

The capacitor and energy

Main parts used

The LEGO capacitor

The capacitor has a capacity of 1 farad and is protected against an overload up to 18 volt. When the capacitor is fully charged (2,5V) a red light starts to blink. The capacitor may be charged with a voltage of no more than 4 volt.



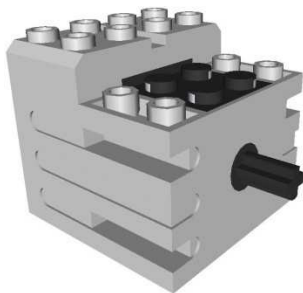
How much energy (W) does the LEGO capacitor contain when it is fully charged?

$$W = \frac{C \cdot U^2}{2} = \frac{1F \cdot (2,5V)^2}{2} = 3,125J$$

with W : energy J : joule
C : capacitance F : farad
U : voltage V : volt

The LEGO motor

There are different types of LEGO motors. We use the type 43362.



This motor is protected by a thermal resistor and a bidirectional diode.

A thermal resistor's resistance increases when heated up. This prevents the motor from being overloaded.

The bidirectional diode protects the motor against too high a voltage (>15V).

The motor can, of course, also be used as a generator.

Electrical circuits of capacitors

Parallel

If 2 or more capacitors are connected in parallel, this physically results in an enlargement of the useful plate surface of the capacitors. This also means the total charge contained by this circuit equals the sum of the charges contained by every single capacitor.

So, in this parallel circuit of 2 capacitors:

$$Q_{tot} = Q_A + Q_B$$

$$C_{tot} = C_A + C_B$$

If we connect 2 LEGO capacitors in parallel, the total capacity of the circuit equals:

$$C_{tot} = 2C$$

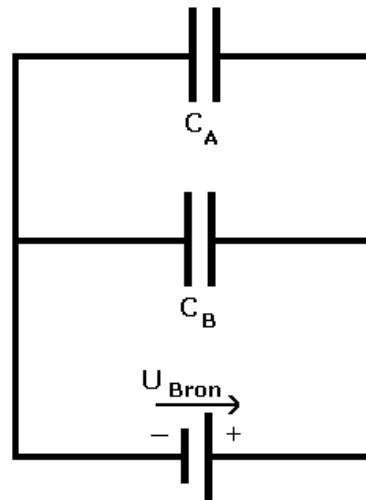
This circuit enlarges the capacity. Consequently:

$$W = \frac{2 \cdot C \cdot U^2}{2}$$

$$W = C \cdot U^2$$

$$W = C \cdot U^2 = 6,250J$$

In fact, the total energy doubles.

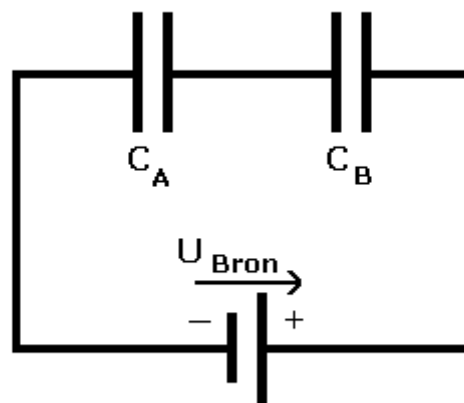


In series

If, in the circuit above, capacitor A wants to absorb a charge Q , this is only possible if that capacitor can unload a charge Q to capacitor B. Thus, the charge contained by every single capacitor in series will be the same.

Over every capacitor in series there will be the same voltage:

$$U_A = \frac{Q}{C_A}$$



$$U_B = \frac{Q}{C_B}$$

The total voltage will be:

$$U_{tot} = U_A + U_B$$

$$\frac{Q}{C_{tot}} = \frac{Q}{C_A} + \frac{Q}{C_B}$$

$$\frac{1}{C_{tot}} = \frac{1}{C_A} + \frac{1}{C_B}$$

Thus, the equivalent capacitance (C_{tot}) will be:

$$C_{tot} = \frac{C_A \cdot C_B}{C_A + C_B}$$

If we connect 2 identical LEGO capacitors in series, the equivalent capacitance is:

$$C_{tot} = \frac{C^2}{2C} = \frac{C}{2} = 0,5 F$$

So, this circuit is not useful to us because the total capacitance decreases.

It is only used to decrease the voltage over the capacitors and in this way increase the total voltage allowed over the circuit. This of course at the cost of capacitance.

Energy and the capacitor

ENSURE THE CAPACITORS USED ARE EMPTY BEFORE STARTING A TASK!

Experiment 1

Use a LEGO-wire to connect the capacitor to the engine and mount a wheel on the engine. Spin the wheel for about one minute, then release the wheel.

What do you notice?

The wheel continues to spin.

Now stop the wheel and release it again. What do you notice now?

The wheel starts to spin again.

Why?

While spinning the wheel mechanical energy was transformed into electrical energy. This energy is stored within the capacitor. Subsequently the capacitor will retransform this energy into mechanical energy. Thus, when you release the wheel this energy is used to power the engine and the wheel starts to spin again.

Experiment 2

Recharge the capacitor and let the wheel spin freely. Let it spin until it stops.

What do you notice concerning the turning speed of the wheel?

The wheel turns slower and slower until it stops.

Why?

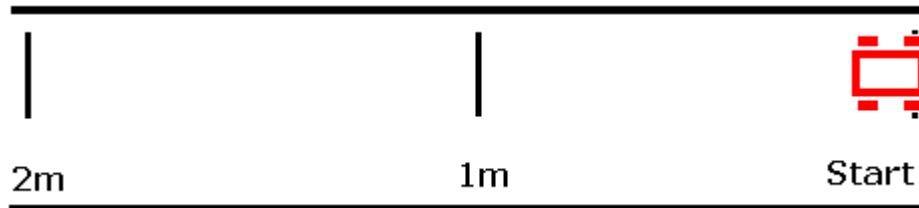
The capacitor, just as a battery, is getting depleted.

Efficiency of the capacitor

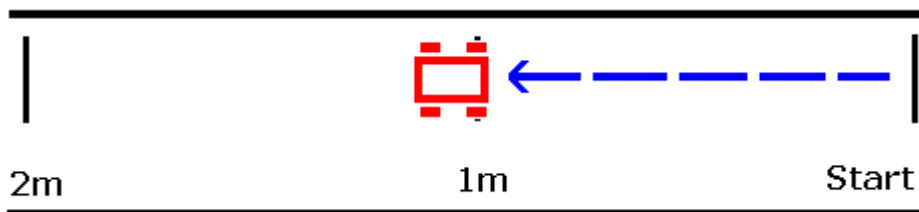
Experiment 1 : Efficiency of one capacitor

Construct a light car that is powered by an engine. Attach an empty capacitor to the car and connect it with the engine.

Measure a distance of 2 meters on the table. Also mark the 1 meter line.



Now push the car from the start to the 1 meter line and release it.



You notice that the car continues along the track. How far does it get? Is this what you had expected?



Do you know why the car doesn't reach the finish?
[Energy is lost due to friction etc.](#)

Experiment 2 : efficiency of capacitors in parallel circuits

Connect an empty capacitor to the car and push it to the 1 meter line and immediately interrupt the connection between the engine and the capacitor. Repeat this with a second capacitor. Afterwards, make a parallel circuit of the engine and the 2 capacitors, put the car at the start and let it drive freely along the track.

How far does it get, compared to the previous experiment?
[The car drives twice as far as it did in the previous task.](#)

What can you conclude concerning capacitors in parallel circuits?

The energy held by the circuit is twice as big as the energy held by one capacitor, but the efficiency remains the same.

Can you explain this mathematically?

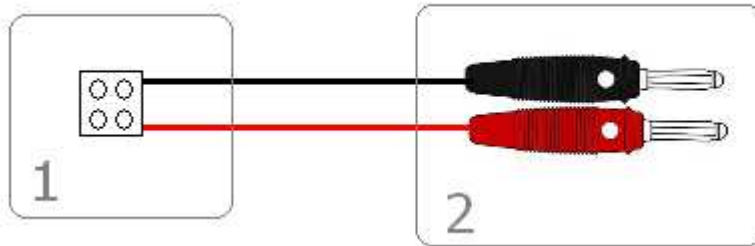
The equivalent capacitance of this circuit equals:

$$2.C = 2.1F = 2F$$

The energy stored within these 2 capacitors in parallel equals: 6,250 J

Unloading a capacitor

Because charging a capacitor with a motor takes quite long we use a voltage source during this task. Because the standard LEGO wires cannot be connected to a voltage source, we made a special set of wires that can be used to connect LEGO components to an independent voltage source. This wire consists of a part of a LEGO wire (1) and two 4 mm plugs (2).



We can also use this wire to connect the capacitor to a multimeter in parallel and measure voltage.

In this experiment you study how a LEGO capacitor unloads.

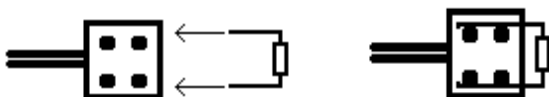
Material:

- LEGO wire with plugs
- LEGO capacitor
- LEGO baseplate
- A resistor of 27Ω
- A voltage source
- A multimeter

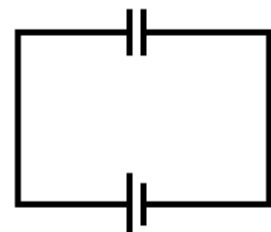
Ensure you have a stop watch and pen and paper at hand.

Preparation:

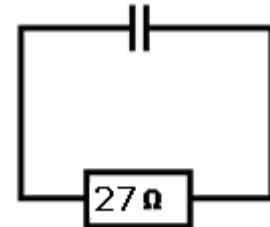
- Because it is quite difficult to connect a resistor directly to a capacitor we first connect the resistor to a LEGO wire. Do this before you start the task, so you don't lose energy before the test starts.



- Switch on the voltage source and turn the voltage to 0.
- Switch on the multimeter. Use the position for voltage measurements with DC (V followed by a dashed line and a full line above it) because unloading capacitors delivers a direct current.
- Connect the capacitor to the voltage source with the plugs (black plug into the black input port, red plug into the red input port)



- Very carefully, because of the peak current, increase the voltage until you reach 2,5V. Ensure that no current higher than 0,3A flows through the capacitor or that there is a voltage higher than 4V over the capacitor at any moment!!!
- If the red light on the capacitor lights up the capacitor is fully loaded. The capacitor does not unload as long as it isn't connected to some form of resistance.
- Now pull the plugs out of the source and put them into the multimeter: the black plug into the COM-input port, the red plug into the V Ω -input port.
- Write down the initial voltage in the table (on the next page).
- Connect the resistor to the capacitor so that it starts to unload.
- Write down the voltage every 10 seconds. Do this for 3 minutes.



Hint: If the values shown by the multimeter change too fast to properly read them, use the HOLD button on the multimeter to temporarily freeze the screen.

Repeat the measuring twice.

ALWAYS TURN THE VOLTAGE SOURCE TO 0 V FIRST!!!

TIME (seconds)	VOLTAGE (volt)		
	Test 1	Test 2	Test 3
0	2,340	2,400	2,400
10	1,646	1,701	1,702
20	1,278	1,333	1,317
30 (0:30 min)	1,000	1,032	1,021
40	0,778	0,805	0,800
50	0,617	0,629	0,613
60 (1:00 min)	0,486	0,495	0,481
70	0,388	0,393	0,378
80	0,317	0,315	0,303
90 (1:30 min)	0,258	0,255	0,244
100	0,214	0,209	0,198
110	0,179	0,172	0,162
120 (2:00 min)	0,152	0,144	0,134
130	0,130	0,121	0,112
140	0,112	0,103	0,094
150 (2:30 min)	0,098	0,088	0,080
160	0,086	0,076	0,069
170	0,076	0,066	0,060
180 (3:00min)	0,068	0,038	0,052

Set out your test results on the graph below that represents voltage over time. Connect the points with a fluent line.

