American Journal of Engineering Research (AJER)
E-ISSN: 2320-0847 p-ISSN: 2320-0936
Volume-8, Issue-1, pp-15-19
www.ajer.org
Research PaperOpen Access

Demonstration of the Lorenz Force in the Study of Physics

AlekseiGavrilov
Tallinn University of Technology, Tallinn, Ehitajate tee 5, EstoniaDepartment of Cybernetics, Division of Physics,
Corresponding Author: Aleksei Gavrilov

ABSTRACT: *the article considers experiments that demonstrate the Lorenz force in the process of studying physics. Describes in details the devicewhich shows rotation of an electrolyte with a flowing current when the electrolyte vessel is placed in the magnetic field. Also describes the demonstration device based on a spark discharge between twoelectrodes at normal atmospheric pressure.*
KEYWORDS: *physics course; demonstration of experiments; Lorenz force.*

Date of Submission: 21-12-2018 Date of acceptance: 05-01-2019

I. INTRODUCTION

If a particle carrying charge q moves in the electric and magnetic field at a speed**v**, then the force**F** acting on it is equal to:

$\mathbf{F}=q(\mathbf{E}+\mathbf{v}x\mathbf{B})$ (1)

Where**E** - electric field intensity and**B** - magnetic induction.

The force defined by formula (1) is called the Lorenz force [1].

However, quite often the Lorenz force implies only the magnetic component$\mathbf{F_m}$ **:**

$\mathbf{F_m}= q\mathbf{v}x\mathbf{B}$(2)

In this article we also consider the Lorenz forcetomean the magnetic force F_m. To demonstrate the Lorenz force, an experiment with circular rotation of electrolyte in a vessel is often used [2].One of the electrodes is located in the centerof the vessel, and the second is located along its perimeter. If we pass current through the electrolyte and place the vessel intothe magnetic field which is directed vertically to the surface of the electrolyte, the liquid will startthe circular motion. This results from the fact that the Lorenz force is always perpendicular to the velocity of the ions, that is, the radial directions (see formula(2)). Note that this experiment demonstrates not only the Lorenz force, but also the presence of "friction" forces between ions and liquid molecules. A detailed description of a similar device is given in our article.

More illustrative is the demonstration of the Lorenz force in a device resembling a cathode–ray tube (kinescope) [3]. In a flask, which also contains an electron gun, a narrow stream of electrons or electron beam is formed. Unlike a vacuum kinescope, this flask is filled with an inert gas at low pressure. Under the influence of electronscollisions with gas molecules, the path of the electron beam glows. Holding a magnet, one can see the curvature of the beam – which means one could directlyobserve the effect of a magnetic field on moving electrons. From the minus side of this device one could noteits complexity.

A simpler demonstration experiment was proposed by the authors of the article [4]. As a trajectory of the motion of charges, they used the trace of a high-voltage spark discharge at normal atmospheric pressure. The high voltage sourceis an ignition coil, the primary winding of which was interrupted at a frequency of the AC mains using an electromagnetic relay. The voltage on the primary winding was applied from a step-down network transformer and subsequent rectification.

The system of two electrodeswas a construction shown in Fig.1. One of the wire electrodes had two ends **A** and **B**, second electrode**C** was single. The distancebetween theelectrodes is 2…3 mm. Under them a round permanent magnet could be placed. Its field was directed perpendicularly to the plane of the electrodes. The magnetic induction near the surface of the magnet was 0.12 T.

When the voltage was applied, a spark discharge between the electrodes **B** and **C**occurred. If the magnet was located under the electrodes in such a pole that the Lorenz force acted on the charged particles in the direction of **A**, then along with the main spark discharge (**C**>**B**) thereoccurredalso a weaker one (**C**>**A**).

When changing the pole of a magnet, the Lorenz force acted in the opposite direction, and this secondary discharge did not arise.

Ourpaper describes a demonstration experiment which is also based on a spark discharge at normal atmospheric pressure. It seems to us to be more clear and illustrative that the one described above. The design also uses a more contemporary high-frequency unipolar high voltage source.

II. DEMONSTRATION EXPERIMENTWITH THE ROTATION OF AN ELECTROLYTE IN THE VESSEL

The appearance of this deviceis shown in Fig.2. The electrolyte is placed in a plastic vessel with a diameter of 82 mm and a height of 44 mm. It fills about a half of the height of the vessel (≈ 120 ml). In the centeris placed a copper electrode with a diameter of 10 mm (anode). A copper flat electrode, 12 mm wide and 2 mm thick, (cathode) is placed at the edge of the vessel. Saturated aqueous solution of copper sulfate ($CuSO_4$) is used as an electrolyte [5]. At 100% purity of copper and copper sulfate, the entire electrolysis reaction theoreticallyrepresents the transfer of copper from anode to cathode. In practice, though, a long-term operation results in a slight precipitate at the anode and in the electrolyte, which is caused by the non-one hundred percentpurity of copper and copper sulfate.

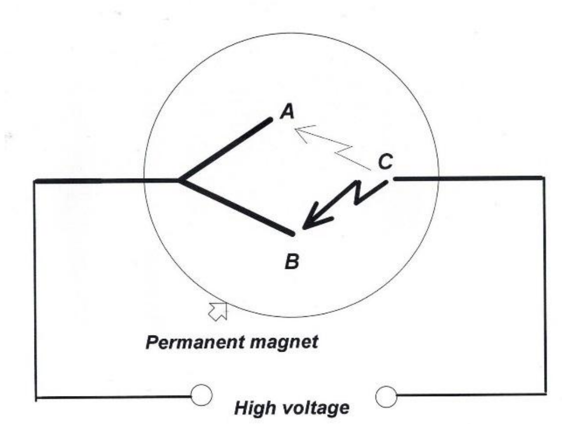

Fig1. Design of the electrodes used in the work[4].

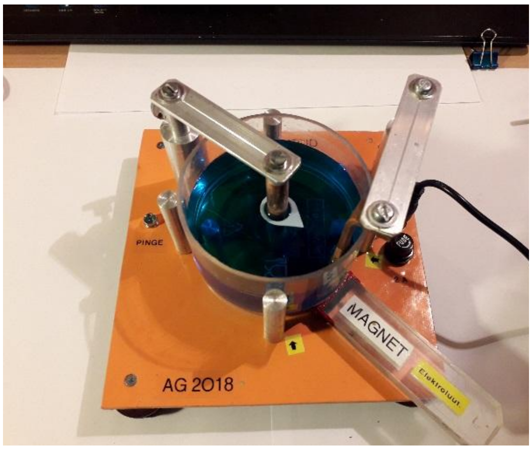

Fig.2. Appearance of the device for the experiment with rotation of the electrolyte.

Both anode and cathode could be easily removed and installed. The vessel is raised by 13 mm above the base of the device, so that a permanent magnet can be placed under it. The experiment uses a neodymium magnet with a diameter of 30 mm and a thickness of 10 mm. The magnetic induction measured near the surface was 0.21 T.

The currentsource isa DC adapter with a voltage 12 V and a maximum load current of 3 A.The copper anode electrode was put on the fluoroplastic arrow, which indicates the rotation of the electrolyte. The arrow has a thickness of 0.4 mm and an inner hole diameter of 13 mm. Despite that fact that the density of fluoroplastic is greater than the density of copper sulfate solution, it keeps well on the surface of the electrolyte due to surface tension forces (when installing, make sure it lies flat on the surface of the electrolyte).

In about a minute after switching on the voltage the current through the electrolyte reaches0.3…0.5 A (depending on the electrolyte prehistory). The speed of rotation of the electrolyte at a current 0.4 A is about 24 rpm. At this time, the magnet is located between the anode and the cathode so that its upper surface lies approximately 4 mm below the electrolyte.

III. DEMONSTRATION EXPERIMENT BASED ON SPARK DISCHARGE IN AIR AT ATMOSPHERIC PRESSURE

Electrical circuit of the device for demonstrating the Lorenz force by means of a spark discharge is shown in Fig.3. The appearance of the device can be seen in Fig.4.

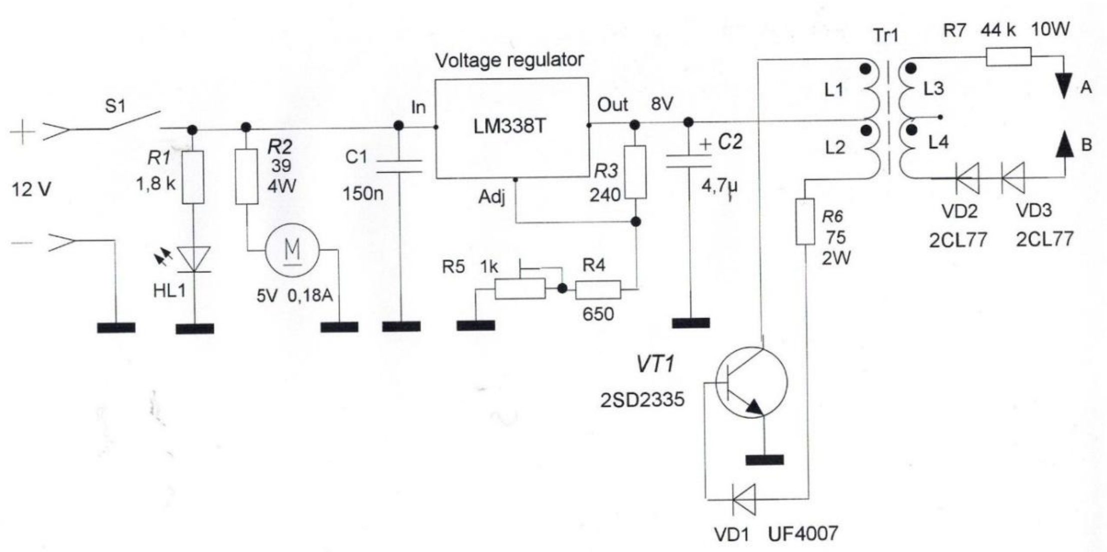

Fig.3. Electrical circuit of the device for the demonstration of the Lorenz force using a spark discharge.

Fig.4. Appearance of the device for the experiment with spark discharge.

Power is supplied from the already mentioned DC 12V 3A adapter. After switch S1, power is supplied to LED HL1. Almost any visible light-emitting diode can be used here. Next, power is supplied to the voltage regulator, assembled on the LM338T chip. The chip itself is located on an aluminium radiator with a total area of approximately 70 sq.cm. Since the power dissipated by the regulator reaches 8…10 W, in the originaldesign it is additionally cooled by a miniature fan M.

With the help of potentiometer R5 at the output of the regulator is set the voltage equal to 8 V. This voltage is applied to a high voltage generator assembled on transistor VT1 and transformer Tr1. The transistor is also installed on the radiator with a total area of 70 sq.cm (without additional cooling). The transformer is made on a square-shaped ferrite core with a side of 6.6 cm and a section of the magnetic core of about 2 sq.cm. The magnetic material is manganese-zinc ferrite with a magnetic permeability of 2500.

Winding L1 on the transformer is made of a wire with diameter of 0.85 mm, and contains 10 turns. Winding feedback L2 contains the same number of turns and is made of a wire with diameter of 0.4 mm. High-voltage windings L3 and L4are interconnected in series and are placed on opposite sides of the magnetic core. Each of the windings is wound on the acrylic six-section frame. Each section contains 100 turns of wire with a diameter of 0.18 mm and is coated with paraffin on top. Thus, the total number of turns of the high-voltage winding is 1200 turns. All high-voltage terminals of the transformer are covered with silicon. The windings L1 and L2 are wound on the side of the core between the sides on which the coils L3 and L4 are placed. The beginnings of each winding are marked with black circles on the circuit.

In general, electrical circuit shows the data elements used in the original design. Naturally, many of these elements can be replaced by others with suitable parameters. For example, transistor 2SD2335 can be replaced with almost any powerful NPN transistor with a permissible collector current of at least 3…5 A and a maximum emitter-collector voltage at least 200 V. For example, suitable would be transistors D13007, BUT11, BU326 and others. Instead of two high-voltage rectifying diodes of the 2CL77 typeit is even better to use one diode with a rectification current of at least 5 mA and a maximum reverse voltage of at least 30 kV. For example diode HVRL400 or G30FS.

Permissible power dissipation of resistors R2, R6 and R7 is shown in the circuit. The power of the remaining resistors should be chosen of not less than 0.2 W.

One of the discharge electrodes (**A** and **B** in the circuit) is the end of a wire with a diameter of 1 mm. It is placed in the center of a hole cut in the metal plate. Thus, the second electrode is the metal edge of this hole, which has a diameterof 11 mm. Both electrodes, like all nearby mounting parts, are made of stainless steel.

When the device is turned on,a spark discharge appears in the form a clearly visible continuous purple „thread“between the central electrode and one of the points of the circular electrode. It shows theline of movement of charges. Dischargelengthis 5 mm. The currentconsumedfromthepowersourceisapproximately 2 A. The open-circuit AC voltage at theoutput of thehigh-voltagewinding (withoutdischargeelectrodes) representsrapidlydampingoscillatorypulses, theamplitude of whichcanreachapproximately 30 kV. In case of continiousdischarge, theoscillogram of therectifiedcurrentrepresentsapproximatelytriangularpulseswith a duration of 17μs andanaveragepulsecurrent of 12mA. The pulserepetitionperiood is 70 μs (i.e., theirfrequencyis14,3 kHz). Thus, theaveragerectifiedcurrent in thesparkdischargeprocessis 2.9 mA.

The neodymium magnet, which causes deflection of the line of the discharge, had a diameter of 20 mm, a thickness of 6 mm and hole in the center with a diameter of 5 mm. The magnetic induction near its surface was 0.08 T. In order for the discharge not to „overflow“ onto the metal surface of the magnet when it is placed too close to the discharge electrodes, it is covered with a layer of epoxy resin. The magnet itself is mounted on the insulated plexiglass handle.

If now, when the device is working, a magnetis placed under the „thread“ ofthedischarge at a sufficientlylargedistancefromit(10…12 mm), the „thread“ will deflect at a certain angle from its initial position. The direction of the deflection (clockwise or contra clockwise) depends on the pole with which the magnet approached the „thread“.With further approaching of the magnet, the „thread“ of the spark discharge will begin rotating round the central electrode. The closer the magnet is, the greater the rotational speed. It is clear that the direction of rotation will also depend on the pole of the magnet, with which it approaches the discharge. Let's state again, that the rotation isdue to the fact that the Lorenz force is always perpendicular to the speed line of the movement of charges, that is to the "thread" of the discharge.

Asparkdischarge in theworkingdeviceisshown in Fig. 5. The bottom of device, thatis, the side of themountedelectronics, isshown in Fig 6.

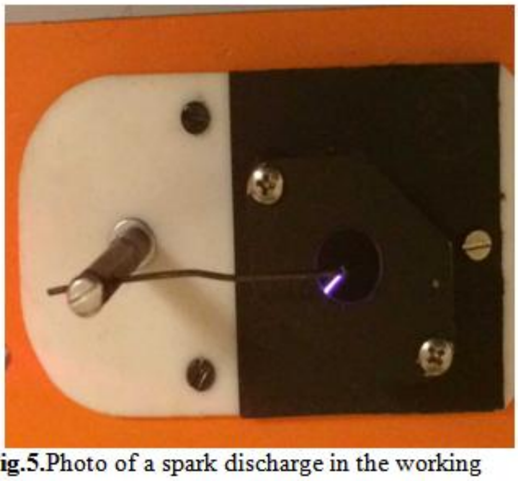

Fig.5. Photo of a spark discharge in the working

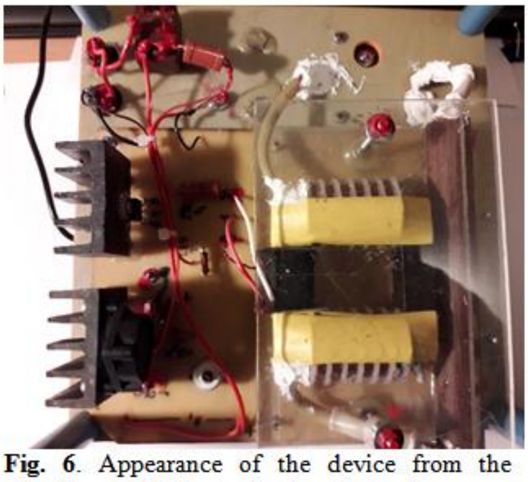

Fig. 6. Appearance of the device from the sideofmounted electronics (see the text)

IV. CONCLUSION

The articlebrieflyreviewedexperiments in physics, demonstratingtheLorenzforce. Detaileddescription of twosimilardevices,designed by theauthor,isgiven. The firstdevicedemonstratesrotation of anelectrolytewiththecurrentflowingthroughit, ifthevesselwiththeelectrolyteisplacedin themagneticfieldwhosedirectionisperpendiculartothespeed of movement of thecharges.Theseconddeviceisbased on a sparkdischargebetweentwoelectrodes in theair at normalatmosphericpressure. Itdemonstratesthedeflection and rotation of a high-voltage spark discharge in the magnetic field. In our opinion, the second demonstration experiment is more illustrative. Both devices are designed to show experiments in the classroom using a document camera with projector. As the experience of teaching physics shows, both theseexperiments contribute to betterunderstanding of the concept of the„Lorenzforce“.

REFERENCES

[1]. Alvin Hudson and Rex Nelson ´´University physics´´. Second Edition, Saunders college publishing, USA, 1990, p.691.
[2]. www.youtube.com/watch?v=W7UkDdxrlIk
[3]. https://www.flinnsci.com/lorenz-force-demonstrator/ap7868/
[4]. Amit Ram Morarka, Chaitanya Dixit ´Low cost demonstration experiment Lorenz force: Change in path of charged particles in magnetic field´´ Resonance, 2013, Vol. 18, Issue 9, pp 849-855.
[5]. https://operpostavka.ru/katalog/dopolnitelnoe-oborudovanie/pribor-dlya-demonstratsii-sily-lorentsa-demonstratsionnyj

Aleksei Gavrilov"Demonstration of the Lorenz Force in the Study of Physics"American Journal of Engineering Research (AJER), vol.8, no.01, 2019,pp.15-19