Work, power and efficiency

Do you still know these formulas?

<u>Work</u>

Work is a measure of the work done by a power source when you are moving an object.

If a force results in a movement, then work is being produced. .
Consequently work is a form of energy.

The work (energy) done by a force of 1 newton (1N) to move an object 1meter (1m),is called 1 joule (1J).

W[J]=F.s [N.m] with W: work or energy
(English? :W[J]=F.d [N.m]) F: force
s: displacement

with J : joule
N: newton
m: meter

<u>Power</u>

Every energy conversion requires a certain time. The amount of work that has been delivered per unit of time is called the power

P[W]=W/t [J/s] with P: power
W: work
t: time

with W: watt
J: joule
s: second

<u>Mechanical power</u>

The mechanical power is expressed by the formula:

P[W]=F.v [N.(m/s)] with F: force
v: velocity

with N : newton
m/s: meter per second

When we lift an object, the force we need is the force of gravity. We can calculate this with the formula:

$F [N]= g . m [(N/kg).kg]$ with g : gravitational acceleration
m : the mass of the weight

with N/kg : newton per kilogram
kg: kilogram

We can calculate the velocity with the formula:

$v[m/s]= s/t[m/s]$ with s : distance / displacement
(English? : $v[m/s]= d/t[m/s]$) or $v=x/t$) t : time

with m: meter
s: second

<u>Electrical power</u>

We can calculate the electrical power with the formula:
$P[W]=U.I[V.A]$ with P: power
U: voltage
I: current

with V : volt
A : ampere

<u>Efficiency</u>

Efficiency is the ratio between the useful power delivered by the motor and the power that you supply to the engine. In most energy conversions energy gets lost (usually in the form of heat). we call this lost energy “losses”.

$\eta=P_n/P_t$ [W/W] with P_n: useful power output
P_t: total power input

Efficiency has no unit and is usually expressed in%.

We calculate the efficiency of the LEGO engine by dividing the useful mechanical power output by the electrical power input.
$\eta= P_{mechanical} / P_{electrical}$

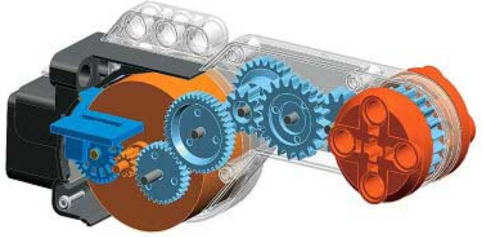
Unloaded characteristics of the motor

What you need:

light sensor
a test meter
cables to measure the current
a voltage source
a LEGO NXT engine with a wheel mounted onto it

NXT motor

This motor is specifically designed for the NXT set.
This motor uses a lot of internal reduction and as a result it has a low speed.



Transmissions in the motor

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10:30:40            = 1:4
       9:27         = 1:3
         10:20      = 1:2
            10:13:20 = 1:2
Overall               1:48
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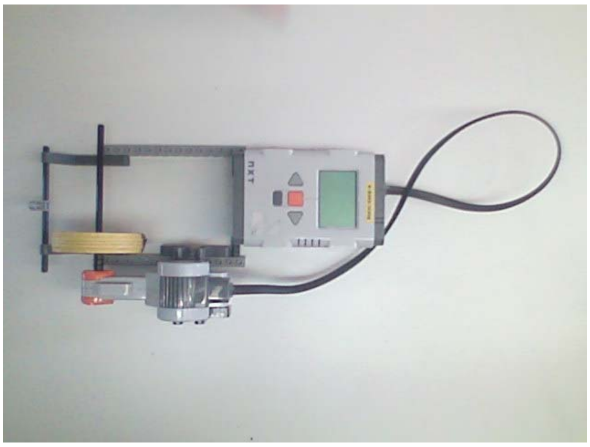
You can also use the motor with another source if you make another cable.

Experiment 1: The motor is powered by the NXT

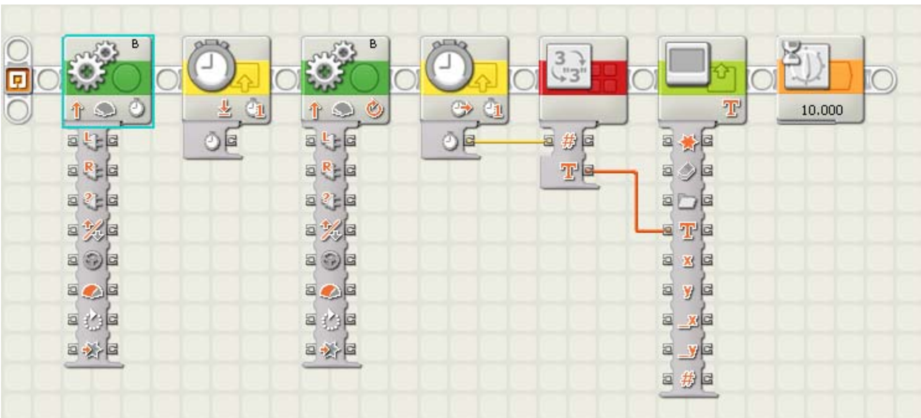


Set-up

Connect a motor to the NXT and let it run for 3s before you set your timer on zero. Then you let the engine run for 30 revolutions and you time how long it takes. Then, for every new execution of the test, you change the power of the NXT motor.
To make it easier to count the number of revolutions you mount a wheel onto the motor. Plaster your wheel with a light coloured tape (like yellow). Finally you put a black mark on that tape. (See picture.)

We use an NXT with a fully charged battery while it’s also connected to a wall outlet.

Program:



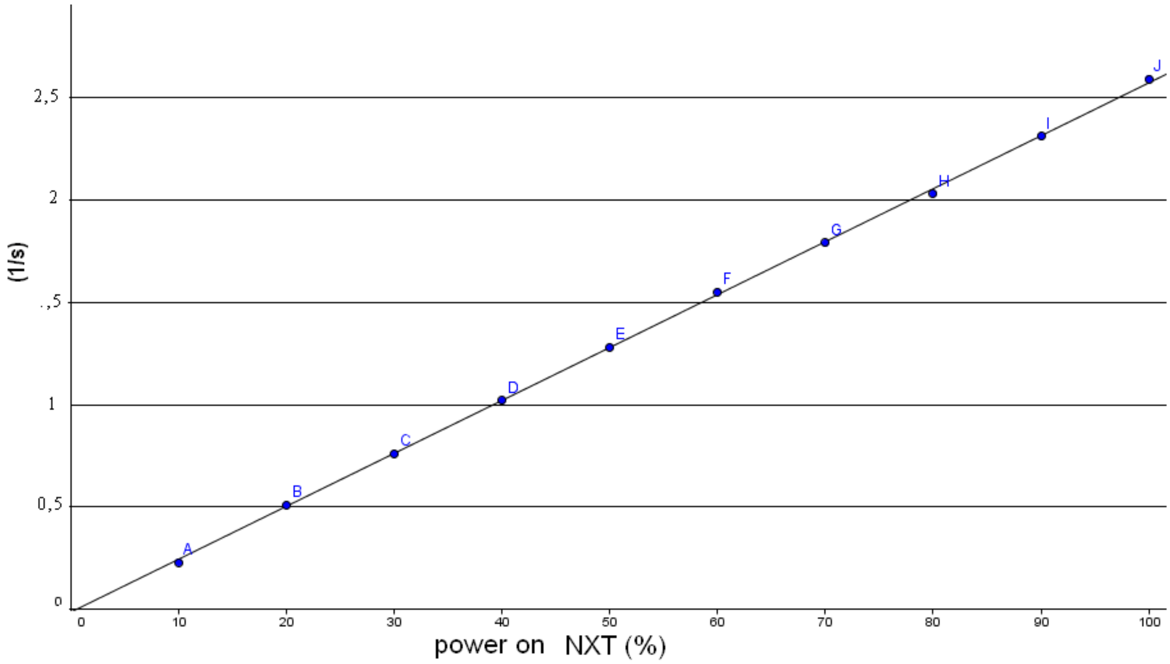
You start by letting the engine run for 3s to render the run-up speed negligible. Then put the timer to zero. Then you let the engine run for 30 revolutions. With the help of the second timer block you read the time on the screen of the NXT. In order to do this you connect the timer block with the button “Number to text” and then the button “Display”.
Finally we make sure this time stays on the screen for 10 seconds by using a block “Wait for time”.

Measurements:

power of NXT	time (s) for 30 revolutions	number of revolutions (s^{-1})
0%	0	0
10%	131,1	0.23
20%	59,4	0.51
30%	39,7	0.76
40%	29,3	1.02
50%	23,5	1.28
60%	19,4	1.55
70%	16,8	1.79
80%	14,8	2.03
90%	13,0	2.31
100%	11,6	2.59

Put these results into the graph.

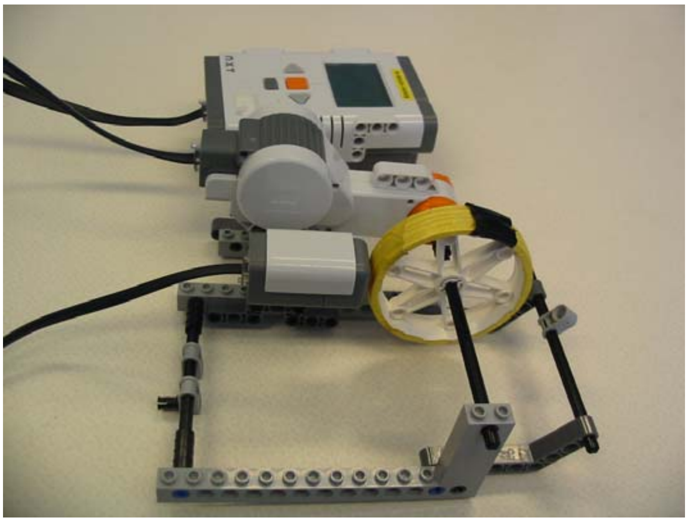
Graph of the number of revolutions in relation to the power of the NXT.



Conclusion:

The larger the power of the NXT the higher the number of revolutions.
Their a linear relation between both.

Experiment 2:The engine is driven by an external voltage source.



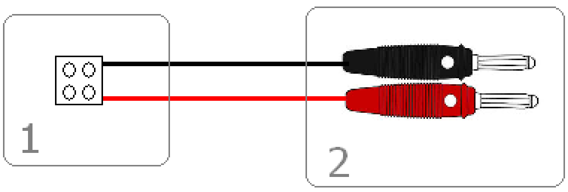
Set-up

This time connect the engine to an adjustable voltage source and repeat the same experiment. On the engine you mount a wheel with yellow tape and a black mark, like described before. The light sensor can detect the black mark. Calibrate the light sensor so that it can easily distinguish between the two colours.

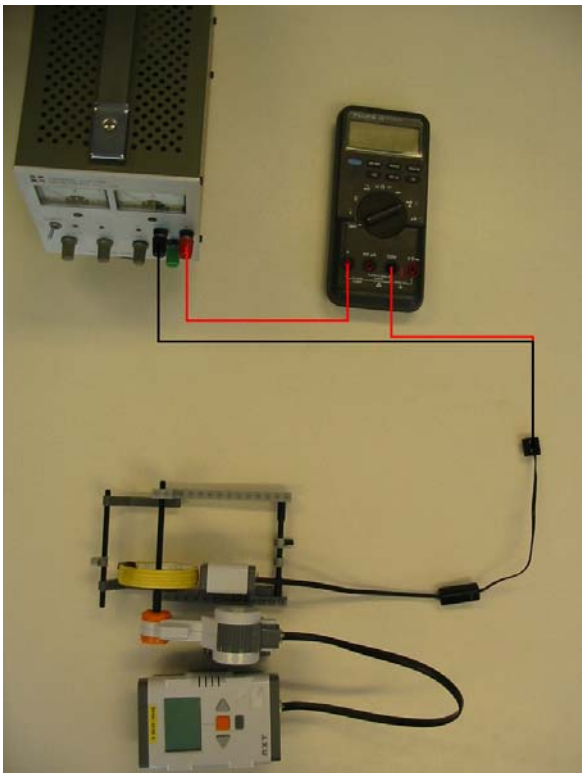
Aim the light sensor at the black mark.
What do you read ? 162

Aim the light sensor at the yellow tape.
What do you read ? 620

Connect the motor to a voltage source and let the wheel make 3 revolutions. Because the standard LEGO cables can't be connected to the voltage source, we need a special cable to connect the LEGO motor to the source . This cable consists of half a LEGO cable (1) and two standard 4 mm plugs (2).



Measure the current with a multimeter.



We measure the current with the current meter (amp meter) that we connect with the motor in a series circuit.

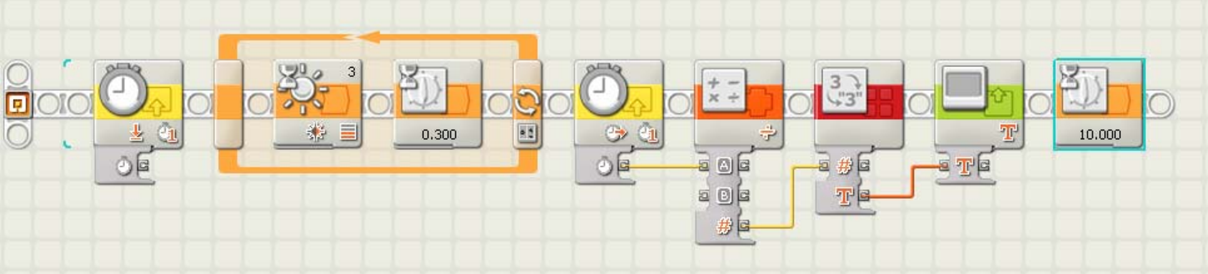
The voltage can be measured in two ways by connecting the voltmeter in a parallel circuit either with the engine or with the source.

The resistance of this motor is large and therefore it is better to use the second method. From the results however we couldn’t distinguish a major difference between the two methods. Moreover, we note that the measured voltage remains very close to the source voltage. Consequently we can use the voltage of the voltage source instead of measuring the voltage.

Let the wheel first run for a few seconds to avoid any influence of the acceleration at the start. Then start the program on the NXT. Do this when the black mark is at the top of the wheel.
The light sensor measures when the black mark passes.

Recalculate the rotational speed of the wheel at different voltages.

Program:



You start the programme by putting the timer to zero . Then you place a loop with a block “Wait for light” and “Wait for time” inside.

How many times do you have to repeat this? 4 times

Then read the timer value on the screen. Because the NXT shows the time in milliseconds we first divide the result by 1000. Finally, we use another block “Wait for time” so that we have enough time to read the result.

The program causes a problem. With the block 

you need to adapt the time to the speed of the motor. If the motor runs too fast the black mark might pass the sensor before the end of the “Wait” time and not be detected.
This would result in a wrong number of revolutions.

For these measurements, we suggest to set this block as follows:

2V,3V – 0.8s
4V-7V – 0.3s
8V-10V – 0.1s

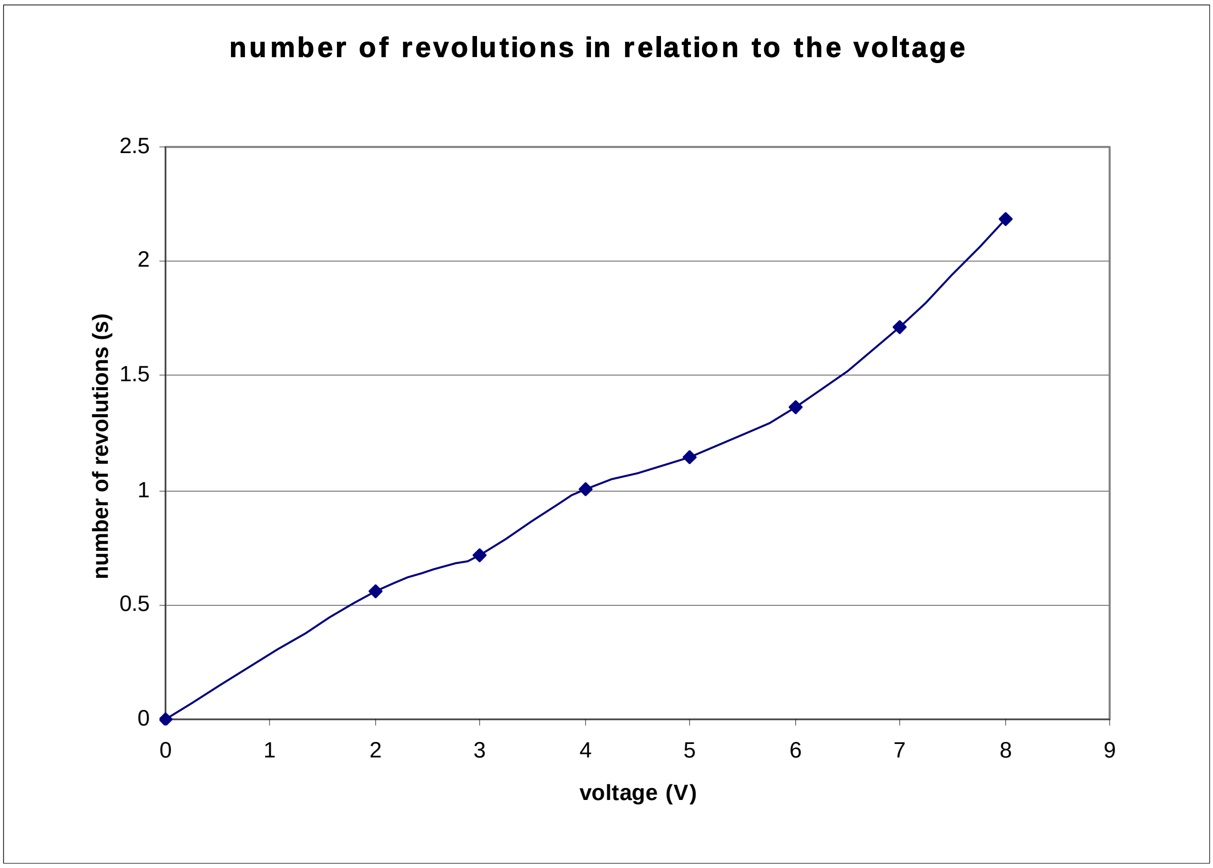
Start the program when the black line is at the top.
In order to avoid incorrect measurements, measure twice and take the average of both measurements. If the two measured values differ too much the lightsensor might have made a mistake. In that case you repeat the measurement.

Measurement results:

voltage(V)	current(mA)	time(s) to make 3 revolutions First measurement	time(s) to make 3 revolutions second measurement	time(s) to make 3 revolutions average	Number of revolutions (s^{-1})
0	0	0	0	0	0
2	40	5,34	5,46	5,40	0,56
3	45	4,11	4,27	4,19	0,72
4	50	3,05	2,93	2,99	1,00
5	51	2,63	2,62	2,63	1,14
6	55	2,18	2,22	2,20	1,36
7	60	1,79	1,72	1,76	1,71
8	62	1,34	1,41	1,38	2,18

Put the results into the graph.

Graph of number of revolutions in relation to the voltage



Conclusion

The higher the voltage, the higher the number of revolutions.

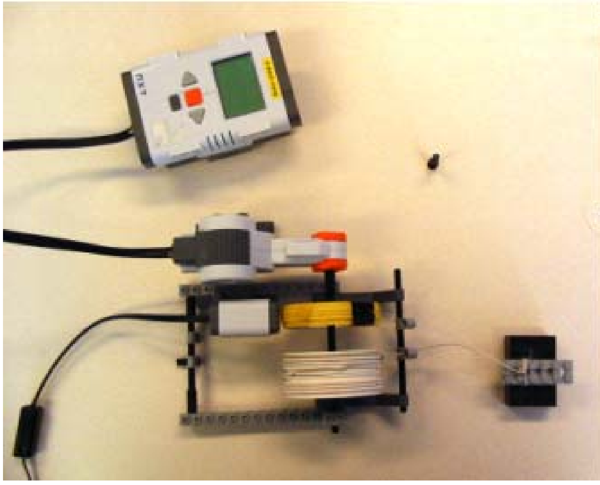
Compare the tables of the two previous measurements.

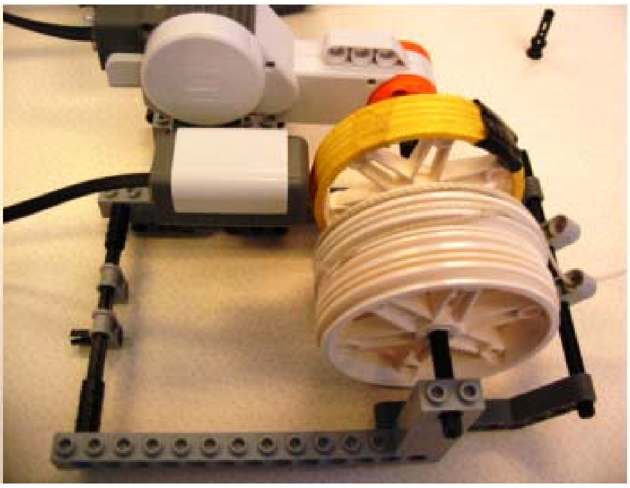
Voltage (V)	number of revolutions(s^{-1})	Power of NXT	number of revolutions (s^{-1})
0	0	0%	0
2	0,56	10%	0.23
3	0,72	20%	0.51
4	1,00	30%	0.76
5	1,14	40%	1.02
6	1,36	50%	1.28
7	1,71	60%	1.55
8	2,18	70%	1.79
10		80%	2.03
		90%	2.31
		100%	2.59

Conclusion:

When we compare these two tables, an NXT-power of 70% seems to correspond to a voltage of 7V. A power of 50% roughly corresponds to a voltage of 4V.

Loaded characteristics of the engine





Set-up

Again connect the motor to an adjustable voltage source. On the engine you mount a second wheel that lifts a mass. Apart from this, use the same set-up as in the previous experiment.

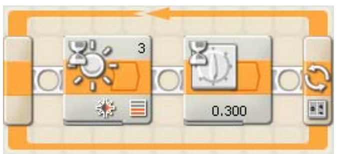
Connect the motor to a voltage source and let the wheel make 3 revolutions. Once more the light sensor detects when the black mark passes. After one turn you start the timer on the NXT. Let the wheel make two more revolutions. Remember that this way you avoid the influence of the acceleration at the start and you can now calculate the rotational speed of the wheel.

Repeat this measurement at a voltage of 2V, 4V, 6V, 8V

Now you can calculate the efficiency of the motor at different voltages.

Program:

Use the same program as in the previous test but now we let the engine make 2 revolutions before we start. The loop is set to 3 times.



Since a mass is being lifted, the turning speed will decrease. Therefore we also adjust the waiting times.

2V : 1s
3V,4V : 0,8s
5V–8V : 0,3s
10V : 0,1s

This time, in order to obtain good measurements, it is best to start the program on the NXT first and only then connect the motor to the voltage source.

Calculating the efficiency of the motor:

In the example you calculate the values from the table, with a voltage of 6V.

Calculate the power:

Establish the mass of the load that you lift : m = 114g =0.114kg

Now calculate the force: F = 0,114kg.9,81N/kg = 1,12N

Calculate the speed:

Calculate the distance travelled if you know that the wheel makes 2 revolutions, and the radius of the wheel is 0,032m.

s= 2.(2.π.R)= 4. π.0,032m= 0,4m

The time needed to make two revolutions can be read on the NXT.

Now you can calculate the velocity

v=s/t =0,4m/1,8s=0,22m/s

Calculate the mechanical power:
P = F.v = 1.12 . 0,22 [$N.m.s^{-1}$] = 0,25W

Calculate the electrical power:

P = U.I = 6.0,2[V.A] =1,20W

Now you can calculate the efficiency.

$\eta = P_{mechanical} / P_{electrical}$ =0,25W / 1,14W= 0,22 = 22%

Fill in the table underneath:

 Voltage(V)	Current (A)	Force (N)	Time for 0,4m (s)	Velocity (m/s)	Mechanical Power (W)	Electrical power (W)	Efficiency (%)
0	0,00	1.12	0	0,00	0,00	0,0	0,0
2	0,19	1.12	8,80	0,05	0,05	0,4	13,4
3	0,19	1.12	4,50	0,09	0,10	0,6	17,5
4	0,19	1.12	3,10	0,13	0,14	0,8	19,0
5	0,19	1.12	2,30	0,17	0,19	1,0	20,5
6	0,19	1.12	1,80	0,22	0,25	1,1	21,8
7	0,19	1.12	1,50	0,27	0,30	1,3	22,5
8	0,19	1.12	1,30	0,31	0,34	1,5	22,7
10	0,20	1.12	1,00	0,40	0,45	2,0	22,4

Conclusion:

You notice that the efficiency of the engine is very low. This is mainly due to frictional losses. You also notice that a higher velocity results in a higher efficiency. This is because at a higher velocity the frictional losses have less influence.

Draw a graph of the velocity in relation to the voltage.