most mobile phones and Smartphones, notebooks and tablet PCs work with lithium polymer (LiPo) or lithium ion (Li-Ion) rechargeable batteries.

This rechargeable battery type has a high energy density at a low weight. The rechargeable batteries are replaceable or firmly installed (soldered in). One problem is that this rechargeable battery form has many different types (flat, round, square, etc.), rather than a consistent standard as in disposable batteries (e.g. mignon and micro cells).

The energy density is at 95–400 Wh/l, depending on materials and use. If the rechargeable battery is only partially charged and then partially discharged again, the number of possible charging cycles is strongly increased. The usable energy density drops at the same time, though.

The charge type is less complicated than is frequently assumed and generally looks as follows: If the rechargeable battery has been discharged very deeply, start with a very low charging current. In regular charging, the cell can be charged at the constant maximum current in the 0.5–1 C range, though.

The final charging voltage is 4.1–4.2 V, depending on type, and should never be exceeded. It serves longevity of the rechargeable battery to keep the final charging voltage a little lower. 3.9–4.0 V (depending on rechargeable battery type) are sensible.

Of course, LiPo and Li-Ion rechargeable batteries can also be charged at a lower charging current. This also increases the number of cycles that can be reached (the number of charging and discharging processes).

The rechargeable battery is completely charged (full) at a final charging voltage of 4.1–4.2 V, the charging current will drop to about C/10. This is also the technical measuring evaluation for automatic chargers to end charging.

Note on discharge

The final discharge voltage must never drop below 2.5 V. Otherwise, the rechargeable battery cell is destroyed. The rechargeable battery management usually integrated in the rechargeable battery therefore usually switches off at 3.0 V.

It is recommended to „gently“ (dis-)charge lithium rechargeable batteries (only to approx. 30 %), since this will extend their service lives.

If you want to build your own charger, precise control of the final charging voltage is mandatory. A stabilised voltage supply is usually built with fixed voltage controllers. At the same time, the market offers complete charging ICs for comfortable and safety-technically good charging of the lithium rechargeable batteries.

Important!

For the following charging experiments, it is urgently recommended to use only lithium rechargeable batteries with integrated protection electronics.

These are removable rechargeable batteries as they are used in mobile phones, cameras, etc.

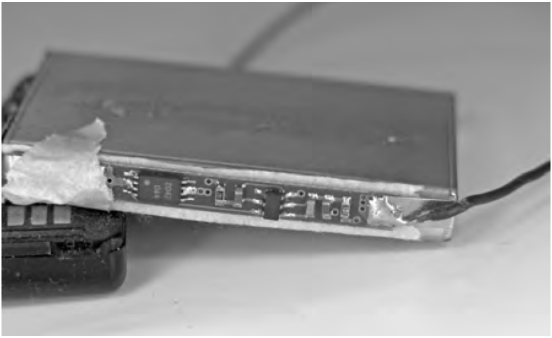


Fig. 038: Suitable rechargeable battery with integrated safety/protection electronics

The integrated safety electronics ensure that the rechargeable battery is not overcharged nor enters undervoltage when discharging, and switches off the connection to the rechargeable battery contacts.

Thus, you can easily experiment with rechargeable batteries of mobile phones while the upper and lower temperature limits and the maximum charging current (1C) are not exceeded.

The charging circuit for charging a lithium rechargeable battery with the USB source is built with very simple components on the plug board. The voltage that is stabilised to 5 V with the USB source must be reduced to a compatible charging end voltage of barely 4 V. The LED ensures that the idle voltage (without rechargeable battery) at the output does not rise above 4 V by a low current consumption. The charging current is also controlled by the components and will reduce with increasing charge/

rechargeable battery voltage. Even through this simple charging circuit works, this is a charging equipment and you must not use any comfort charger.

The contacts of the lithium rechargeable battery can be connected to the alligator clamps. Depending on rechargeable battery type, this will work more or less well. It would of course, be most reliable to solder two cables to the gold contacts if you have soldering equipment at hand. Otherwise, you can lift the upper area of the rechargeable battery where the contacts are off the rechargeable battery body slightly so that the terminals will be attached between the contact strip and the rechargeable battery body.

Fig. 039: Clamping connection with the rechargeable battery contacts

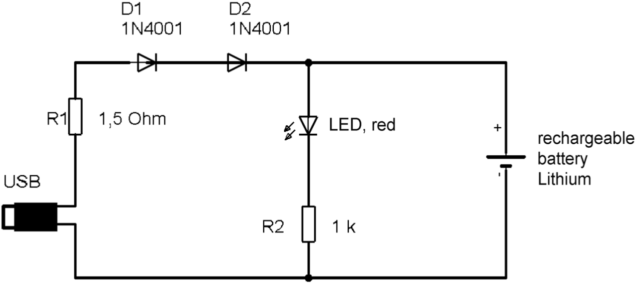
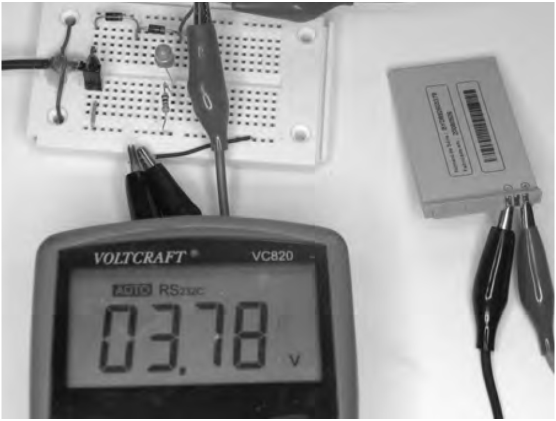


Fig. 040: Circuit diagram of a simple lithium charger

If a multimeter is at hand, you can measure the rising rechargeable battery voltage of the charging current.

a) 

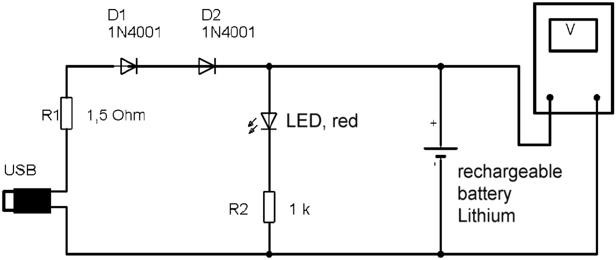
b) 

Fig. 041: a) Rechargeable battery charging and monitoring with the multimeter.
b) The circuit diagram for it

12. Monitoring Charging

There are several ways to determine the output values around the rechargeable battery to be charged:

- Display with LEDs
- Measurement with a multimeter
- LC display
- Measurement and evaluation with the PC

Light-emitting diodes can be used for simple measuring tasks (e.g. polarity display) or general function displays (e.g. whether a charging current is flowing or not). If detailed measuring information is desired, a multimeter is a good aid. The learning package implements simple measurements and function displays with LEDs. If you have a multimeter at hand, you can use it additionally.

12.1 Rechargeable Battery Tank Display

Test setup: Plug board, USB cable, flashing LED, LED orange, diode 1N4001, resistance 1 kΩ, lithium rechargeable battery

Is the energy accumulator flat, half charged or charged? We need a display similar to the tank indicator in the car, except that an indicative tank indicator for the charging status of a rechargeable battery is much more complicated. The charge status depends on many factors, such as the charging and discharging types, capacity, etc. However, there are quite a number of other factors, such as the operating temperature, age of the rechargeable battery (service life) and some others that can influence the charging condition further.

To keep a grip on all factors, there are sophisticated monitoring electronics with microprocessors and elaborate software.

You can use the parts in your learning package to set up a simple charge status display to learn the basic principle.

Fig. 042 shows the test setup for a very simple charge status display. After setting up the components, first connect the lithium rechargeable battery to the plug board with the alligator clamps. Then the orange LED lights up. Once the USB plug is plugged into the USB mains adapter, the rechargeable battery is charged at approx. 200 mA. A short time later, the flashing LED starts to flash and indicates that the rechargeable battery has reached the voltage of about 4 V. The flashing LED will first slow down and then speed up. This indicates that charging must be terminated at once. A comfortable charger would do this automatically.

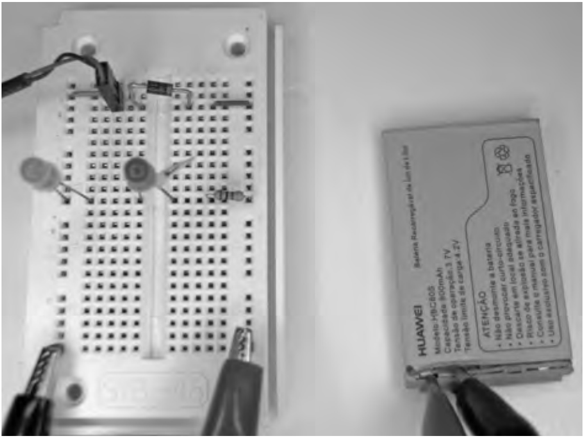


Fig. 042: Test setup of a simple charge status display

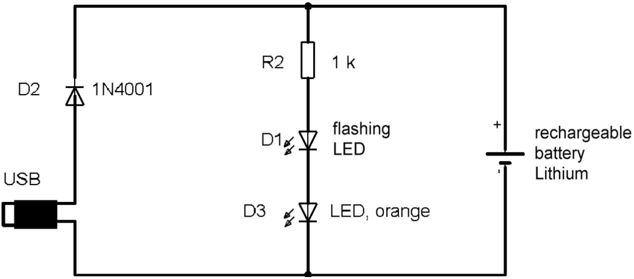


Fig. 043: Circuit diagram of the charge status display

The simple battery tank display is still implemented via the voltage measurement of the rechargeable battery. It would be progress to perform the voltages measurement under load (current tapping from the rechargeable battery). The load should have a current consumption of about 10% of the rechargeable battery capacity and could be activated at the time of measurement using a button.

13. Testing Rechargeable Batteries

Everyone knows it: You have rechargeable batteries for many different uses in your drawer, but you do not know how much charge they still have. This is particularly important when using several rechargeable batteries. An electronic device will only work if all of them are sufficiently charged. Only measuring voltage will tell you little about the „charge capacity“ of a rechargeable battery.

Fig. 044 shows a simple rechargeable battery tester with a rotary coil instrument and a light bulb (1.5 V) as load resistor – the benefit of the light bulb is that it provides a good visual signal indicating the rechargeable battery‘s performance capacity.

The alternative to the glow bulb is a load resistor or 10 Ω. The load current for the rechargeable battery is then approx. 150 mA.

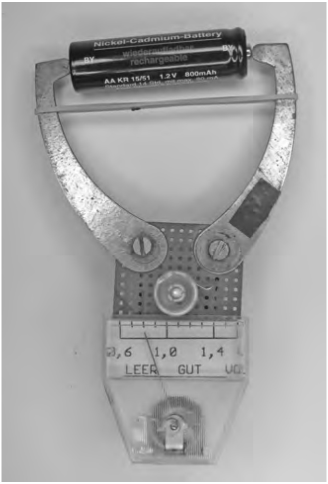


Fig. 044: Simple rechargeable battery tester (self-made test unit) for AA and AAA rechargeable battery cells with rotary coil instrument and glow bulb (1.5 V) as load resistor

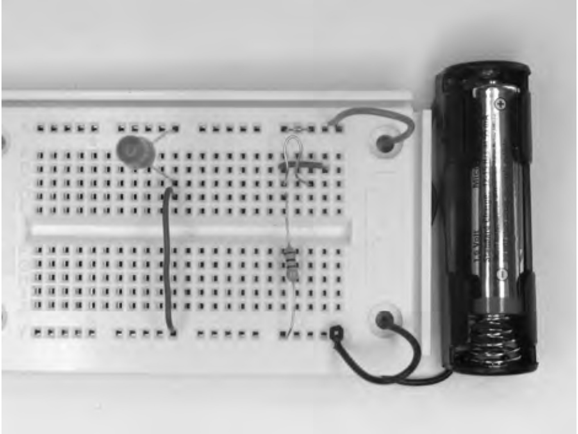
Subsequently, rechargeable battery status test circuits for nickel-zinc cells are presented.

13.1 Test at Low Current

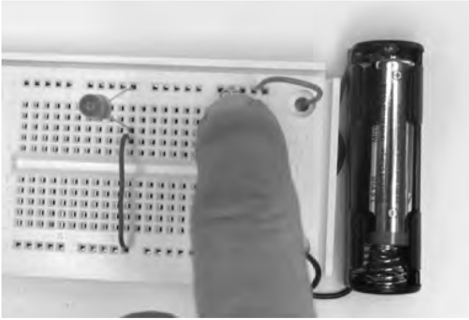
Test setup: Plug board, red LED, resistor 100 Ω, battery holder, NiZn rechargeable battery, micro AAA.

> The tests can be performed with different rechargeable battery types as well if you have a multimeter with which the rechargeable battery voltage under load can be displayed.

The test at low current load usually is not a big problem even for older rechargeable batteries that have been freshly charged. The button switch for the rechargeable battery test is a piece of stripped wire, installed in the contacts of the plug board as illustrated.



a)

b) 

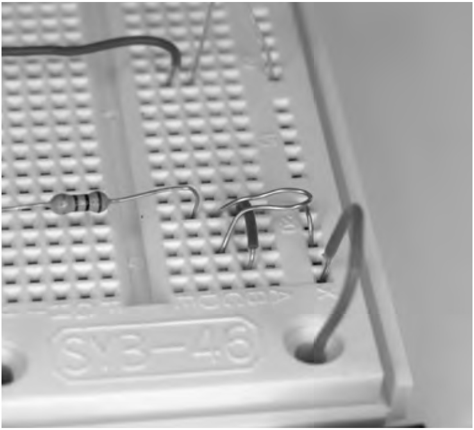
c) 

Fig. 045 a, b, c: Plug board setup for the rechargeable battery test

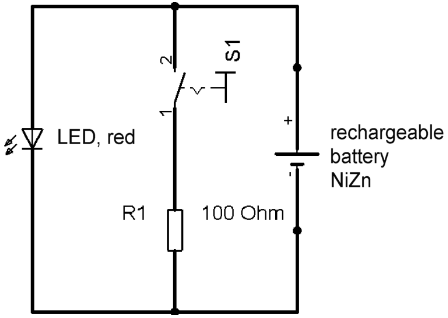


Fig. 046: Circuit diagram

Insert the rechargeable battery in the battery holder; when the rechargeable battery cell is fully charged. The LED lights up. Now push the button. The LED will darken slightly. With the 100 Ω resistor, about 15 mA of load current will flow. This is easily possible for the rechargeable battery. Therefore, the rechargeable battery voltage will only drop slightly.

13.2 Test at High Current

Test setup: Plug board, red LED, resistor 1.2 Ω, battery holder, rechargeable

> The tests can be performed with different rechargeable battery types as well if you have a multimeter with which the rechargeable battery voltage under load can be displayed.

The test at higher current is a bigger challenge for the rechargeable battery. Observe the maximum discharge current to be applied to the rechargeable battery without damaging it. In lithium rechargeable batteries, it is usually a current of twice the capacity, in nickel-zinc rechargeable batteries, the recommendation is: do not discharge any lower than to the voltage of 1.2 V and at no more than 1C.

For the AA-mignon rechargeable battery, that means a maximum current of 1.5 A and for the smaller AAA cell a maximum discharge current of approx. 550 mA.

Now the resistor R1 is replaced. Instead of the 100 Ω resistor, the 1.2 Ω resistor is now put into the plug board. If you push the wire button now, the LED will go out. The load current is approx. 1 A when calculated with the formula R = U / I and about 0.5 A when measured with the multimeter.

The practical measuring result may deviate from the calculated value. This is because of the plug board contacts, battery holder contacts, cables, internal resistors of the rechargeable battery, etc.

When the button is released again and the rechargeable battery has been charged well, the LED will be lit as before. If it is not, charge the rechargeable battery. It has not passed the stress test.

You can check the measurements with the multimeter: Without stress, the NiZn rechargeable battery cell has, e.g., 1.75 V. Under load, the voltage drops to 1.3 V.

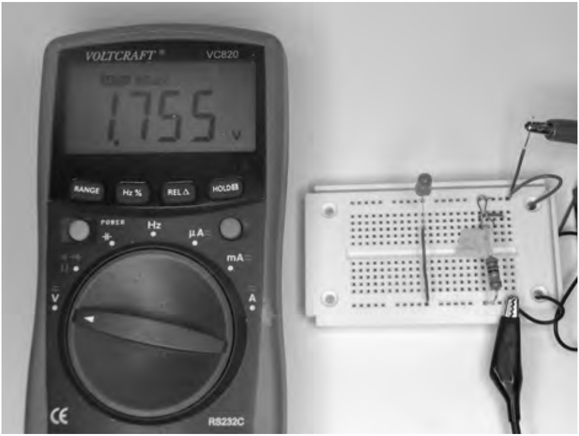


Fig. 047: Plug board setup

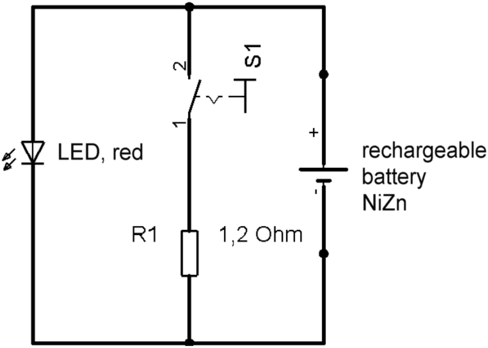


Fig. 048: Circuit diagram

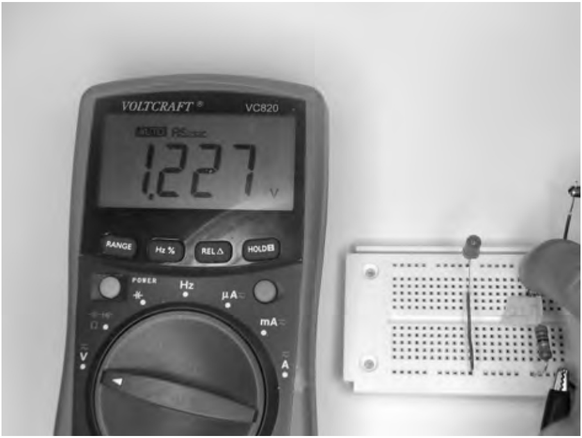


Fig. 049: Measuring setup with multimeter

Rechargeable battery efficiencies

The rechargeable battery efficiency states the amount charged in it and how much of it can be taken from the rechargeable battery again.

The efficiencies of the different rechargeable battery types fluctuates strongly from approx. 70-90 %.

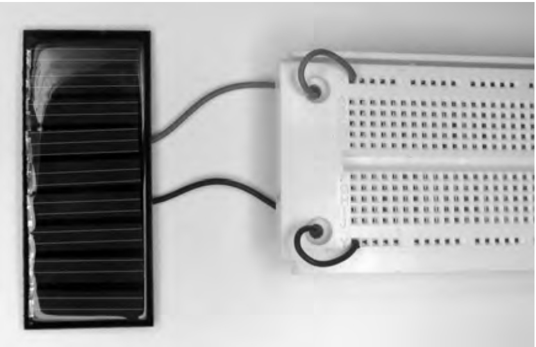
14. Rechargeable Battery and Solar Module

Test setup: Solar module, plug board, plug pins, resistor 100 Ω, red LED

The front of the unused solar module is protected with a film. This must be removed first.

On the rear of the module there are two soldering connections with soldered-on cables. The module supplies direct current. Thus, there are a red cable, the plus pole, and a black cable, the minus pole, like in a battery. Push the cable through the bores of the plug board (tension relief) and then connect the black and the red cable to the plug board. It is recommended to plug the black connection into the bottom rail and the red connection into the top rail.

The solar module may remain connected for the subsequent experiments.

a) 

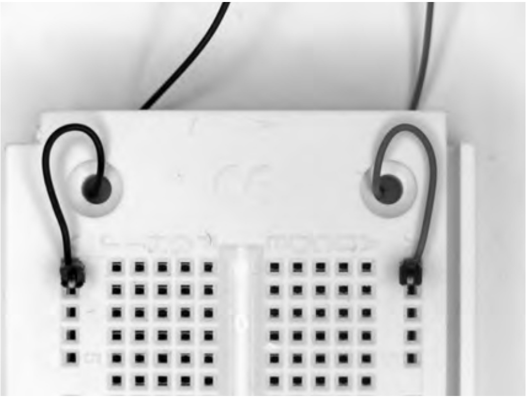
b) 

Fig. 050: a) Connect the connection lines of the solar module to the plug board.
b) The cables can be additionally secured with the plug pins.

Place the solar module so that sufficiently bright light, preferably sunlight, falls onto it.

> If the sun does not shine during the experiments, you can replace it with a bright desk lamp, e.g. with a halogen light bulb (at least 30 W). Energy savings lamps and LED lamps are not suitable.

Now plug the connections of the red LED and the dropping resistor 100 Ω into the plug board. The longer connection of the light-emitting diode is to be connected to the +-»side«. Depending on the radiation intensity, the light-emitting diode will light up more or less brightly. If the LED does not light up, either there is not enough „light energy" or the LED has been connected in the wrong polarity. If the light-emitting diode flashes, you have accidentally used the flashing LED.

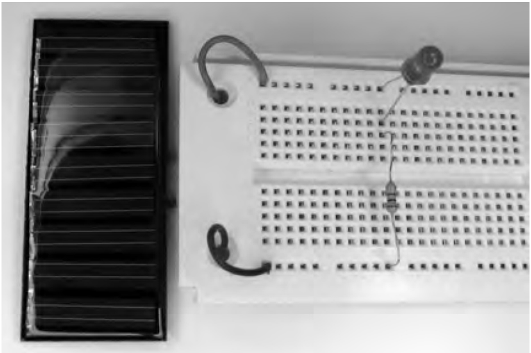


Fig. 051: Plug board setup; simple function test with the red light-emitting diode

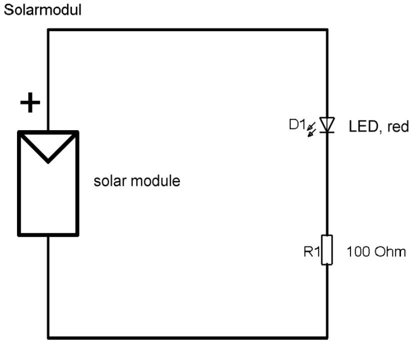


Fig. 052: Circuit diagram

You can perform this experiment with different light sources, e.g. with sunlight, a halogen lamp, a light bulb, a flashlight, an energy savings lamp, a fluorescent lamp, etc. You can tell by the brightness at which the LED is lit whether they are suitable or less suitable light sources. This experiment is important to teach you about suitable lighting for the subsequent experiments.

14.1 Charging Rechargeable Batteries with Solar Energy

Test setup: Solar modules, plug board, LED red, battery holder, rechargeable battery

If there is sufficient sunlight available, it is a lot of fun to use this energy to charge rechargeable batteries. The power is free of charge and you are independent of a socket.

The solar module of the learning package can be used to charge any previously described rechargeable battery types, such as NiMh, NiCd, NiZn, Li-Ion and LiPo.

The solar module has a great technical benefit. Both for power limiting and for the maximum charge voltage, you usually do not need any further components if the solar module has been adjusted to the power conditions of the rechargeable battery. Thus, the solar module from the learning package – which supplies approx. 35 mA current and a maximum voltage of 4.5 V at full sunlight, can safely load the listed rechargeable battery types and also ensure that any self-retention will automatically be balanced out (charge retention).

> The proportionality of solar module and rechargeable battery changes in „larger“ (higher-performing) solar modules that can supply more current and higher voltages. A charging current limitation and/or charging electronics are urgently required then. Else, the rechargeable battery will be damaged or destroyed.

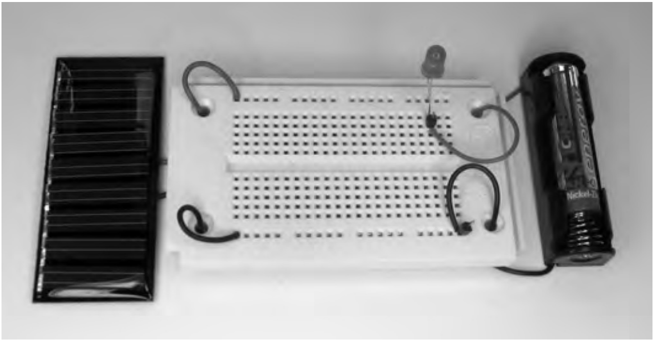


Fig. 053: Plug board setup: Simple solar charger with LED as charging display

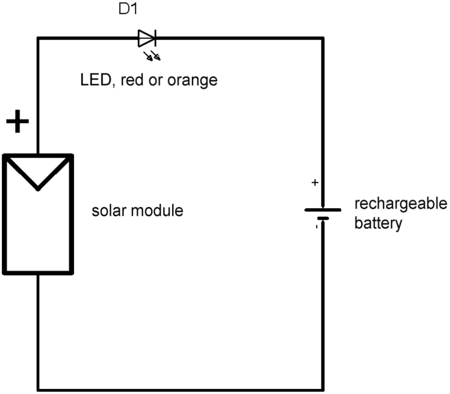


Fig. 054: Circuit diagram; charging current display with one LED

Both the red and the orange LED can be used in the charging circuit. The charging current is a little higher with the orange LED.

14.2 Solar Charger – What to Observe

Test setup (as before): Solar modules, plug board, LED, battery holder, rechargeable battery

Depending on rechargeable battery type, there is a number of options for customising the solar modules so that the rechargeable battery is charged in the best manner. The number of solar cells in series leads to the maximum upper charging voltage. The size and quality of the solar cells determines the maximum charging current. The charging current of course also depends on the radiation energy of the sun.

In smaller NiCd and NiMH rechargeable batteries, it is a simple option of doing this via the maximum charging current from the solar module.

Lead acid and lead gel rechargeable batteries in their simplest versions, in contrast, are controlled via the amount of the charge end voltage.

A „large“ solar lead rechargeable battery with 12 V rechargeable battery voltage can thus be easily charged at the solar module with a maximum cell voltage (idle voltage) of 15 V. The charging curve adjusts on its own. The higher the charging voltage of the rechargeable battery to be charged rises, the lower will the charging current that the solar module supplies be (automatic adjustment). This charging type is practical but not perfect for complete usability and service life of the rechargeable batteries.

The alignment of the solar module is decisive. Take the solar module between your thumb and index finger (without casting a shadow on the surface) and align the surface of the module at a right angle to the light source (sun). When will the LED light up more brightly? Vary the alignment to the light source by moving the solar module back and forth, and observe the LED. The more brightly it lights up, the bigger the charging current that flows from the module to the rechargeable battery.

The more vertically the light hits the solar module, the more light energy can be converted to electrical current by the solar cells and the bigger the charging current that will flow from the module to the rechargeable battery.

Fig. 055: Experiment with the alignment of the module to the light source

15. Using a Return-Current Block

Experimenting setup: Solar module, plug board, electrolytic capacitor 1.000 µF, Schottky diode, resistor 100 Ω, LED red

During solar charging of a rechargeable battery, the charge would „reverse“ unload through the solar module again if it didn‘t have the protective diode. Therefore, a return current lock in the form of a diode must be inserted. The diode works like a valve that only permits the energy current to flow in one direction while preventing it in the other.

To clarify the principle, perform the experiment with the electrolytic capacitor 1,000 µF (remove the rechargeable battery from the holder for this). In addition to the current storage electrolytical capacitor, plug an LED and a dropping resistor into the plug board. This way, you can examine the storage effect depending on the return current diode.

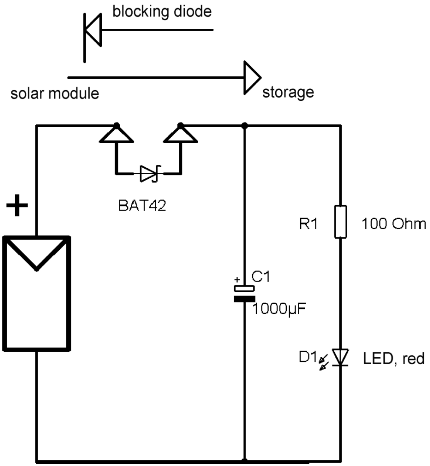
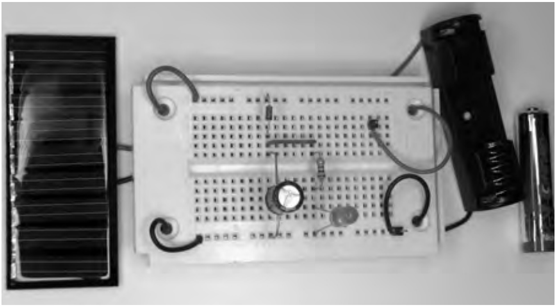


Fig. 056: Principle of the circuit with blocking diode

Turn the diode around in the plug board once – what happens? The LED is no longer lit, since the current coming from the solar module is blocked.

Blocking diodes prevent discharge of the energy storage via the unlit solar cell.

a)



b)

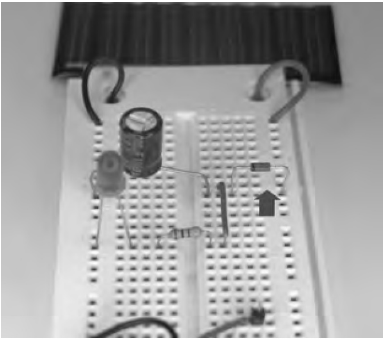


Fig. 057: a) Plug board setup, b) Detail. The blocking diode is shown on the right in the image (arrow)

16. Using the Charge Controller

Test setup: Solar module, plug board, red LED, electrolytic capacitor 1,000 µF, transistor T1 2N3906, resistor 2.2 k, button switch, battery holder, rechargeable battery

In photovoltaic island systems, the entire current supply is gained by regeneration. The rechargeable battery storage stores this energy for later use. A charge controller ensuring that the rechargeable battery is as fully charged as possible without being overcharged is important for charging rechargeable batteries.

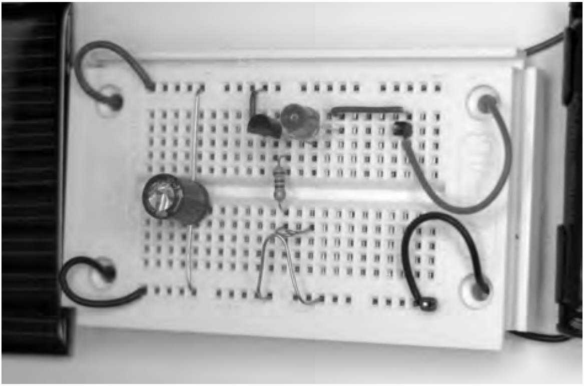


Fig. 058: Test setup of the charging controller on the plug board

In the test setup the control electronics are replaced by a wire button that you can operate manually. The longitudinal transistor T1 is controlled via its basis and controls the charging current and voltage via the collector-emitter section. The red LED shows when the charging current is flowing and flashes briefly when the button is pushed and energy flows into the rechargeable battery.

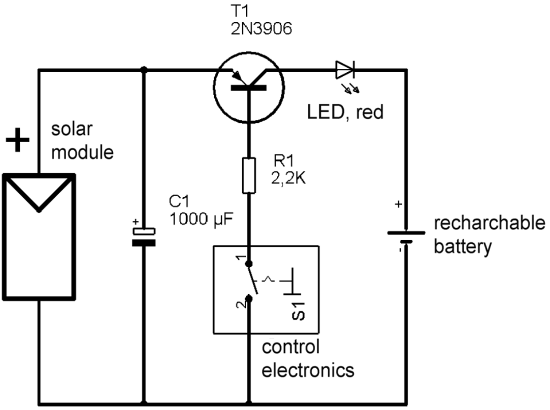


Fig. 059: Circuit diagram charging controller

With the charging controller built on the plug board, you can understand the principle of a serial shunt controller (longitudinal controller). The longitudinal transistor used for the charge control controls the current flowing from the solar module to the rechargeable battery and the voltage. In the test setup the control is achieved by manual cycling (manually) of the supplied current (cycle length and frequency) with the switch S1. This cycling happens electronically in automatic controllers. Then more current flows if the breaks from one cycle to the next are reduced and the cycle frequency is increased. During charging, the rechargeable battery is thus given short current impulses that are shorter or longer depending on the charge voltage height (pulse width modulation). Control of the charging current is adjusted electronically via the longitudinal controller depending on the charging voltage of the rechargeable battery.

Another benefit of the longitudinal transistor is the fact that it prevents the charged rechargeable battery from „reverse“ discharging at night again.

17. Solar Charge Monitoring of the Lithium Rechargeable Battery

Test setup: Solar module, plug board, flashing LED, red LED, orange LED, Schottky diode BAT 42, electrolytic capacitor 1,000 µF, resistor 1 kΩ, alligator clamps, lithium rechargeable battery

Fig. 060 shows the test setup of a simple charge monitoring system for solar charging of the lithium rechargeable battery. The upper red LED indicates the flowing charging current and is lit while the lithium rechargeable battery is charged. The middle flashing LED (»B«) in connection with the diode and the orange LED starts to light up then and thus shows when the rechargeable battery is half or fully charged. Since D1, D5 and the red LED are switched in series, the LED will only flash starting at a voltage of approx. 3.8 V.

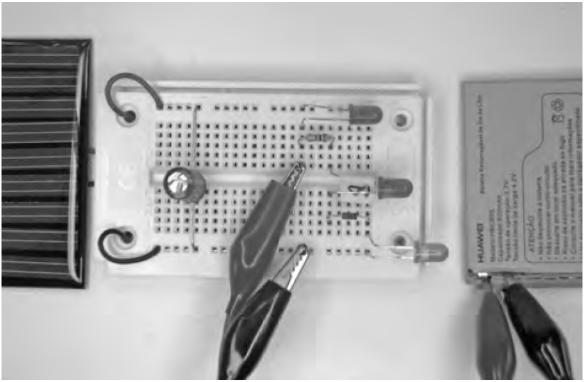


Fig. 060: Test setup on the plug board

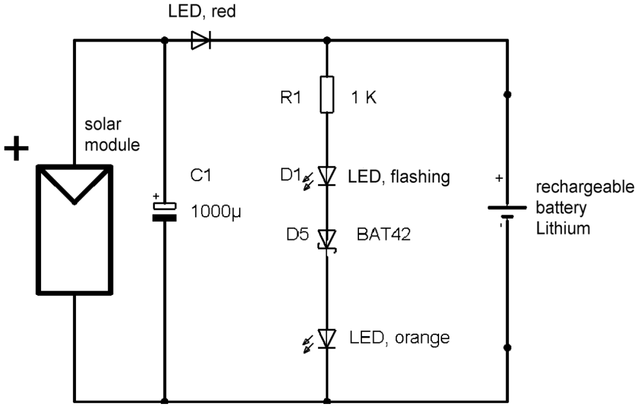


Fig. 061: Circuit diagram of the charge status display

Simplest rechargeable battery monitoring is implemented by voltage measurement of the rechargeable battery.

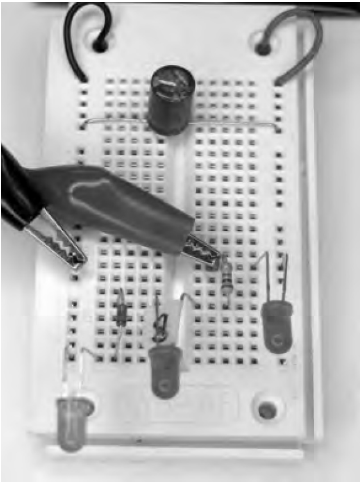


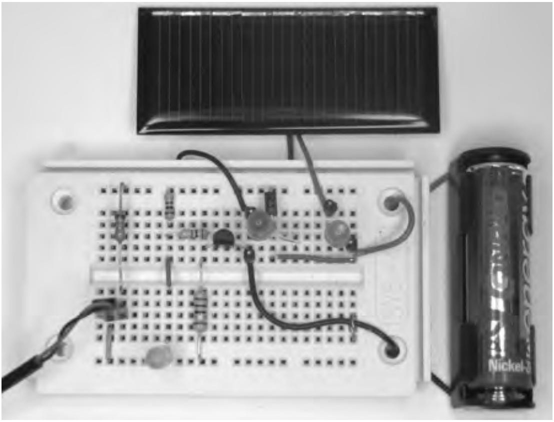
Fig. 062: Detail of the plug board setup; the lithium rechargeable battery is connected with the alligator cables

18. Combination Chargers, Charging and Maintenance of Charge

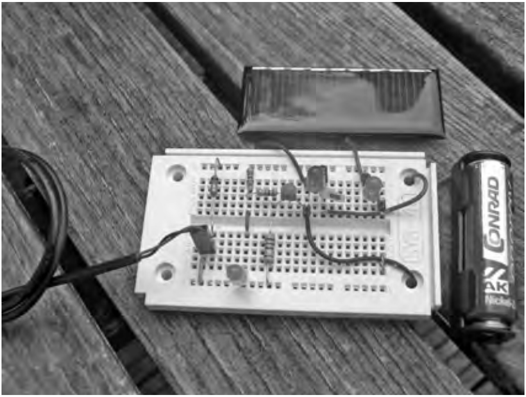
Test setup: Solar module, plug board, USB cable, flashing LED, red LED, orange LED, diode 1N 4001, resistor 1.5 Ω, resistor 1.2 Ω, 2 resistors 1 k, transistor 2N3904, battery holder, NiZn-rechargeable battery

The self-discharge differs according to rechargeable battery type. If the rechargeable battery has been fully charged, then put in interim storage and is urgently needed, it is annoying to have to charge it again first.

Subsequently, a combination of a USB mains charger for quick charging of the rechargeable battery cell and a solar module (with free current) for gentle charging or alternatively solar permanently charging is explained.



a)

b)


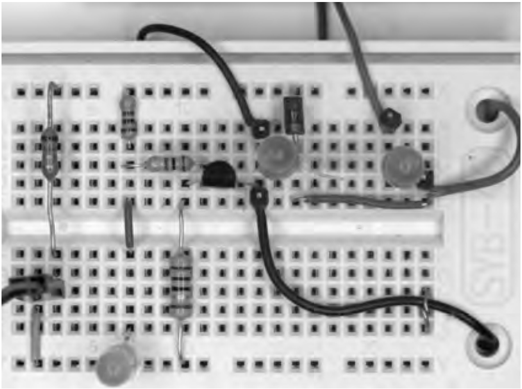
c)


Fig. 063: a) Plug board setup, b) Practical application and c) Detail

Function: If the USB plug is connected to the USB source, the orange LED lights up. The rechargeable battery is charged with a consonant current of approx. 70–80 mA. As of a rechargeable battery voltage of approx. 1.7 V, the flashing LED starts to flash, signalling that the rechargeable battery cell will soon be charged. Additionally, the red LED lights up when the rechargeable battery is also being charged with solar energy via the connected solar module – independently of whether the rechargeable battery is charged via USB or not.

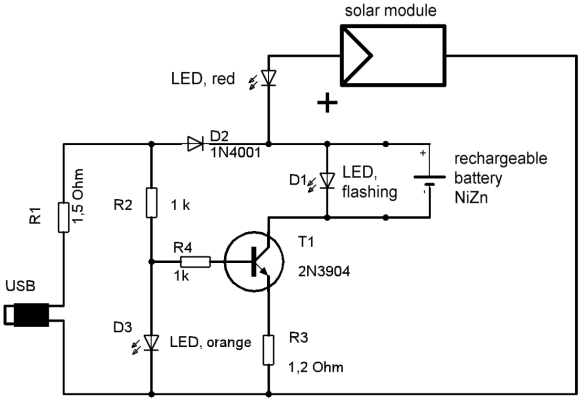


Fig. 064: Circuit diagram

This circuit setup can also be found in the coloured illustration on the learning package cover.

19. Solar Night Light

Test setup: Solar module, plug board, orange LED, transistor T1 2N3904, diode D1 1N4001, resistor R1 100 kΩ, electrolytic capacitor 1,000 µF, alligator cables and clamps, lithium or old mobile phone rechargeable battery

The following experiment charges an energy accumulator during the day. In darkness, it will emit the energy again – in the experiment setup via the light-emitting diode. The energy is emitted until the stored energy is used up. The experiment can be performed with a rechargeable battery as well as with the electrolytic capacitor (1,000 µF). The small capacitor accumulator has the benefit of making the functional principle easy to understand without long charging times.

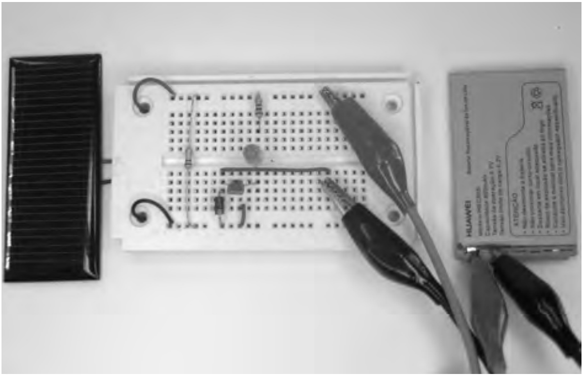


Fig. 066: Test setup of the night light

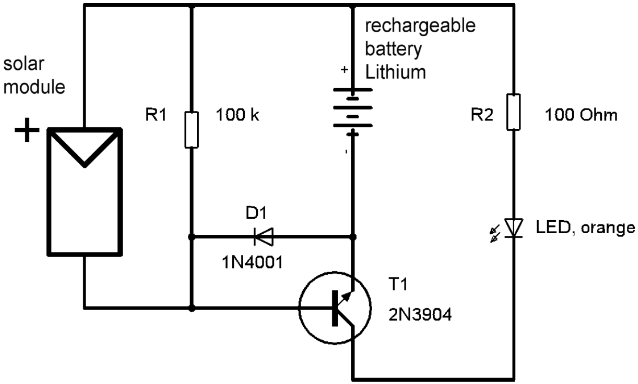


Fig. 067: Circuit diagram for the solar night light

Once it grows dark (e.g. with the solar module covered), the LED will light up. It goes out once the solar module is exposed to light again.

The current from the lit solar modules blocks the T1 collector-emitter section via its basis. The rechargeable battery is charged via the diode D1. If no light hits the solar module anymore, the basis current stops and the collector-emitter section routes the current from the rechargeable battery via the LED. The LED lights up.

A lithium rechargeable battery no longer suitable for mobile phones can still be sensibly used in this manner. In practical use, the rechargeable battery is charged during the day and will emit energy again in darkness - in the experiment setup here through an orange light-emitting diode. Depending on rechargeable battery capacity and charge duration, the LED may be lit all night. E.g. candle LEDs in a self-made lantern are ideal for operation. The lantern casing can easily be made, e.g. from an empty tetra pack.

Fig. 068: Cable light lantern according to the above principle

For a long-term experiment, a red and a black cable can be soldered to the gold contacts of the older mobile phone rechargeable battery or the contacts can be connected via the alligator clamps.

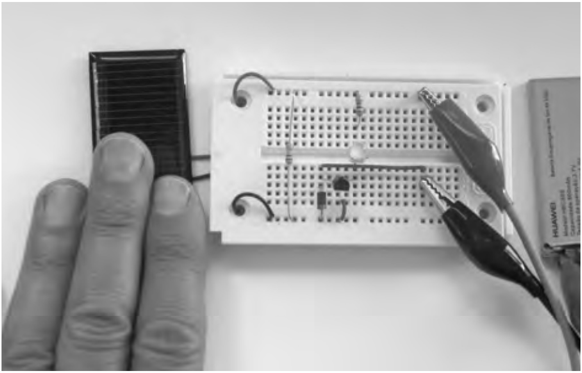


Fig. 069: Covering one module will be enough to activate the night light.

20. Maintenance of the Capacity of Rechargeable Batteries

20.1 Rechargeable Battery Emergency Rescue

Test setup: Lithium rechargeable battery, alligator cable, rechargeable battery cell (deep discharged)

Rechargeable batteries that have been stored unused for a long time or connected to a permanent current consumer (e.g. an electrical watch) often collapse. This affects NiCd- as well as NiMh-rechargeable battery cells that then have an operating voltage that his so low that they are not recognised by automatic rechargeable battery chargers nor rechargeable.

This can be remedied by short, strong current impulses at a higher voltage, e.g. from a lithium or 12-V car battery.

Fig. 065: Use with lithium rechargeable battery and alligator cable

Lead batteries that have been used for an extended time form an insulation layer on the plate surface and thus become high-impedance and cannot be charged anymore.

This can be remedied by alternating voltages being supplied to the rechargeable battery. Voltage applied with the „wrong“ polarity can help remove the inner insulation layers again.

There are rechargeable battery refreshers to prevent this. The rechargeable battery is continually „shot at“ by short impulses in the millisecond range. The energy for this is taken from the rechargeable battery and lower than the self-discharge that takes place anyway.

20.2 Rechargeable Battery Care

Test setup: Rechargeable battery stored for days and months

Rechargeable batteries for operation of electrical and electronic devices that are often also used as replacements for expensive disposable batteries are not very cheap. They should therefore work as long as possible. Depending on the technical procedure with which the rechargeable battery is charged, the possible charge and discharge amount (capacity) and specifically the service life (cycles) of the rechargeable battery vary.

There are now so many recommendations on rechargeable battery care that there is great confusion. How to treat which rechargeable battery type? It is important not to treat all rechargeable batteries the same way.

Rechargeable battery types as pre-set in the learning package are chemical energy accumulators. In rechargeable battery technology, there are different models that mainly differ by the chemical components and inner structure. This can be told by abbreviations such as NiZn, NiMh etc. These connections have additional special features. NiMh rechargeable batteries have a high, lithium rechargeable batteries an extremely low self-discharge.

At the same time, there are some general properties and characteristics to be observed:

- Chemical reactions are influenced by the ambience temperature. Too high and too low temperatures are harmful. The rechargeable battery is best kept at an even temperature in the range of approx. 10–15 °C. The refrigerator is too cold.
- The higher the cell voltage, the faster will rechargeable batteries age during storage. Therefore, rechargeable batteries should best be stored only half-charged.
- High discharge currents stress the rechargeable battery. If the rechargeable battery is discharged at a lower current than indicated, it will last longer. Old mobile phone rechargeable batteries can easily be used for a long time, e.g., for economic LED flashlights.
- Too-deep-discharged rechargeable batteries that are then stored will age more quickly or cannot be used anymore. Therefore, the charge status must be monitored at extended storage and the rechargeable battery may have to be recharged.

GB Legal Notice

These operating instructions are a publication by Conrad Electronic SE, Klaus-Conrad-Str. 1, D-92240 Hirschau (www.conrad.com).

These operating instructions represent the technical status at the time of printing. Changes in technology and equipment reserved.