Replication of the Trouton-Noble Experiment

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The basic aim of the 1903 Trouton-Noble experiment was to detect an absolute motion of the Earth through the ether. The experiment presented in this paper is a replication of the Trouton-Noble experiment done with present technology, free from previous imperfections. Contrary to previous results, a positive result has been observed since the sensitivity of the experimental setup has been improved by a factor 100 with respect to the original 1903 experiment. Namely, a continuous measurement of the rotation of the capacitor was observed when a high voltage (33.7 kV) was applied to the capacitor. This indicates that indeed the present experiment is the electrostatic equivalent of the Michelson-Gale experiment.

I. INTRODUCTION

In 1903 two physicists, Trouton and Noble [1], conceived an electrostatic experiment which is the analogue of the Michelson-Morley experiment, since the purpose of these two experiments is to show that the Earth is moving through the ether. The fundamental idea of this experiment is as follows: a capacitor suspended with a wire in the reference frame of the terrestrial laboratory must undergo a stimulated rotation when it is charged using an electrostatic source. Indeed, if the Earth is moving in the ether, a charged capacitor creates a magnetic field between its two plates which is a consequence of the movement of the charges in the ether. It results from this that the capacitor must be subjected to a torque, as will be shown below. The problem has been well discussed in the literature, as can be seen in the references [1–22]. Moreover, different approaches have been used to explain the null result and the so-called Trouton-Noble paradox, wherein observers in different inertial frames moving relative to each other, arrive at conflicting conclusions about the turning tendency of a suspended charged capacitor. One of us [10] replicated the experiment with positive results, which was criticized [20] for a failure to shield the apparatus from external electric fields induced via nearby objects, unlike earlier experiments. Nieves *et al.* also predict that a very slight positive result might arise from the interaction with the Earth's magnetic field and its axial rotation, such a result could explain the result by Cornille, as Cornille's observation was qualitative and not quantitative. These critics will be answered in this paper. We will not deal with the TN calculation in this paper, since the problem is well debated in the references [1–21] and in the book [22]. However, one important point deserves to be discussed, namely all the authors except those in references [11–16, 22] deal

with the rigid motion of positive and negative surface charges, as if the capacitor was perfect and has no leakage current. In fact there is a leakage current, which can also explain the positive results.

II. THEORETICAL STUDY

The null experiment result has been analyzed from different points of view by the authors of the references [1–22]. For example, Jefimenko [17] thinks that the electromagnetic field angular momentum balances the mechanical angular momentum so that no torque can be observed. However, as stated above, all the theories and calculations considered by the authors are done for a rigid motion of charges (no leakage current). Therefore, even if the interpretation of Jefimenko is correct, it remains that the rotation will occur for a non-rigid motion of the charges when leakage current is present. One can state the problem of change of reference frames in simple terms, since the problem has been fully discussed by one of the authors in several references [11, 22]. Let us first consider the case of two charges q_e and q_i with the condition $q_e = -q_i$ moving with the same velocity $\mathbf{U}_e = \mathbf{U}_i$ (rigid motion) with respect to a given reference frame. By using the classical Maxwell equations, one can demonstrate that the magnetic forces of interaction between the two charges bounded together by a dielectric of thickness $R = \mid \mathbf{R}_{ei} \mid = \mid \mathbf{R}_{ie} \mid$ are given by the relations:

$$\mathbf{B}_e = \frac{q_e}{cR^3} \, \mathbf{U}_e \wedge \mathbf{R}_{ei}, \qquad \mathbf{B}_i = \frac{q_i}{cR^3} \, \mathbf{U}_i \wedge \mathbf{R}_{ie}, \tag{1}$$

$$\mathbf{F}_{ie} = \frac{q_i}{c} \, \mathbf{U}_i \wedge \mathbf{B}_e, \qquad \mathbf{F}_{ei} = \frac{q_e}{c} \, \mathbf{U}_e \wedge \mathbf{B}_i, \tag{2}$$

since $\mathbf{U}_e = \mathbf{U}_i$, we have $\mathbf{B}_e = \mathbf{B}_i$ and $\mathbf{F}_{ei} = -\mathbf{F}_{ie}$. Therefore, for fixed charges on the surfaces of the capacitor plates, a mechanical torque is expected to be observed due to the motion of Earth through space. Let now consider the more general case of mobile charges located in an external magnetic field $\mathbf{B}_{ext}$, we get:

$$\mathbf{F}_{ie} = \frac{q_i}{c} \, \mathbf{U}_i \wedge [\mathbf{B}_e + \mathbf{B}_{ext}], \qquad \mathbf{F}_{ei} = \frac{q_e}{c} \, \mathbf{U}_e \wedge [\mathbf{B}_i + \mathbf{B}_{ext}]. \tag{3}$$

Assuming that $\mathbf{U}_e = \mathbf{U}_i + \mathbf{V}$, where $\mathbf{V}$ is the velocity of electrons defined with respect to the rest frame of the ions, then one can calculate the resulting force $\mathbf{F} = \mathbf{F}_{ei} + \mathbf{F}_{ie}$ when the distances between the electrons and the ions approach zero, which becomes after calculation:

$$\mathbf{F} = \frac{q_e}{c} \, \mathbf{V} \wedge \mathbf{B}_{ext} + \frac{q_i^2}{c^2 R^3} \, [[\mathbf{U}_i \cdot \mathbf{R}_{ie}]\mathbf{V} - [\mathbf{V} \cdot \mathbf{R}_{ie}]\mathbf{U}_i]. \tag{4}$$

In the special relativity theory, the second term between the square brackets in the above equation is assumed to be zero whether or not there is a leakage current. Indeed, in the earth reference frame, for a neutral conductor $q_e + q_i = 0$ submitted to an external magnetic field

where a current $q_e\mathbf{V}$ is circulating, the contribution of the forces for two kinds of charges cancels one another, either because we have a rigid motion of the charges $\mathbf{V} = 0$ or because we assume $\mathbf{U}_i = 0$. In that case, there remains only the magnetic force due to the external magnetic field which is often written in the literature in the form

$$\mathbf{F} = \frac{I}{c}\mathbf{l}\wedge \mathbf{B}_{ext}. \tag{5}$$

If there is a leakage current I in the capacitor dielectric, we can expect a rectilinear and rotational motion of a suspended capacitor charged with a high voltage, because of the presence of the second term in Equation (4). The case of a rectilinear motion of an electrostatic pendulum is discussed in the book [22], which shows that the external force resulting from the violation of Newton's third law is indeed proportional to the leakage current.

As correctly stated by Nieves *et al.* [20], a torque can result from the action of the Earth's magnetic field acting as an external field according to formula (4), which differs from the physical interpretation given by Nieves in their formula (5). In fact, the current which flows in the test circuit causes the device to act as a compass. To minimize this effect, the plates of the capacitor are initially positioned in the west-to-east direction before applying the voltage. Therefore, the leakage current through the dielectric is directed in the north-to-south direction, making the torque zero according to the formula (5). However, the torque (formula (5)) induced by the Earth magnetic field is quite small in this experiment, for $B = 0.5$ gauss, $R = 2$ mm and a leakage current $I = 6\,10^{-5}$ A, we get $\Gamma_m = 9.6\,10^{-14}$ Nm.

The positive result in the experiment [10] was also criticized because of the absence of a shielding screen around the capacitor, as was the case in previous TN experiments. These criticisms show an ignorance of what a Faraday cage does. A Faraday cage splits space in two regions, inside and outside the cage. Firstly, a Faraday cage has no shielding effect about the magnetic effect. Moreover, the purpose of a Faraday cage used in any experiment is to prevent outside electrostatic and radiation effects from influencing the inside space. However, it does not prevent electrostatic induction to occur in the inside wall of the cage creating an electrostatic field which interacts with the dipole. This interaction may cancel or increase the magnetic effect depending on the initial condition of the dipole.

The electric field created outside the capacitor which must necessary be taken into account in the analysis of the induction effect, results from the finite dimension of the capacitor. Indeed, it is shown that for a plane capacitor made up of two discs of diameter D separated by a distance l, the external electric field $\mathbf{E}_e$ is related to the internal electric field $\mathbf{E}_i$ by the formula $\mathbf{E}_e = -\mathbf{E}_i\,l/D$. The magnitude of the internal electric field $E_i \approx 3.5\,10^7$ volt/m is thus more significant than the external electric field by a factor which exceeds 10^2. The external electric field can induce an electric field in the vicinity if there is any metallic object close to the capacitor. Moreover, the induced electric field will be a function of time if the capacitor has a rotational movement.

For a Faraday cage very close to the capacitor, the induced electrostatic forces can be several times greater than the magnetic forces. Therefore, not only is a Faraday cage not needed in such an experiment but its presence can badly interfere with the result expected

from a TN experiment. To decrease the effect of induced electrostatic fields, no metallic object was allowed near the dipole, the distance between the capacitor and any object is more than 2 meters. Also the wood pieces of the vertical squirrel cage where the capacitor is suspended are covered with aluminium foils which are grounded to Earth in order to evacuate the induced charges to Earth. We made also a test by bringing a large metallic plate near by the squirrel cage with no effect on the rotation of the capacitor.

We also used two professional positive (+25 kV) and negative (-25 kV) high voltage power supplies which are shielded and grounded to Earth. The cables bringing the voltage to the capacitor are also shielded and grounded to Earth and are positioned along the axis of symmetry of the suspended capacitor coming from the ground and the ceiling. The potential difference (32 kV) between the capacitor plates is kept constant all the time during the measurements. The leakage current is around 40 to 80 microampere. All the experimental setup was designed to insure an almost perfect cylindrical symmetry in order to avoid any induced anisotropy in the electrical field around the capacitor. By taking these precautions, one can be certain of decreasing the effect of induced electrostatic fields below the effect of magnetic fields. A rotation is expected in the Trouton-Noble experiment, a null effect can result only from a badly conceived experiment.

The experiment performed by Trouton and Noble and that by Tomaschek and Chase used heavy shielded capacitors, weighing several kg instead of 160 g in the present experiment, with frictional couples comparable in size to the couple that would result from a motion through space. Since 1926, no TN experiment has been replicated with modern technology. The replication of the TN experiment by Hayden [6] cannot be considered as a TN experiment, since he used a cylindrical capacitor and not a parallel plate capacitor. The reason why a cylindrical capacitor cannot show a rotational effect is by symmetry, the torques forces will cancel one another, no TN effect can be expected in Hayden's experiment. Moreover, the choice of too small voltages (2 and 0.6 kV) in the experiments quoted above does not make it possible to highlight the stimulated effect of rotation due to homogeneous and inhomogeneous charge distributions in the capacitor.

III. THE TROUTON-NOBLE EXPERIMENT

In the literature, one simplifies the study of the problem by supposing that the charged capacitor moves with an uniform velocity with respect to a reference frame where the ether is at rest. Moreover, it is admitted that only the surface charges $Q = Q_1 = -Q_2$ located on the metal plates of the capacitor as shown in Figure 1 contribute to the torque effect. It follows that the forces of induction are null as well as the sum of the electrostatic and magnetic forces. The attractive electrostatic forces for the charges on the surface of the plates are compensated by the forces coming from the insulating parts which maintain the plates of the capacitor apart. Moreover, one supposes that the electrostatic forces between the charges which are not face to face compensate also, which implies a symmetrical distribution of the charges on each plate preventing any deformation of the capacitor likely to cause a rotation of the capacitor.

There thus remains only the magnetic forces that each plate of the capacitor exerts on one another. These forces, which satisfy Newton's third law, have for their expression

$$\mathbf{F}_{B1} = -\frac{Q^2}{c^2 R^3}\,\mathbf{U}\wedge[\mathbf{U}\wedge\mathbf{R}] = -\mathbf{F}_{B2}. \tag{6}$$

The force is not along the direction of the vector $\mathbf{R}$. As a result, the electromagnetic torque will tend to rotate the capacitor plates parallel to the velocity. Therefore, if a parallel plate capacitor is suspended by means of a fine torsion fiber and charged, an electromagnetic torque is expected due to magnetic forces, since the capacitor is moving through the ether. Specifically, the torque $\Gamma = -[Q^2 U^2/2c^2 R]\sin^2(\psi)\sin(2\theta)$ where Q is the charge of the capacitor, R the distance between the plates, U the velocity of the capacitor carried along by the Earth in its motion around the Sun, θ the angle between the azimuth of the apex and the normal to the capacitor plates, ψ is the angle between the azimuth of the apex and the suspension fiber of the capacitor. The original Trouton-Noble experiment looked for the effect due to the orbital velocity $U = 30$ km/s of Earth around the Sun. They claim that the experiment gave a null result. Other more accurate experiments [2, 3, 6] confirmed this null result. However, experimental problems were identified [10–16, 18–19] making the Trouton-Noble null result inconclusive. Moreover, special relativity theory is at a loss in explaining this null result, as shown by the discussions published in the references [5, 7, 17].

A recent study by Szames [11] shed new light on the historical aspects of the Trouton-Noble experiment. This author reviewed the Trouton-Noble original papers and their subsequent, inadequate analysis by physicists. In fact, in the early 20s, positive results of Trouton-Noble-like experiments were achieved by Thomas T. Brown and his professor, Dr. Paul A. Biefeld [11], giving birth to the Biefeld-Brown effect. The connection between the two experiments was not established at that time. The full details of this story and some of its possible applications have been explored in depth by Szames [11].

The magnetic torque applied to the capacitor in CGS units is

$$\Gamma_m = \frac{Q^2}{2R}\frac{U^2}{c^2}\sin^2(\psi)\sin(2\theta). \tag{7}$$

In the preceeding formula, we must take into account the velocity of the Earth in the Milky Way which is in first approximation

$$\mathbf{U} = \mathbf{U}_s + \mathbf{U}_o + \mathbf{U}_e, \tag{8}$$

where the velocities $\mathbf{U}_s$, $\mathbf{U}_o$, $\mathbf{U}_e$ are respectively the velocity of the solar system, and the orbital and spin velocities of the Earth with the values $U_s \approx 300$ km/s, $U_o \approx 30$ km/s, $U_e \approx 0.5$ km/s. The square magnitude of this velocity has for its value

$$\mathbf{U}^2 = \mathbf{U}_s^2 + 2\mathbf{U}_s\cdot\mathbf{U}_o + \mathbf{U}_o^2 + 2\mathbf{U}_s\cdot\mathbf{U}_e + 2\mathbf{U}_o\cdot\mathbf{U}_e + \mathbf{U}_e^2 \tag{9}$$

where the terms in the above formula are written in decreasing order according to their magnitude. It results from formula (7) that the torque value for a capacitor of 232 pF

charged under a voltage of 32 kV is $\Gamma_m = 1.22\,10^{-6}\sin^2(\psi)\sin(2\theta)$ Nm for $U^2 \approx U_o^2$. A capacitor of $C = 232$ pF charged with a 32 kV voltage has a charge $Q = 7.4\,10^{-6}$ Coulomb to be compared with the charge $Q = It$ caused by a continuous leakage current of $I = 6\,10^{-5}$ Ampere. It follows that after 0.12 second, we might think that the volume effect will override the surface effect. This is not true since the term in U^2 in formula (7) must be replaced by a term of the form

$$\mathbf{U} \cdot \mathbf{V} = \mathbf{U}_s \cdot \mathbf{V} + \mathbf{U}_o \cdot \mathbf{V} + \mathbf{U}_e \cdot \mathbf{V}, \tag{10}$$

where $\mathbf{V}$ is the velocity of the conduction electrons in the laboratory frame. Knowing that $U_o \approx 30$ km/s and the velocity of electrons in a metal is V = 3 mm/s, we can see that the force due to the leakage current is 10^{-7} lower than the force due to the classical Trouton-Noble effect for the same amount of charges involved in the calculation. As shown by the formula above, the surface charges on the plates and the volume charges flowing through the dielectric participate with the same physical interpretation, namely an absolute motion with respect to the ether.

It should be stressed that we observed the effects of translation and rotation in the experiments of Trouton-Noble and Biefeld-Brown in the electrostatic pendulum experiment described in reference [22], in a concomitant way in time by oscillating the high voltage applied to the capacitor when this capacitor is hung as a pendulum. The same physical interpretation thus applies for both the effects of translation and rotation.

In a recently published paper [23], the author tries to prove that there is no torque from a theoretical point of view. This paper is not correct since the author made some wrong assumptions from the beginning.

Firstly, the author states that the two point charges are connected by a rigid rod and calculates an acceleration of the charges along the rod which contradicts his assertion that the charges are fixed at the ends of the rod. In order to solve his Equation (5), he has to set to zero the component of the acceleration along the direction of the rod.

Secondly, this author calculates the electromagnetic field of each charge by stating that his Equations (1) and (2) are obtained with constant velocity of the charges, which cannot be correct since both charges are accelerating. His Equation (1) is not correct if the velocity of each charge is not a constant. Indeed, a term depending on the velocity is missing. The correct formulation is given by Cornille [22], Equation (98), p. 539 or by Jackson [24], Equation (14.14), p. 657.

IV. THE EXPERIMENTAL SETUP

The experimental setup is shown in Figure 2. It has been described in detail in the proceedings of the conference held in Nancy [25]. The capacitor ($C = 232$ pF, mass=160 g) is made of two copper plates fixed on each side of a plexiglas plate (2 mm thick) suspended on a silk wire of 10 cm length. The torsion constant of the suspension wire has been measured and found to be $K = 2.2\,10^{-6}$ Nm/rad. The upper and lower ends of the suspension are fixed to the structure of the stratified wood cage by the motion systems shown in Figure 2.

The electrical connection is insured by special electrodes dipping into mercury filled cups. The capacitor can turn up to ten complete revolutions without losing electrical contact.

The capacitor is filmed by a camera placed above the capacitor during all the time the experiment is running. Therefore, the position of the capacitor plates is monitored and calculated each second. The result of this calculation is registered in a text file in order to avoid registering huge picture files. The temperature and pressure in the room are also monitored. No correlation between these quantities and the rotation of the dipole was observed. Since everything is controlled automatically by electronics, no observer is needed to be present in the room during the time the experiment is running.

The measurements were done during two days before and after the equinox occurring on september 23, 2007, because we may expect a time variation of the couple due to the time variation of the angles in the composition law of the velocities (see formula (9)); this time variation should be greater for the solstice positions of Earth. The capacitor was positioned to cancel the effect of the earth magnetic field, namely the perpendicular to the capacitor plates is directed to the north direction. As soon as the high voltage ($+16.326$ kV, -17.419 kV) is applied, one observes a rotation of the dipole of 42 degrees with respect to the north direction as shown in Figure 3. The variation of 42 degrees occurs in a lapse of time of 13 hours. We replicated the same experiment on December 7 and we obtained the same variation of angle. Therefore, the variation of 42 degrees seems to be not correlated to the equinox position. We can also point out that the measured couple calculated with the formula $K\theta = \Gamma_0 = 1.62\,10^{-6}$ Nm is about the same as the value $\Gamma_0 = 1.36\,10^{-6}$ Nm calculated from the theory.

To calculate the numerical solution exactly, one has to solve a second-order non-linear differential equation:

$$I\frac{d^2\theta}{dt^2} + F\frac{d\theta}{dt} + K\theta = \Gamma_0 \sin^2(\psi)\sin(2\theta - 2\theta_0), \tag{11}$$

where I is the moment of inertia, F the friction coefficient, and K the restoring torque coefficient. Curiously, no paper dealing with the TN experiment gives this equation, which is fundamental. Indeed, one can observe in Figure 3 the fast increase of the angle when the voltage is switched on, an effect which is expected from the theory that supports the experimental result. The torsional pendulum works around the critical regime for $F = 2\sqrt{KI}$ since no oscillatory motion is observed. Knowing $I = 8.33\,10^{-4}$ kg m^2, $K = 2.22\,10^{-6}$ Nm/rad, we get $F = 8.6\,10^{-5}$ kg m^2/s. The angle ψ is also a function of time, but is taken as a constant in a first step, since the apparatus is not sensitive enough to the time effect because of the friction term which is still too high. We use "Mathematica" to solve this equation with $\theta_0 = 0$ and $F = 3\,10^{-5}$ kg m^2/s; the curve is represented in Figure 3. The result is lower than the experimental results, since $\Gamma_0 = 1.36\,10^{-6}$ Nm. We recall that the applied couple in the original TN experiment is about $\Gamma_0 = 10^{-8}$ Nm making the present experimental setup 100 times more sensitive than the TN experiment. We observe plateaus in the measurements. These plateaus can be the result of the measurement process, since the position of the capacitor plates is measured with a one degree accuracy.

V. CONCLUSION

The experiment presented in this paper is a replication of the Trouton-Noble experiment done with present technology, free from previous imperfections, such as a too heavy capacitor and a too low voltage used in the TN experiment—2 kV instead of the 33.7 kV used in the present experiment. Such an accurate experiment, the sensitivity has been increased by a factor 100 with respect to the original TN experiment, has not been done since the Tomaschek experiment in 1925. It took several years to settle correctly this experimental setup, which will now be used to perform systematic measurements in the near future with a better dipole and improved accuracy. As shown above, no effect from the Earth's magnetic field can be expected in this experiment. Moreover, the effect of any induced electrical field has been decreased by a proper design of the experimental setup. Contrary to previous results, a first positive result has been observed. Continuous measurements of the rotation of the capacitor during the presence of the high voltage suggests that indeed the present experiment is the electrostatic equivalent of the Michelson-Gale experiment [27]. The positive result obtained in this experiment, and the good agreement between the experimental and theoretical curves, confirm one more time the soundness of the Maxwell theory. This experiment can be added to the long list of experiments from 1851 to 2007 proving that one may measure the absolute motion of the Earth by internal experiments. Depending on the kind of experiments and the accuracy achieved, one could measure the absolute motion: spin rotation [26–28], orbital rotation [10, 29–33], and galactic motion [34–38] of the Earth through the ether. We quote 14 experimental measurements that contradict the assertions of the special relativity theory, which denies the possibility of such a measurement. We must also stress that space cannot be relative when rectilinear motion is concerned and becomes absolute when rotational motion is observed. Therefore, all these experimental results imply new definitions for the words absolute and relative, as discussed in reference [22].

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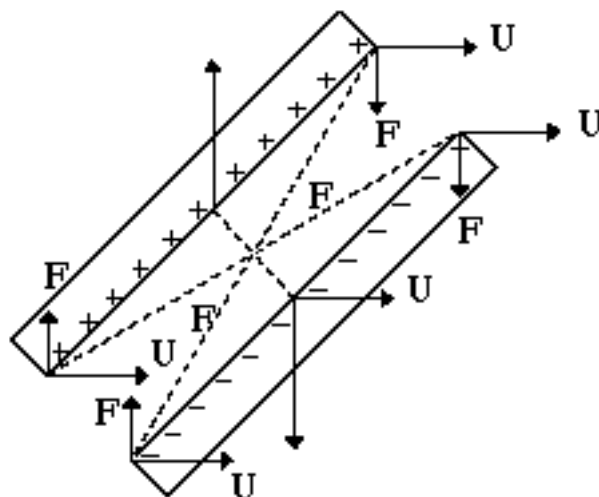

FIG. 1: Trouton-Noble experimental setup and the generation of a stimulated torque for a capacitor in motion through the ether.
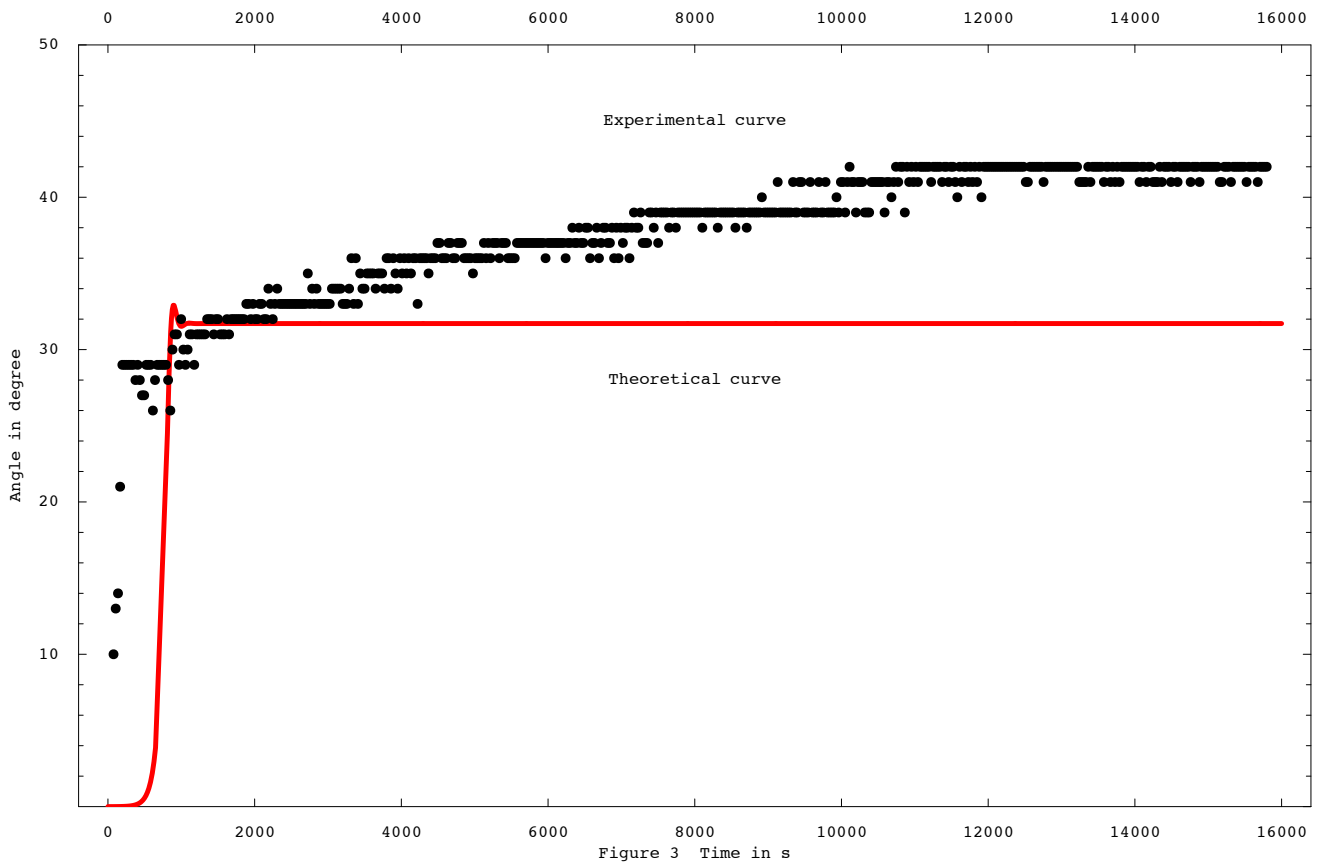
FIG. 2: The experimental setup.

FIG. 3: Time in s.