The Worldwide Simplest and Oldest Motor

How to explain its function?

Some time ago, various publications reported an electric motor which in its simplicity is truly unbeatable. It consists of 4 components: a 4.5 V battery, a cylindrical neodymium magnet, a ferrous pointed screw or nail and a short copper cable.
This paper questions the published explanations on the operation of this engine. These explanations are confronted with the result of an experiment with slightly altered experimental conditions and with the principle that internal forces can not cause the rotation of a body. References are listed where further information about the history of this motor and an explanation how it works based on the work of an Ampère and Wilhelm Weber can be found. .
The little motor to be discussed here is shown in fig. 1.

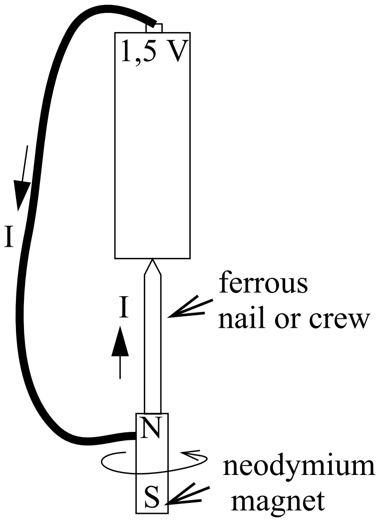

Fig.1. The "simplest" motor (see text)

After closing the circuit, the screw and magnet begin to rotate, to the surprise of the audience with an amazingly high speed. It is recommended here to all teachers to try this motor for themselves and to demonstrate it to their students. But this not only because of the amazing effect. This motor is of particular interest in didactic terms for two reasons.

1. It has a history that goes back nearly 200 years to the earliest days of electricity. Faraday constructed a similar motor in 1821, and shortly thereafter Ampère succeeded in demonstrating that a magnet could be made to rotate around its own axis.
2. Already Ampère and Faraday have argued about its function, and some of the authors of the publications cited [1 - 4] offer explanations which, while keeping in line with the traditional school physics, raises some fundamental questions.

The first point, the history of the engine, has been described by Assis together with a detailed description of the dispute between Faraday and Ampère concerning this motor[6].
In this paper the published explanations, for which the Lorentz force is fundamental, will be discussed in detail and an alternative will be indicated.

Problematic explanations

Fig. 2 clarifies the explanation offered in one of the cited publications[2].

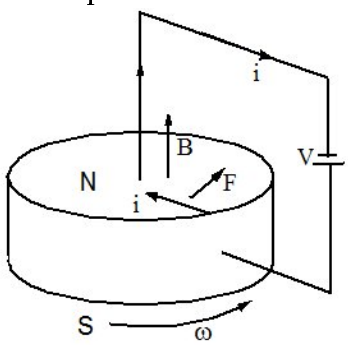

Fig.2. Magnet with field and electric circuit (see text)

The electric current passes through the magnet and its magnetic field. A Lorentz force is applied to the current and - so it is said -this force transforms into a torque on the magnet and causes its rotation.
Since there are no indications as to how this transformation can take place, one could conclude that this Lorentz force - an internal force - can set the magnet in rotation.

The Problem

At this point, the question arises: How should it be possible for a body, driven by internal forces, to rotate. Magnetism and the electric current are inside the magnet, and are parts of the same body. If the rotation is to be caused by an interaction of these parts, this would contradict Newton's principle of action equals reaction.
The controversy between Faraday and Ampère was about the same question: Can a body be set in rotation by internal forces? Ampère insisted that such a rotation could only be effected by an external influence, and he also provided a corresponding explanation by his force law[7].

The Experiment

This question can be answered by a simple experiment.
If you put a slightly thicker metallic (but not magnetic) ring around the magnet, with the ring firmly connected to the magnet, you move the contact point into an area with a much smaller magnetic field.
The electric current is not changed by this metallic ring, the magnetic field remains the same and thus also the effect of the Lorentz force postulated in the interior.

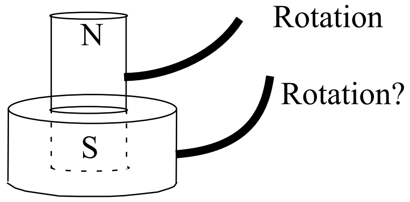

Fig.3. Arrangement for moving the contact point to the outside

The experimental result is clear. Already with an aluminium ring with the wall thickness of 1mm it is much more difficult to effect a rotation.
With a wall thickness of 5 mm no rotation can be induced. There is a video available on the net showing this experiment [8].
On the internet more videos available showing different kinds of this motor and different setups. [9,10]

Discussion

Taking the proposition of Newton´s 3rd law seriously, it should be clear from the outset that internal forces alone can not cause the rotation, but that an external action is required. Such an explanation, based on the Lorentz force and in connection with this motor has already been published.[5]
The explanation presented there sets the focus on an interaction between the drifting free electrons near the contact point and the rather strong magnetic field at this area outside the magnet.
Fig. 3[5] illustrates this explanation.

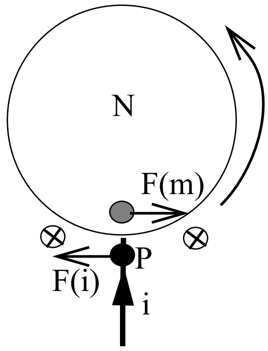

Fig.4. Top view on the motor indicating the action and reaction force (see text)

The current is considered at point P. There, due to the magnetic field, the Lorentz force F(i) acts on the drifting free electrons. According to Newton´s action-reaction principle, so the argument, there exists a force F(m) of equal strength inside the magnet, pushing the magnet in the opposite direction. Due to the torque formed by F(i) and F(m), the magnet rotates in the indicated direction. This explanation, presented by Wong[5], is rather unsatisfactory because it just refers to the action - reaction principle and could not satisfy a curious student asking: How can this current produce this reaction force?
To answer this question about action and reaction one would have to go into more details, speak about microphysical circulating currents or spins inside the magnet as origin of the magnetic field, notice a magnetic field caused by the main current inside of the magnet, which interacts through a Lorentz force with these numerous circular

currents and one must finally state that because of the principle "action = reaction", this force is just as large as the force FI on the current at the point P, but in the opposite direction.

But the question arises as to whether this reference to Newton's 3rd law is applicable at all, to explain the function of this motor.

Is the current not crossing the external magnetic field (direction from the north to the south pole) and is also crossing the internal magnetic field (direction from the south to the north pole)? Could it be possible that due to this crossing two opposing Lorentz forces are created? Could this explain the rotation, as long as these two forces act on two separate bodies, namely conductor and magnet? And could this explain why the rotation is missing when the point of application of the Lorentz force in the aluminium ring is acting on a body which is firmly connected to the magnet?

First of all, such an explanation has nothing to do with Newton´s 3rd law. This law refers to the mutual interaction of two separate currents. It cannot be applied to the action of one single current. In addition the same objection from above can be raised here: internal forces cannot cause the rotation of an object. The magnetic field B inside the magnet has its cause in some internal processes, the electrons are drifting with a velocity v inside the magnet. Therefore any explanation based on a Lorentz force according to v x B to explain the rotation of the magnet is questionable since from Newton´s action/reaction principle follows that internal forces cannot cause the rotation of a body.

Conclusion

Obviously classical physics can only explain the function of this little motor by stating that in this case Newton´s 3rd law does not apply to the Lorentz force.

There is another constellation where according to classical physics this is the case. Consider a proton at the origin, moving in the x direction, and an electron on the x axis, moving in the y direction. The electric forces obey Newton's 3rd law, but the magnetic forces do not. The proton contributes zero magnetic field at the location of the electron but the electron contributes a nonzero magnetic field at the location of the proton.

Is it allows to transfer this singular constellation to the more general case of the simple motor?

Such a transfer should not be taken lightly because it nourishes the suspicion that here a fundamental principle is changed only to resolve a contradiction.

If there was no alternative to the Lorentz force this would have to be accepted. Then nature would be so complicated that it provides a force that is not oriented in the direction of the interacting partners, as in the case of gravitational force or Coulomb force, but acts perpendicularly to relevant directions with respect to these partners. And besides, this special force does at least in some cases not obey Newton´s 3rd law.

However, there is an alternative which, in any case, leaves the experimental results unchanged, but which greatly simplifies not only the interpretation of the Lorentz force but the interpretation of all induction processes. It was published more than 150 years ago in 1846 by the German physicist Wilhelm Weber (1804 - 1891).

A first introduction to the work of Wilhelm Weber together with a discussion of the historical development of the standard knowledge related to electromagnetic induction can be found in the internet[11] as well as a detailed comparison between the standard theory and Weber‘s approach[12], including the topics „interaction between parallel or anti-parallel oriented currents“, „mutual and self induction“, unipolar induction, and finally an answer to the question: How does the simplest motor (fig 1) function?

The benefit of such a project could lead us educators and teachers to a treatment of the topic of „electromagnetic induction“ in a more cautious and relativistic manor, both at school and at university.

Literature

1. D. Featonby, Inspiring experiments exploit strong attraction of magnets, 2006 Phys. Educ. 41 292
2. C. Chiaverina, “The simplest motor?,” The Physics Teacher 42, 553 (2004).
3. H. J. Schlichting and C. Ucke, “Der einfachste Elektromotor der Welt,” Physik in Unserer Zeit, 35, 272-273 (2004)
4. [3] H. J. Schlichting and C. Ucke, “A fast, high-tech, low cost electric motor construction,” (2004). This article is a modified version which was published originally in German in the journal „Physik in unserer Zeit“ 35, 272-273 (2004). English Translation by J. Williams. Available at: http://www.fysikbasen.dk/Referencemateriale/PDFartikler/Unipolarmotor_English.pdf
5. H. K. Wong, Motional Mechanisms of Homopolar Motors & Rollers, The Physics Teacher, 47,463-465(2009)
6. A. K. T. Assis, J. P. M. C. Chaib, Ampère’s motor: Its history and the controversies surrounding its working mechanism, American Journal of Physics, Vol. 80, 990-995 (2012)
7. A. K. T. Assis, J. P. M. C. Chaib, Ampère’s Electrodynamics, available under: http://www.ifi.unicamp.br/~assis/Amperes-Electrodynamics.pdf
8. Video showing the experiment at: http://www.astrophysik.uni-kiel.de/~hhaertel/Videos/Einfachster-Motor.mp4
9. https://www.youtube.com/watch?v=ho-vbatdTLA&index=25&list=PL1BEC89F3BB0B94B2
10. https://www.youtube.com/watch?v=sdQHMuU_sOU
11. H. Härtel, Electromagnetic Induction from a new Perspective, available at: http://www.astrophysik.uni-kiel.de/~hhaertel/PUB/Induction-new-perspective.pdf
12. H.Härtel, Electromagnetic Induction - an Alternative, available at: http://www.astrophysik.uni-kiel.de/~hhaertel/PUB/induction-alternative.pdf