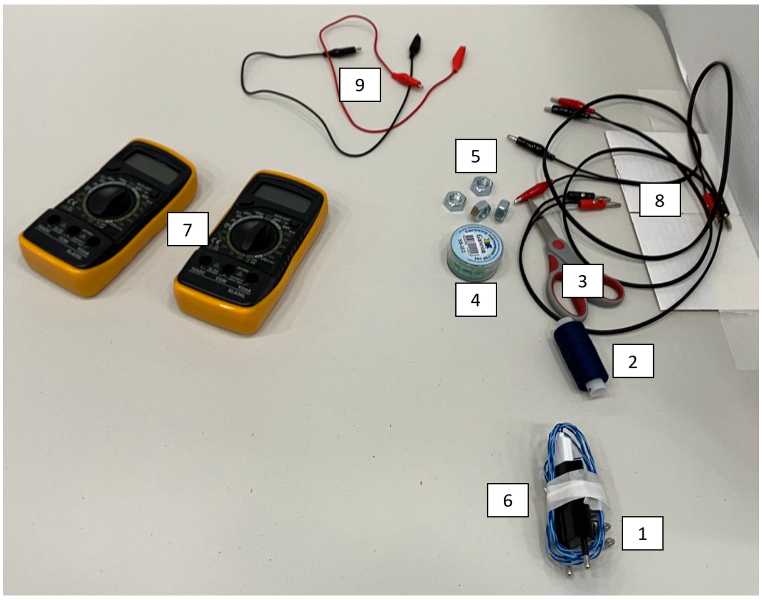
J1a - Electric motor

Equipment:

1. Electric motor with spool
2. Thread
3. Scissors
4. Ruler
5. Four M10 nuts
6. Voltage source
7. Two multimeters
8. Two pairs of «Banana-Alligator» wire
9. «Alligator-Alligator» wire



Electric motors are an essential part of our lives, but their theoretical description within the framework of school physics turns out to be somewhat unclear.

Let us consider the behavior of an electric motor in the simplest case: when it is directly connected to a constant voltage source with the voltage equal to $\mathcal{E}$.

An electric motor consists of a wire wound in a specific way near permanent magnets. The resistance of the wire is R, and a naive approach would suggest that the current flowing through this wire is $\mathcal{E}/R$.

However, this turns out not to be the case. If a current I flows throught the winding, the voltage source do work $\mathcal{E}I\Delta t$ over a time interval Δt. At the same time, heat $I^2R\Delta t$ is dissipated in the motor winding. Additionaly, the motor do mechanical work $P\Delta t$ (work against friction and useful work). Thus, from the energy conservation we have:

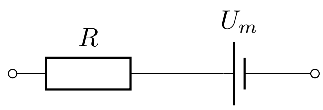
$$\mathcal{E}I = I^2R + P. \tag{1}$$

With this expression it's clear that naive approach $I = \mathcal{E}/R$ based on a simple Ohm's law is valid only when $P = 0$.

Let's rewrite the expression (1):

$$(\mathcal{E} - IR)I = P.$$

In this form it looks like the work of the voltage source with the voltage $U_m = \mathcal{E} - IR$. Now, we can propose an equivalent electrical circuit for the motor: a ristor R connected in a series with a battery with the voltage U_m (this voltage dependse on the operating mode of the motor).



The mechanical power P could be expressed in terams of the torque M acting on the motor shaft and the rotational frequence ν of the shaft:

$$IU_m = P = 2\pi\nu M.$$

If the rotational frequency of the shaft is ν, then $1/\nu$ is the time of one full rotation of shaft.

A1 It turns out that either **2.0**

$$I \propto \nu, \quad U_m \propto M$$

either

$$I \propto M, \quad U_m \propto \nu.$$

Show which case takes place. The method will be evaluated ONLY by drawn diagrams.

A2 Determine the winding resistance R using two methods: **2.0**

1. Using an ohmmeter;
2. Using a voltage source, voltmeter and ammeter.

The method will be evaluated ONLY by drawn diagrams.

Let us carry out an experimental study of the voltage U_m generated in the electric motor. Take a thread of length L and attach four nuts to one end and spool the other. Then, wind the thread around the spool and realise it, allowing the nuts to unwind the spool as they fall.

The nuts are heavy enough to cause the spool to unwind freely, i.e.the tension force in the thread acting on the failling nuts can be neglected, and the nuts essentially fall freely.

To measure U_m, connect a voltmeter to the motor. The unwinding process is very fast, so the voltmeter will only update its readings a few times on its screen. However, by repeating the experiment several times, it is possible to run the experiment so that the voltmeter updates its reading for the last time close to the moment when the thread is almost completely unwound.

A3 Measure the dependence of the voltage U, displayed by the voltmeter at a moment close to the end of the thread unwinding, on the length of the thread L. Perfrom measurements for 10 different values of L. **2.0**

A4 Linearize the dependence of U on L and plot a linear graph. **2.0**

A5 Determine the radius of the spool r. **1.0**
The method will be evaluated ONLY by drawn diagrams.

A6 To prevent the shaft of our electric motor from rotating, we should apply the torque M_{min} to it. Calculate the value of M_{min}, **1.0**