IE1206 Embedded Electronics

Le1 → Le2 — PIC-block Documentation, Seriecom Pulse sensors

Le3 → Ex1 → KC1 LAB1 — *I*, *U*, *R*, *P*, serial and parallell

Pulsesensors, Menuprogram

- ***Start of programing task***

Le4 → Ex2 — Kirchoffs laws Node analysis Two ports R2R AD

Le5 → Ex3 → KC2 LAB2 — ***Two ports, AD, Comparator/Schmitt***

Le6 → Ex4 → Le7 → KC3 LAB3 — Transients PWM

Step-up, RC-oscillator

Le8 → Ex5 → Le9 — Phasor jω PWM CCP KAP/IND-sensor

Ex6 → Le10 → Le11 → KC4 LAB4 — ***LC-osc, DC-motor, CCP PWM***

Le12 → Ex7 → Display — LP-filter Trafo

- ***Display of programing task***

Le13 → Written exam — Trafo, Ethernetcontact

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Batteries

It is becoming more commonplace with devices that run on batteries. In the car, the screwdriver, laptops, MP3 players and mobile phones - we all come into daily contact with battery-powered equipment.

This can apply to primary batteries, which contain a predefined amount of energy, and then are discarded and replaced when exhausted, or secondary batteries that can be charged and discharged with new energy again and again. (If they are managed properly ...)

Batteries

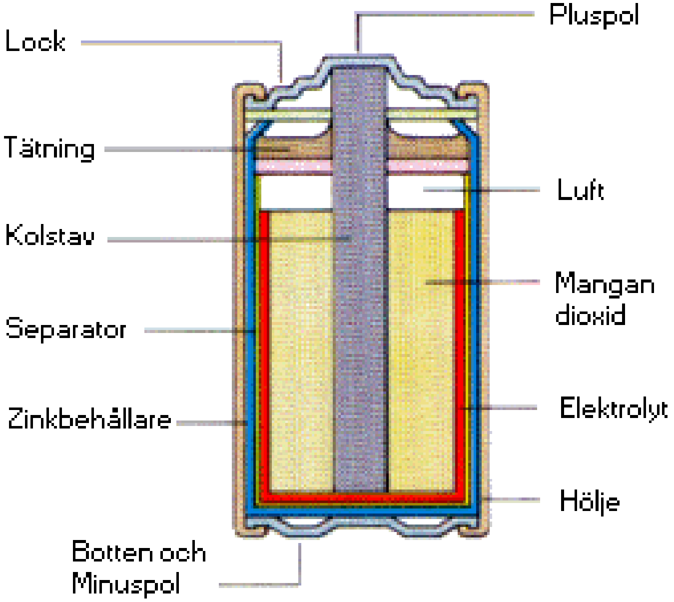
- Voltaic pile

Batteries

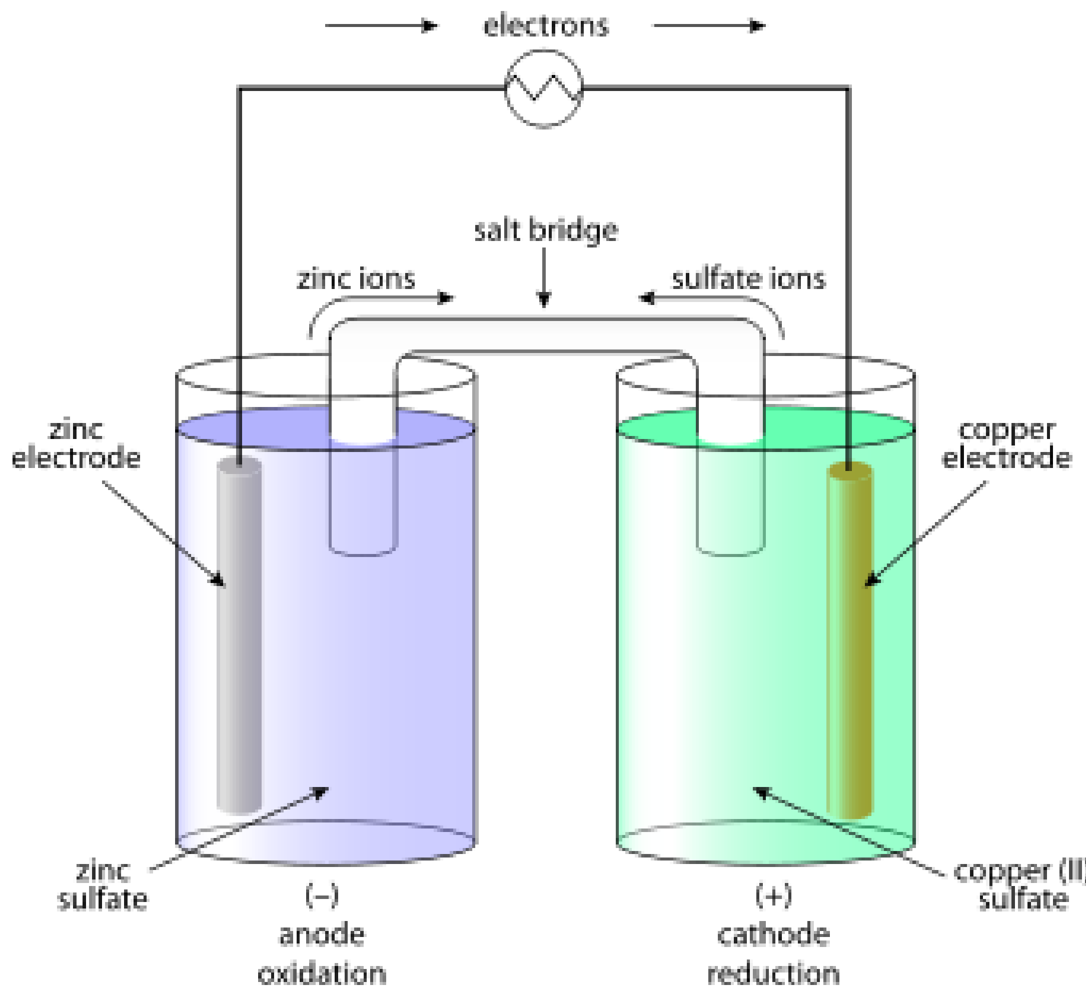
Today there are many different types of batteries to choose from, each with their strengths and weaknesses. Primary batteries have been around since 1800, when the Alessandro Volta built a “pile" of zinc and silver plates with salt-soaked blotting paper in between. The more elements that were included in the stack, the stronger "shock", he received when he touched it. This experiment is why the unit for the electric voltage is Volt.

Practical manageable and economical batteries, we have had since the 1890s in the form of the so-called manganese battery. It is the classic type of battery for example in flashlights, and other applications where low price is more important than capacity.

It is the type of battery that is easiest to take care of at our recycling centers.



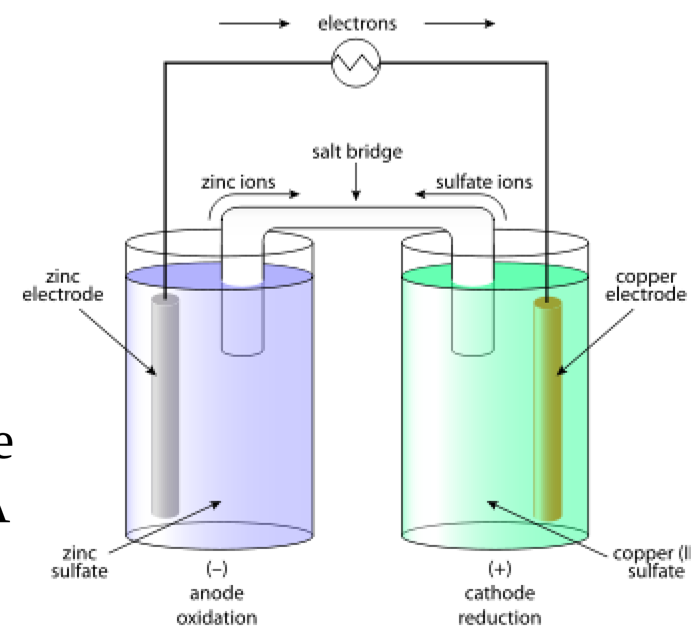
The electrochemical cell function



The electrochemical cell function

In a battery or electrochemical cell, the energy is stored within the electrode materials and the chemicals. When we take out electric energy from the battery the electro-chemical energy is converted to electrical, and some of the chemicals are used.

If a metal is put in an electrically conductive liquid, an electrolyte, it takes place an exchange of electrons between the metal and the liquid. A portion of the metal atoms become charged, become ions, and gets into the liquid.



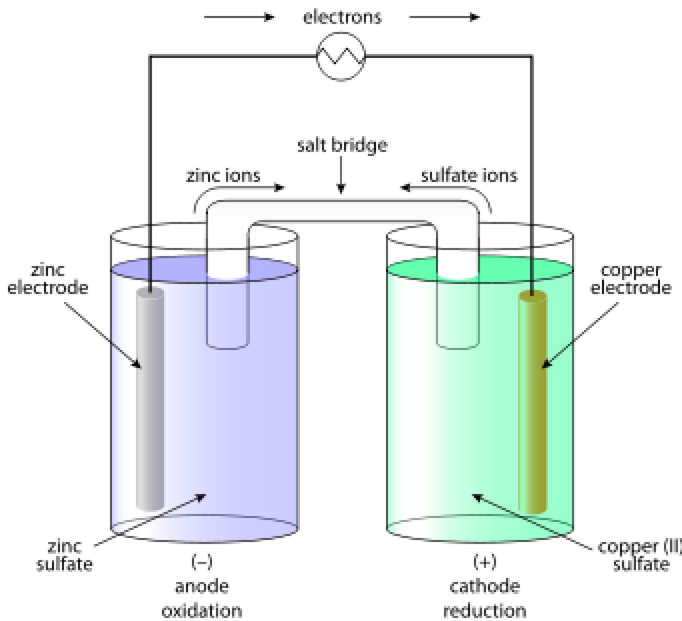
It then forms a small electrical voltage between the metal and the electrolyte, the size of this depends onthe metal. Lithium and Zinc provide a negative voltage, while Copper, Silver and Mercury gives positive voltages. Battery Designers are trying to find two materials with such a large voltage difference as possible, because it is this difference that becomes the cell voltage.

The electrochemical cell function

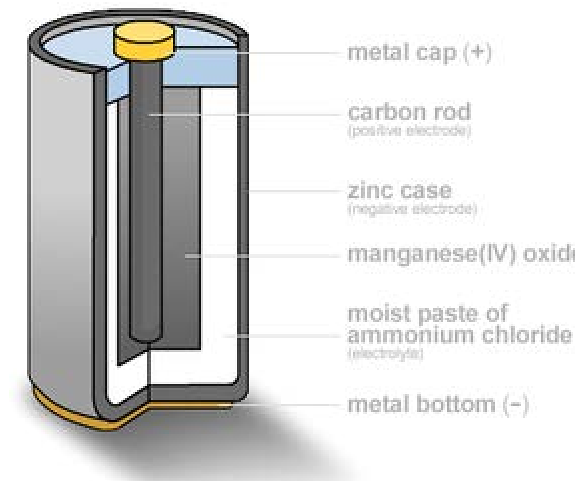
If two such different pieces of metal electrodes are placed in an electrolyte, there arises a chemical reaction between the ions from these. The one substance loses an electron, oxidation, while the other takes up an electron, reduction (collectively, there is a redox reaction). The oxidation reaction occurs at the electrode that is taking up electrons. This becomes the negative electrode. The reduction reaction occurs at the other electrode, the positive electrode.

When the electrodes in this way becomes charged they repel further ions so that the chemical reaction stops. If, however, the two electrodes are connected to each other with an electric conductor outside the battery the charge difference between them will be averaged, and the chemical reaction is kept going. The resistance of the connected electrical load determines the chemical reaction rate. The chemical reaction proceeds as long as the electrical circuit is closed and there is chemically active material left in the cell.

The electrochemical cell function



Wet cell



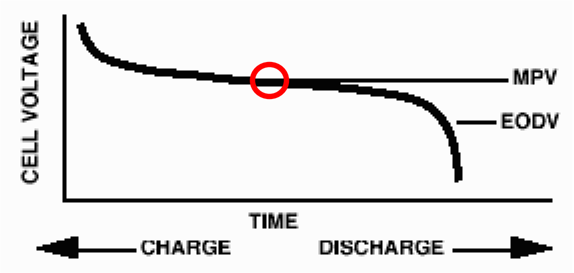
Dry cell

The electrochemical cell in figure above is of "wet" type, but if the electrolyte is sucked by a porous material you get a dry cell. Dry Cells can be rotated and reversed anyway without any fluid leaking out - and that's how we are used to handle today's batteries.

Discharge curve and capacity

A battery's capacity is expressed in Ampere Hours [Ah], which is the same as the amount of charge present in the chemically active materials in the battery. Ampere Hour number is defined as the current [A] battery could supply for one hour and then running out.

A battery's capacity rating C is based on the discharge curves from real-discharge experiments. Discharging proceeds at constant current until the battery voltage drops to a final value, EoDV (End Of Discharge Voltage).



Curve midpoint is called MPV (Midpoint Voltage) and it is this value of voltage that is usually stated as the terminal voltage. The discharge does not necessarily have last for one hour. The discharge time is therefore indicated with the capacity number index.

C_{20} = 60 Ah means that the discharge lasted for 20 hours and the battery capacity $I \times t$ was 60 Ah. The constant discharge current used I then was 60/20 = 3 A.

Example - capacity calculations

- (**Ex. 4.1**) Suppose a battery with the capacity rating C_{20} = 60 Ah is used for a lamp that consumes the current 1 A. How long will the battery last?

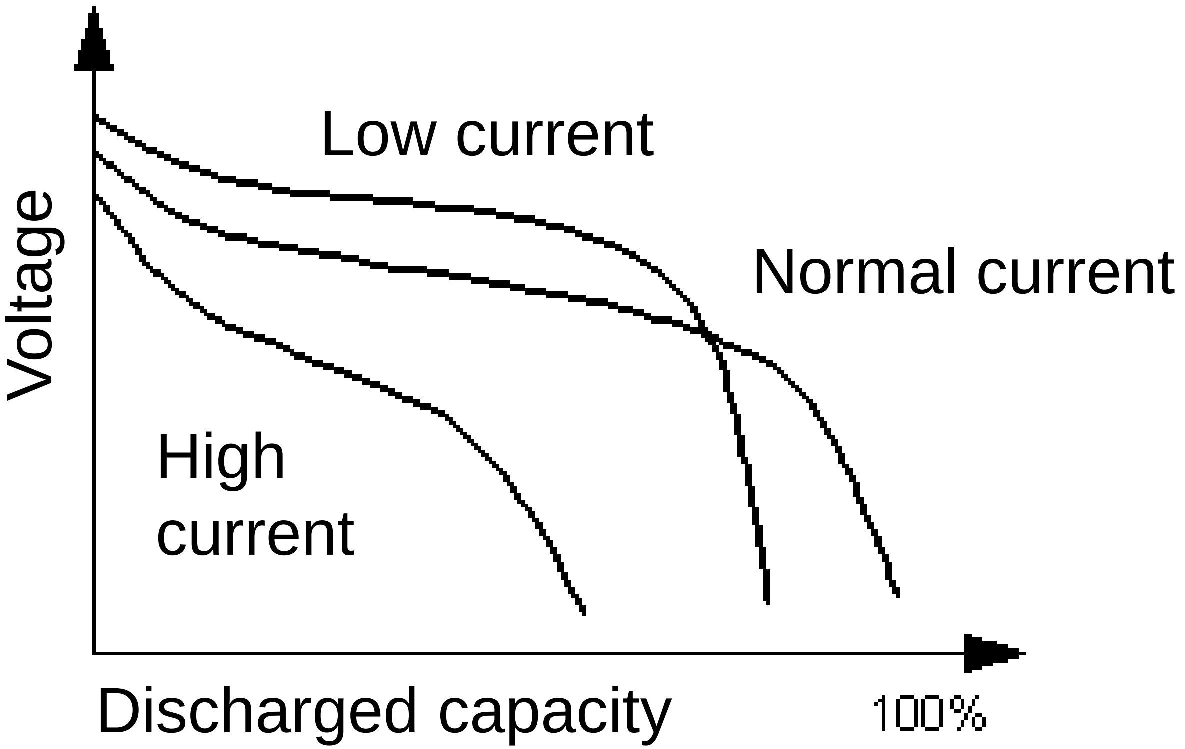
The capacity number was developed at the current 3 A. Then one can assume that the battery capacity is unchanged at the nearby current value of 1 A. We get $t = C/I = 60/1 = 60$ h.

- Suppose now that the battery will power a starter motor with the current 300 A. How long does the battery last? The high current 300 A is a completely different operating condition than that used by the manufacturer to develop the capacity number. From experience (here given) we know that the capacity gets lower at high currents. Therefore, it is expected that the capacity rate is to be reduced to 70%.

$C' = 0{,}7 \times C = 0{,}7 \times 60 = 42$.

We get $t = C'/I = 42/300 = 0{,}14$ h $0{,}14 \times 60 = 8{,}4$ min.

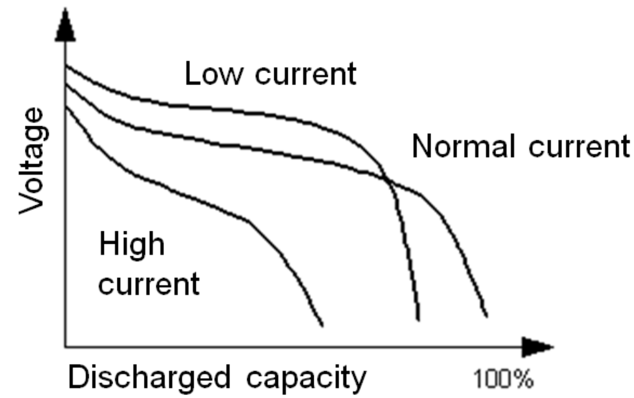
Different discharge cases, self-discharge



Different discharge cases, self-discharge

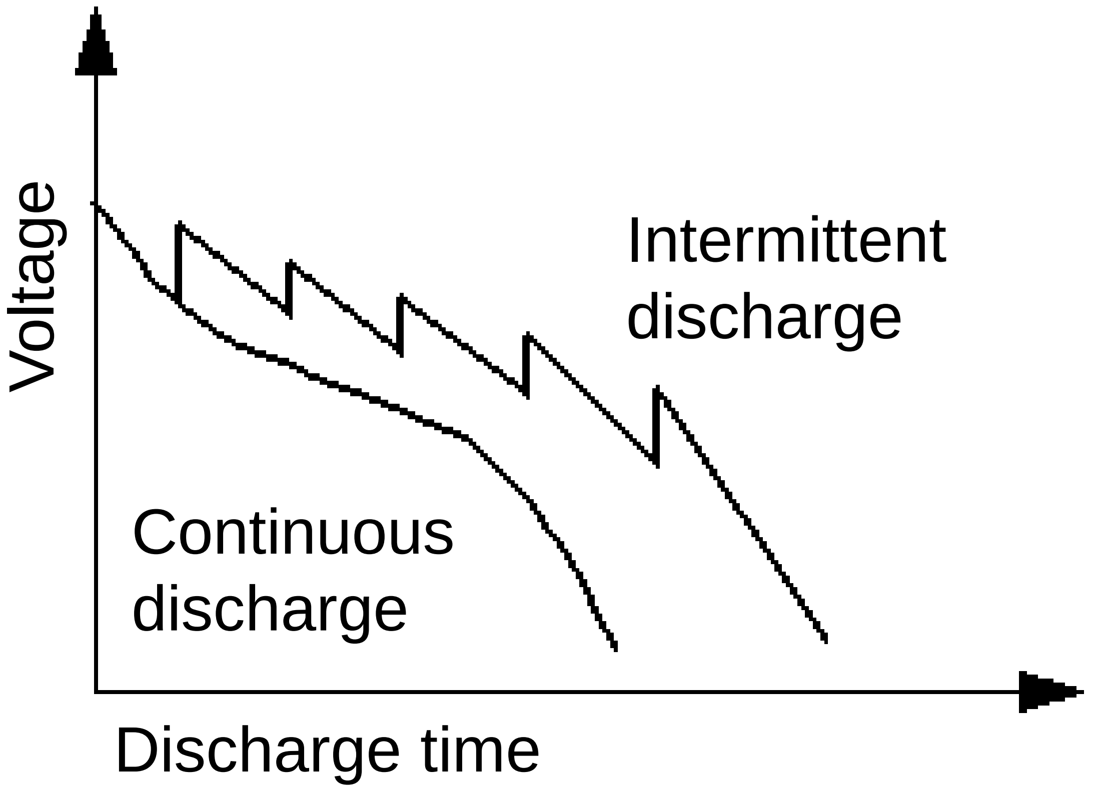
Capacity of a battery depends of course on the size and how much chemically active material are available. That is why you can buy as many different sizes. In addition to the battery size, the actual capacity depends largely on the manner in which the discharge is performed.

We have already mentioned that the very high discharge currents reduces the capacity of a battery. The high current gives rise to losses in the battery's internal resistance, and the part of the energy that can leave the battery will therefore be lower.

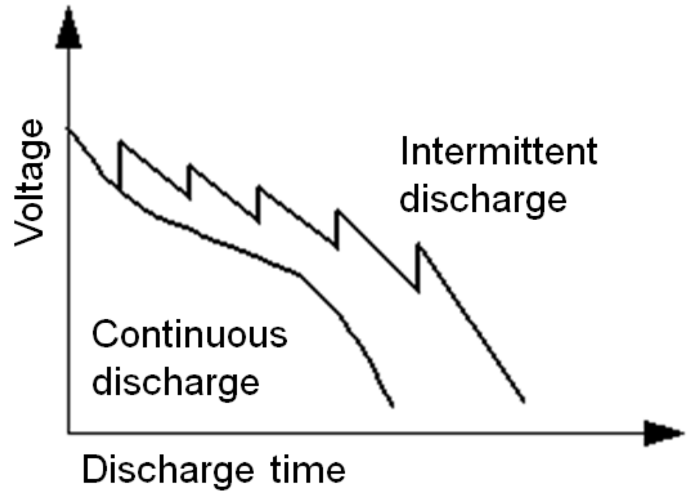


With normal currents the capacity is 100%, but at low currents the capacity will be less. This is because the battery has a certain self-discharge, the electrolyte has a certain electrical conductivity. So even without external discharge current the capacity decreases with time.
Self-discharge is temperature dependent. It is customary to store batteries in the refrigerator to reduce self-discharge.

Different discharge cases, intermittent use

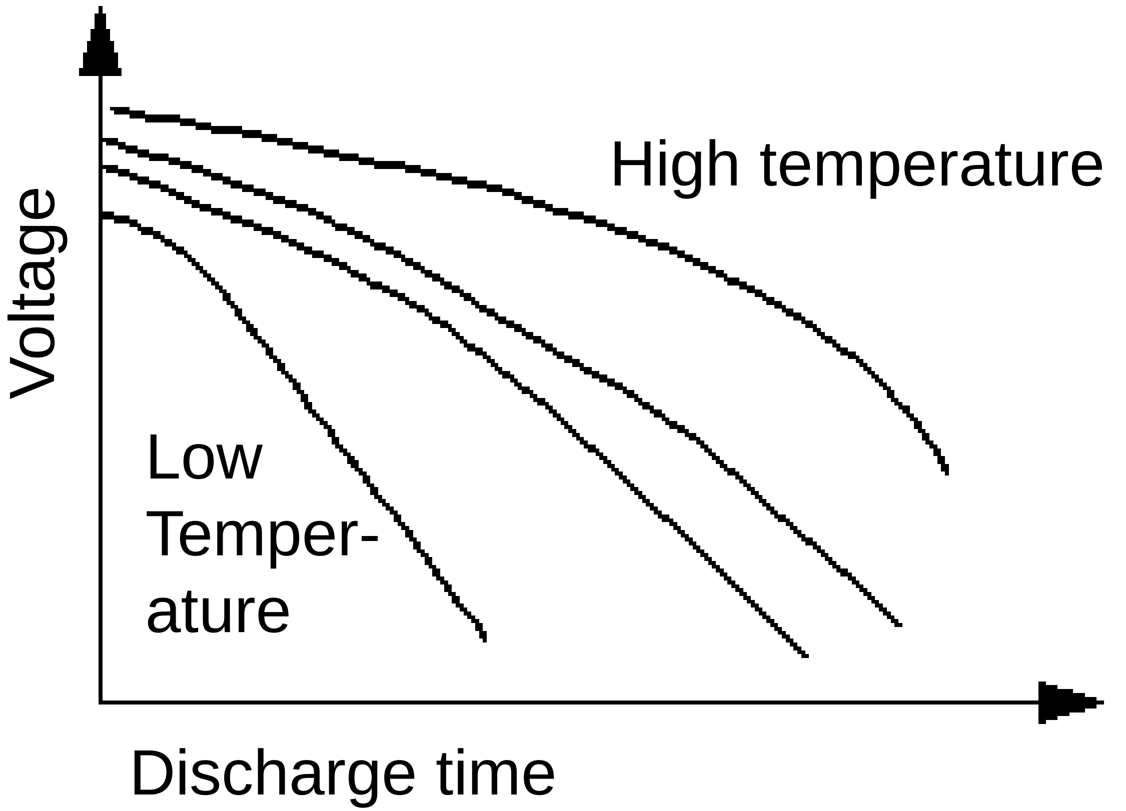


Different discharge cases, intermittent use



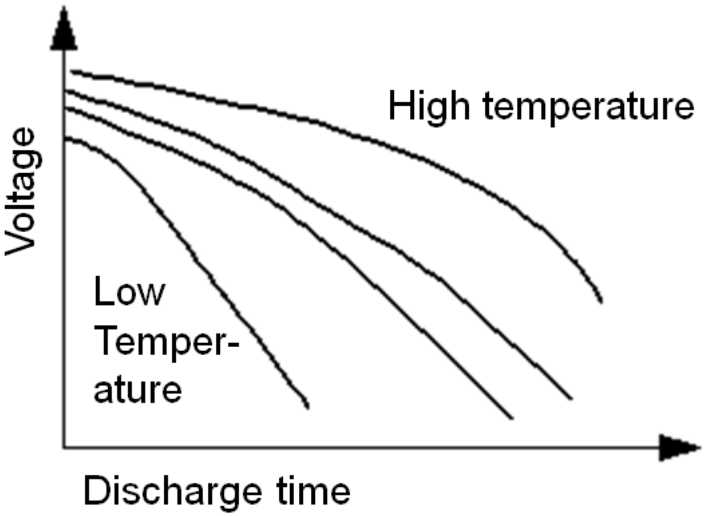
Anyone who used a flashlight in the dark has certainly noticed that you get longer battery life if you give the battery opportunity to occasionally recover. (This fact has an electro-chemical explanation). If you have multiple batteries and can switch between batteries so they may alternately be discharged or recovered. Then you get totally more energy out than using the batteries in succession. This effect is so pronounced that it should be used by electronics engineers - something that is not done yet...

Different discharge cases, battery temperature



Different discharge cases, battery temperature

The electrochemical processes are temperature dependent. At low temperatures the batteries only able to deliver a fraction of the energy that can be extracted at normal temperature. Whoever listens to the advice to store batteries in the refrigerator, do well to wait to use them until they warmed up to room temperature.



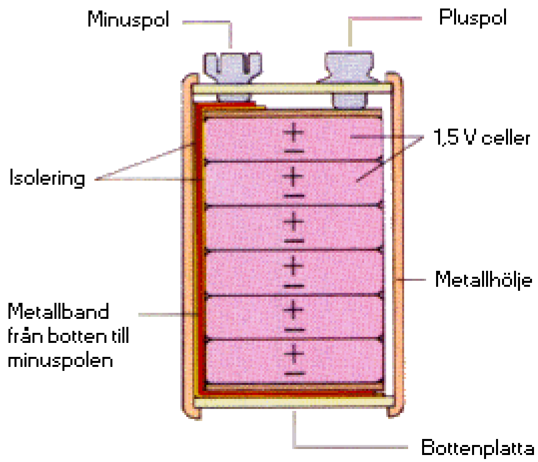
With increasing temperature the electrochemical processes are faster, this will increase capacity, but note that this is counteracted by increased self-discharge at high temperatures.
Probably it would pay to heat/cool the battery to an optimum working temperature even if one were to take the energy to this from the battery itself!

Cell and Battery

If you are to be careful with the concepts so is a **cell** a single electrochemical system with its own positive and negative electrodes, while what is called a **battery** is a collection of such cells.

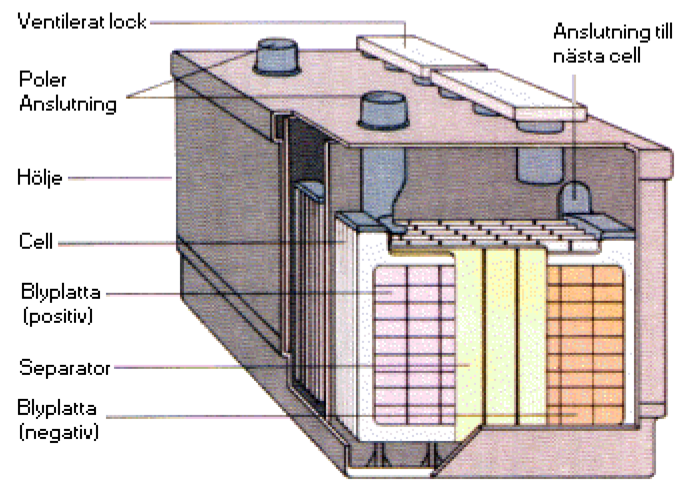
The term is borrowed from the artillery where a battery is a number of guns that can be fired serially or simultaneously. The electrical battery is composed of cells in series or in parallel. In the figure above, there is really only one battery, the 9V battery.

Cell and Batteri



The 9V battery has six 1.5V cells in series to achieve total voltage 9 volts.

The car battery has 6 2V cells in series to achieve total voltage of 12 V. The cells are here of a type derived from the Frenchman Gaston Planté (1859), and they can both be discharged and recharged. The chemical processes which take place at the plates are reversible. Batterys that can be charged are called **secondary batteries**.



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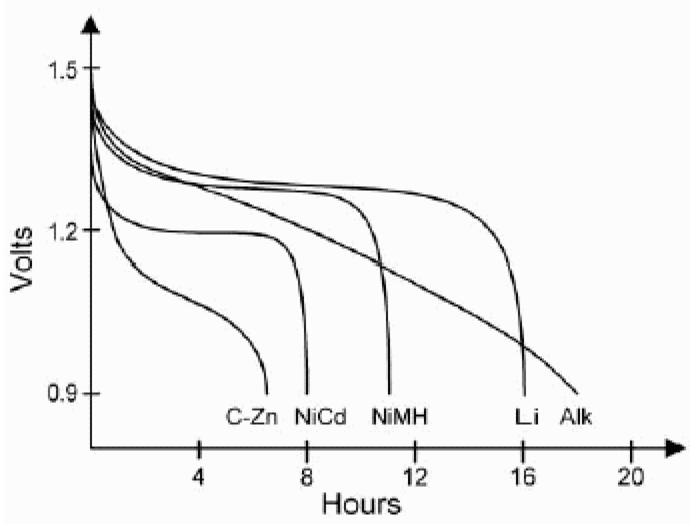
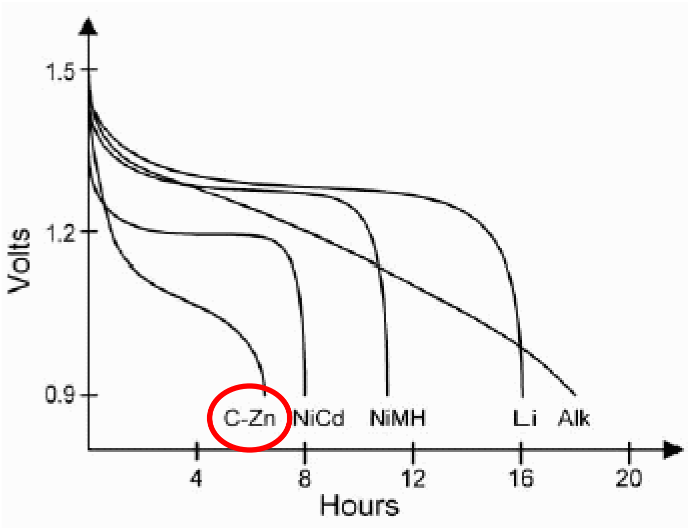
Comparisons between battery types

If you draw the discharge curves for different battery types in the same graph, one can compare their properties. The figure shows standard 1.5V AA cells that on the outside look the same, but the inside are of different technologies.



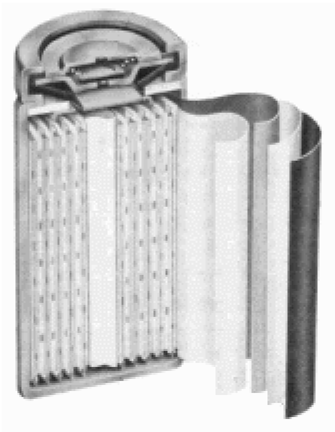
The cells have been discharged at the constant current I = 100 mA. The area under the discharge curves is proportional to the extracted electric energy ($W = U \times I \times t$, I is constant).

C-Zn



This is the oldest cell-type, but still in use (why?). The capacity is low and it drops the voltage fast. Could be stored a long time with low self-discharge.

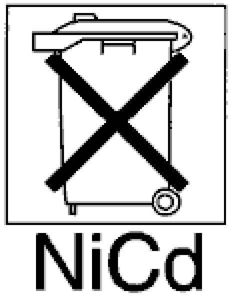
NiCd



Nickel-Cadmium cell voltage falls rapidly down to 1.2V where it stays until the end. The cell can be recharged with the current $I = C/10$ for 14 hours which is then 40% longer than theoretically needed to charge the cell. At this low charging current the cell can withstand overcharging.

You can also Rapid Charge the cell for example with current $I = C$. Charging then takes theoretically one hour, but the charger must besides the charging time also monitor the cell voltage and temperature, as overcharging with this high current is very harmful to the cell.

NiCd cell self-discharge is approximately 1%/day - after three months, the cell is completely empty. If you want to store a fully charged NiCd cell it must be connected to a trickle charger that constantly charging it with a small current that outweigh the self discharge current ($I = 0,05C$).



If NiCd cells frequently recharged before being fully discharged, there may be a so-called memory effect. The discharge curvethen falls by about 150 mV long before the cell depleted. This should not have any significance, but it can "fool" electronics erroneously indicating "battery exhausted"

NiMh, Li

NiMH

Nickel-metal hydride battery has higher capacity than NiCd cell, but otherwise similar properties. NiMH cell has no "memory effect". The cell contains no environmentally hazardous metals..

Li

Lithium cells can provide terminal voltage up to 3.3 V. There is 1.5V cells and it is such as depicted in the diagram. Lithium is the lightest metal and a lithium cell is about half as heavy as the other cell types. Self discharge is low so the cell can be stored for up to 10 years. Capacity is the comparison by far the highest - but this is a very expensive cell!

Rechargeable Lithium 3.3V cells found in your mobile phone.

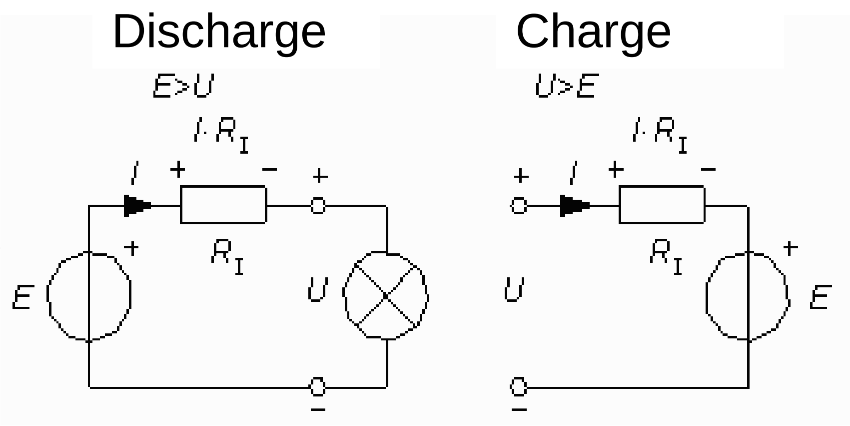
Alk

Alkaline cell is a further development of manganese cell. It has much higher capacity than this and has therefore become the most common and most used type of battery.

Nowadays, Alkaline cells are made without mercury, and therefore contain no harmful metals.

Emf internal resistance and terminal voltage

As a simple model for batteries one usually use an emf (an ideal voltage source) in series with an internal resistance. These are not constants, but numerical values that change with operating cases and with battery condition.



One speaks of a battery emf E, internal resistance R_I and terminal voltage U . The terminal voltage can be measured outside of the battery. If you connect a load, for example a lamp to the battery, so the battery current will cause a voltage drop across the internal resistance ($I \times R_I$). The terminal voltage is therefore lower than the battery emf, $E > U$. Bigger batteries with higher capacity, lower internal resistance, will thus have a terminal voltage that is closer to emf.

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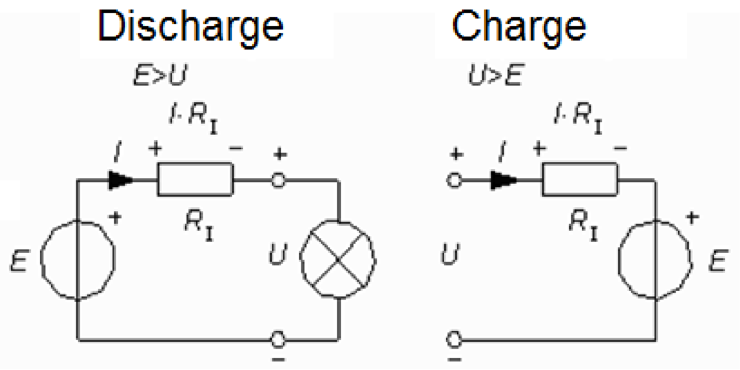
Emf internal resistance and terminal voltage

If you connect a terminal voltage that is greater than the battery emf, $U > E$, so the current flows in the opposite direction. If it's a secondary battery, in which the electro-chemical processes are reversible, so the battery will be recharged.



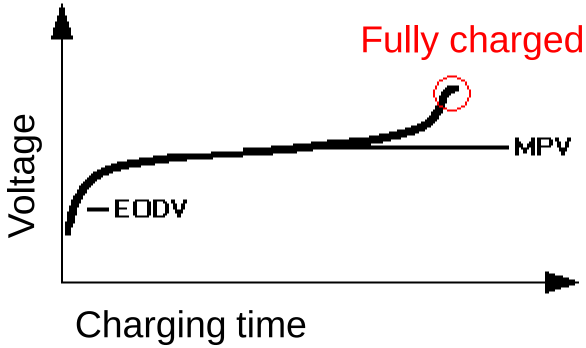
Kirchoff's voltage law gives: $U = I \times R_I + E$

If we extend this expression with the "I" we get the relationship between three powers. $U \times I = I^2 \times R_I + E \times I$

$U \times I$ is the power to or from the battery. $I^2 \times R_I$ is the power losses inside the battery and $E \times I$ is a expression for the chemical energy that is consumed from the battery or stored in it.

If "over charging" a battery then also the term $E \times I$ stands for losses. This means that "over charging" will result in battery overheating!

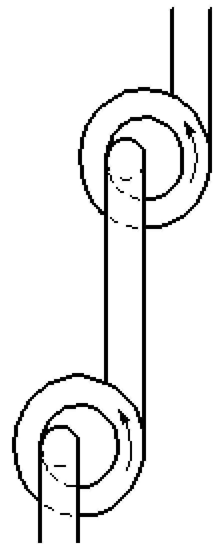
The charging curve



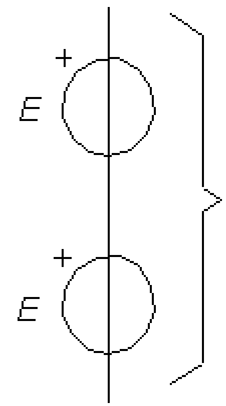
A battery charging curve is basically the discharge curve mirrored backwards. When the battery is fully charged the battery voltage decreases instead of increasing (-dV). "Smart" battery chargers usually use this as "signs" that the battery is fully charged and finishes charging.

Series connection of cells

A cell voltage is determined by the combination of electrode material. Frequently cell voltages are between 1 ... 3 V. In order to obtain higher voltages one has to series-connect the cells. Examples of this are the 9V battery and the 12V battery.



Double pressure
same flow limit



Double voltage
same current limit

Centrifugal pumps for liquids can be connected in series to provide higher lifting height. The liquid flow that can pass through the pump remains the same. Similarly, the two series-connected cells gets twice the voltage, but the ability to supply current is unchanged.

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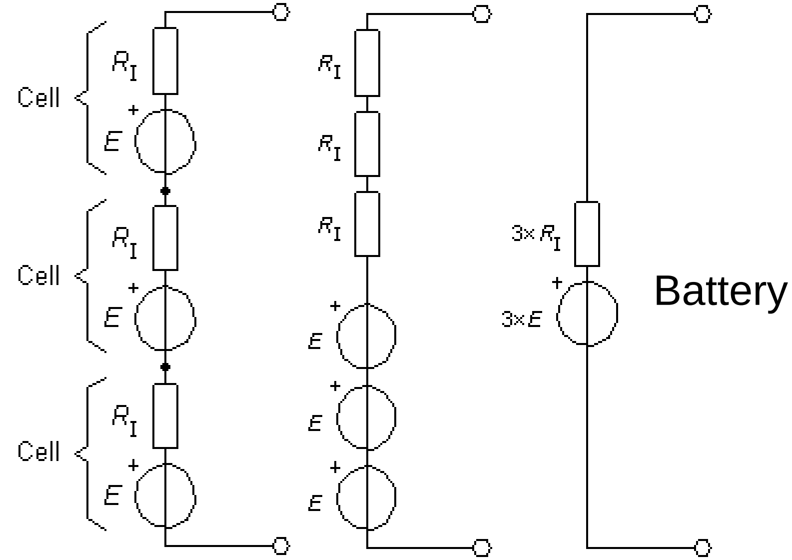
Example - How many cells are needed?

The battery to an older laptop is broken. The choice is between ordering a new one for high "spare part" prices or to build yourself a battery of common NiCd cells.
How many NiCd-cells with E = 1,1 V and R_I = 0,1 Ω would be needed?

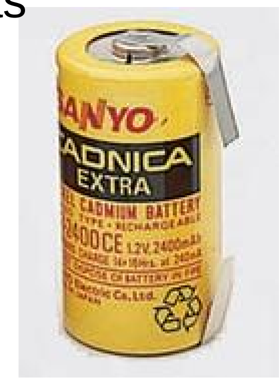


First, we need to know the current needs. One finds that the computer consumes 1.7 A at 14 V.

Three series-connected cells.
Cells E and R_I can be summed. The series-connected battery pack can be seen as a cell with 3E and $3R_I$.

Example - How many cells are needed?

It is not so simple that it is enough with 13 cells ($13 \times 1.1 = 14.3$) as the battery voltage drops when you pull the current out of it.

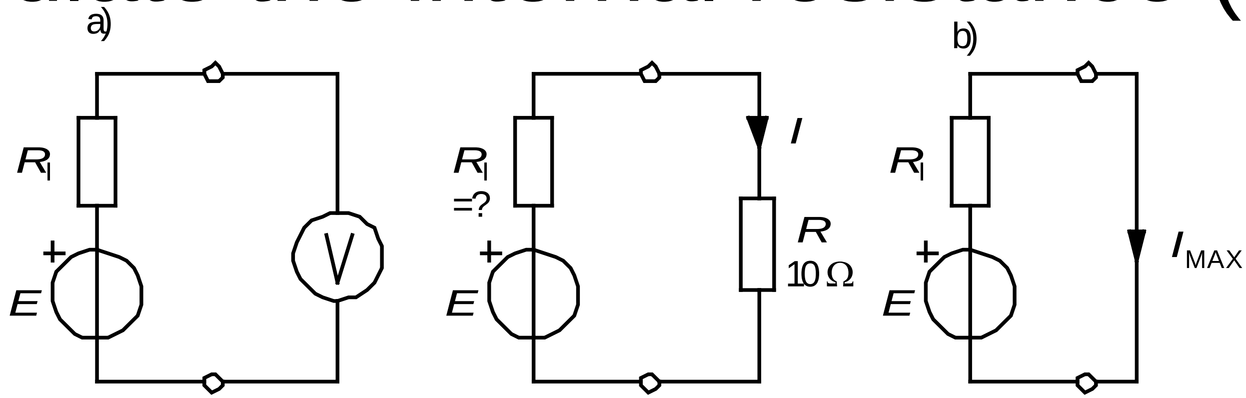


To calculate how many cells n is needed:
Kirchhoff's voltage law provides:
$n \times E - n \times R_l \times I - U = 0$
$n = U/(E - R_l \times I) = 14/(1,1 - 0,1 \times 1,7) = 15,05$

The number of cells must of course be an integer, so the practical answer is that the homebuilt computer battery should have **15** cells.

You choose a type with "solder ends" to easily connect them in series.

Calculate the internal resistance (**4.2**)



In order to determine a battery's internal resistance R_I one made two measurements. First the battery emf was measured with a good voltmeter E = 1,4 V, and then the battery was loaded with a known resistor R =10 Ω and the current I through the resistor then was measured to I = 123 mA.

a) What was the battery internal resistance? R_I = ? [Ω]

$$I = \frac{E}{R_I + R} \quad \Rightarrow \quad R_I = \frac{E}{I} - R = \frac{1{,}4}{0{,}123} - 10 = 1{,}38\,\Omega$$

b) What's largest current I_{MAX} would one be able to take out from the battery if this was short-circuited?

I_{MAX} = E/R_I = 1,4/1,38 = 1,01 A

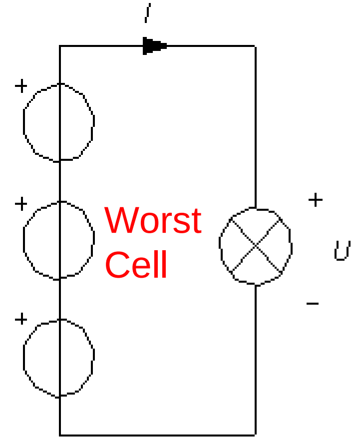
The risk with series connection
- reverse cell voltage

A flashlight powered by three series-connected cells. We assume that one of them (eg. The one in the middle) has the worst/less capacity.

Cell voltages [V]

1,5	1,5	1,5
1,5	0	-1,5
1,5	1,5	1,5

t →



Lamp voltage *U* [V]

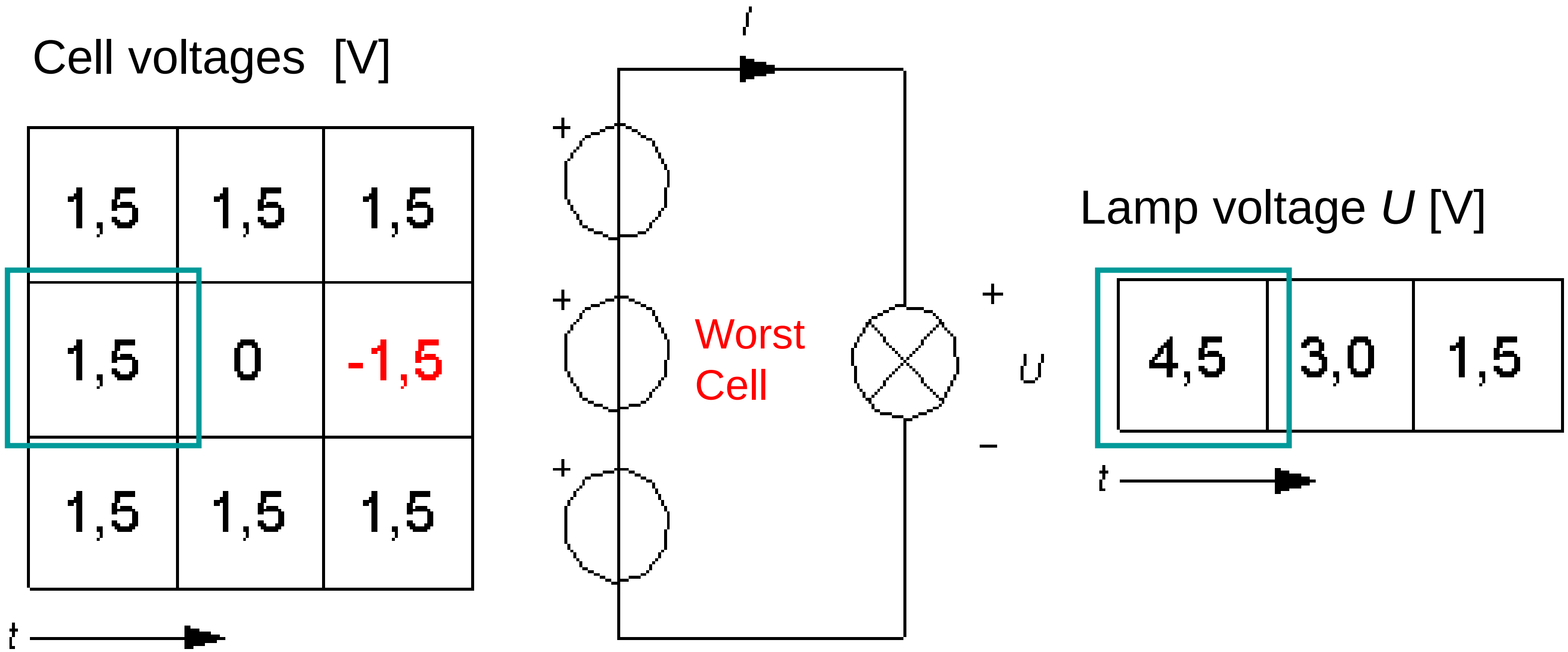
4,5	3,0	1,5

t →

First light is normal with three cells connected in series and the lamp voltage 4.5 V. After a while, the "worst" cell run out and then the lamp is lit weaker with voltage 3 V. Now if you continue to let the light on, the cell which is the final will receive current from the other two cells. The cell will be chemically uploaded, but with the wrong polarity, finally with full incorrect cell voltage -1.5 V!

The lamp now only has 1.5V and glow faded. In this mode it would be better to take out the empty battery and replace it with a "short circuit wire" - then the lamp voltage again would become 3 V.

Reverse cell voltage



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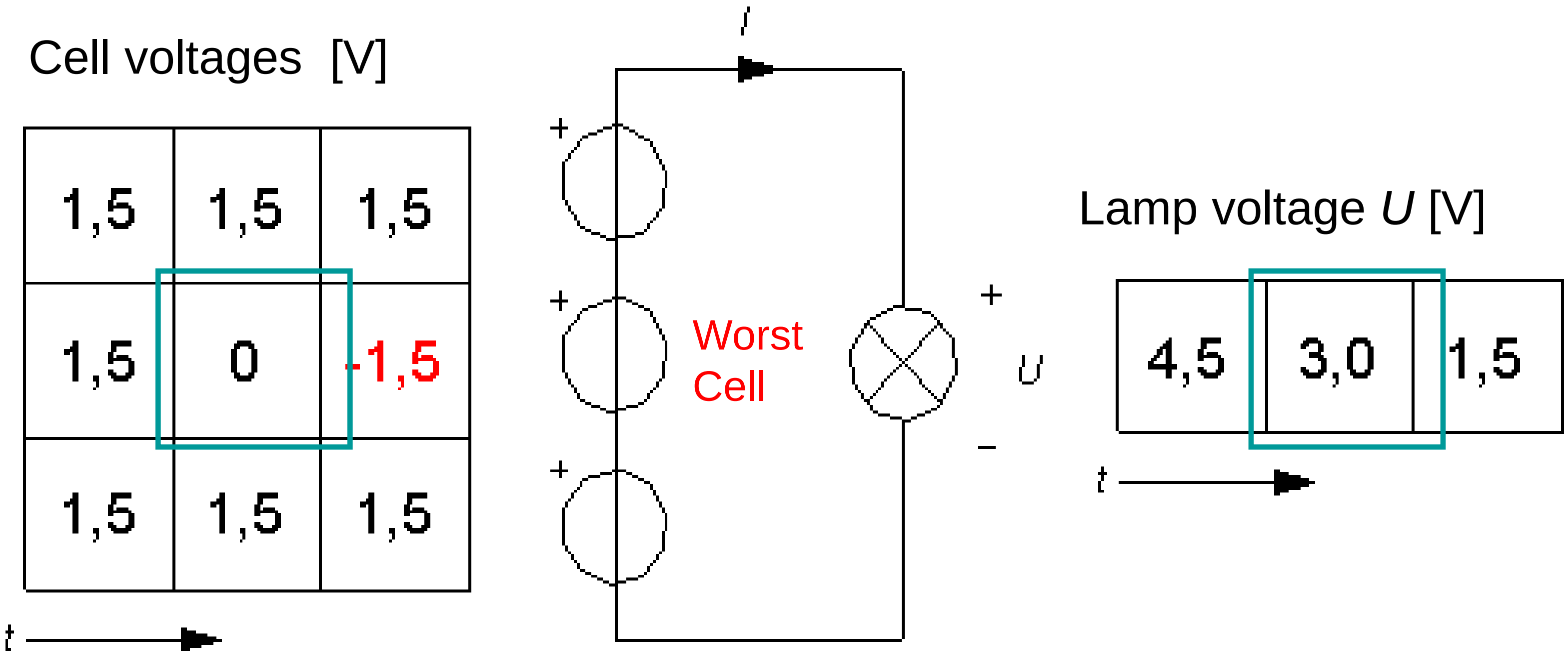
Reverse cell voltage



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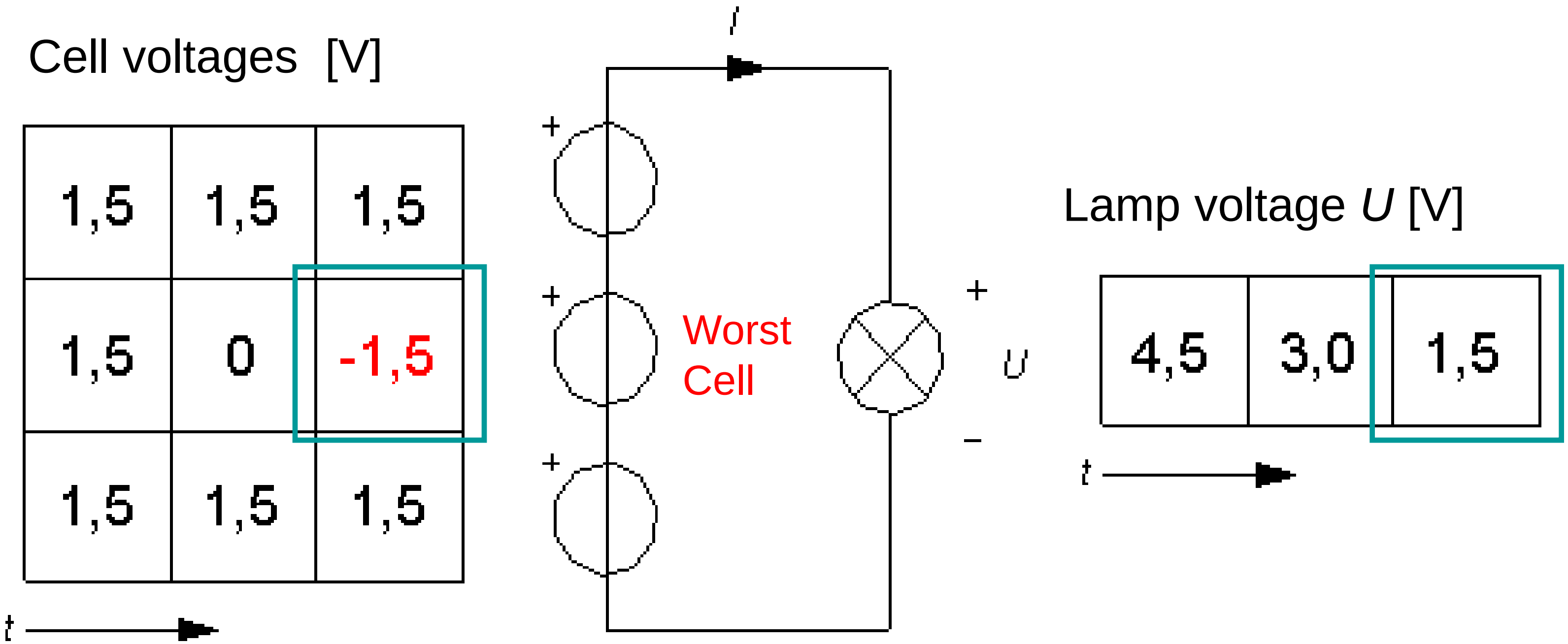
Reverse cell voltage



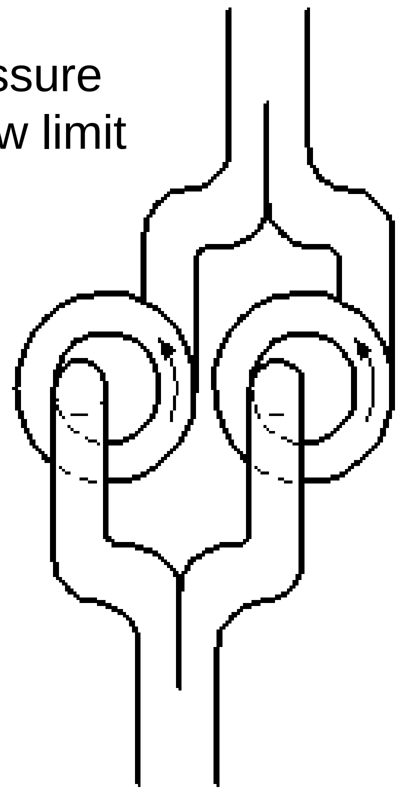
The risk with series connection - reverse cell voltage

This shows that it is important that all cells in a series connection has the same capacity. Therefore, most of the battery-powered devices use battery packs made up of cells which are all taken from the plant at the same time. If the cells have different capacity it is poor battery economy, when it’s rechargeable batteries you run the risk that the reverse cell voltage reduces the cell's lifespan.

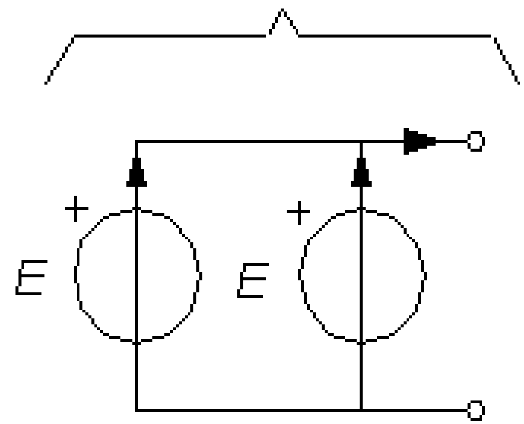
Capacity number C [Ah] for a series connected battery is the same as for the individual cells. If the cells have different capacities (this should be avoided) the weakest cell will determine the capacity of the battery - when the weakest cell is finished, the entire battery in practice unusable.

Parallel connection of cells

Same pressure
Double flow limit



Same voltage
Double current capability
Double capacity



Centrifugal pumps for liquids can be paralleled to provide greater flow. The lifting height/pressure stays the same. In the same way, two cells connected in parallel together can deliver higher current. The voltage remains unchanged. Capacity C [Ah] is doubled.

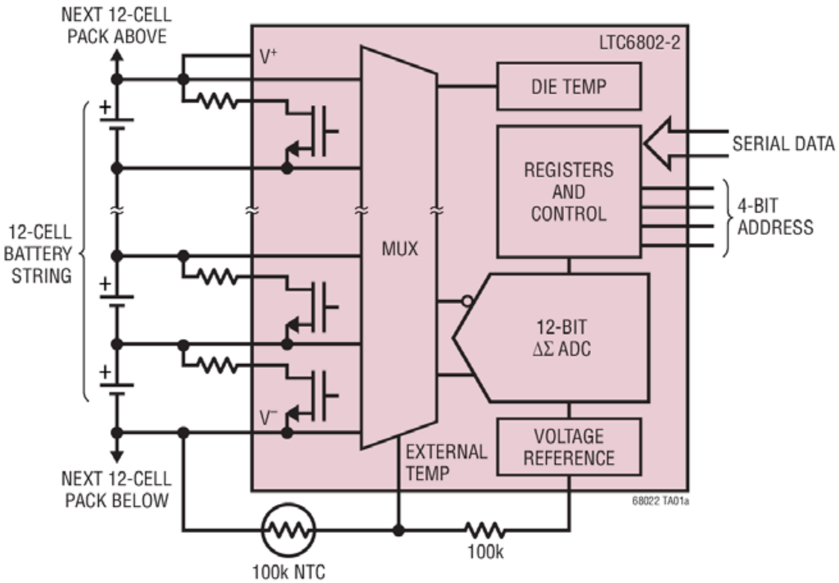
Parallel connection of cells

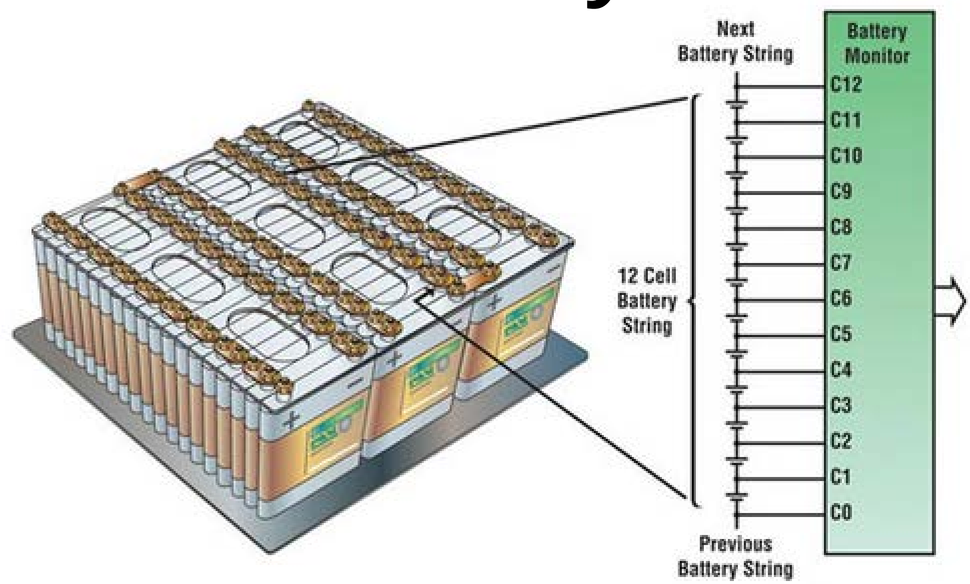
Cells are available in a variety of standard sizes. The larger the size, the higher capacity. The easiest way to get a higher capacity is thus to change to larger cells.

The number of standardized cell sizes are very large.

Since the batteries are heavy components, this would sometimes lead to an unfavorable weight distribution - just think of a model plane that has the battery inside one wing, but nothing inside the other! Then it may be better to share capacity across multiple parallel-connected cells.

Electric Vehicle Battery?





Electric car battery consists of many series connected cells. Special circuitry monitors cell voltages in groups of 12 cells. They balance the charge flows to the cells. A control computer then monitors the entire battery.

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