Marinov's Paradoxical Motor

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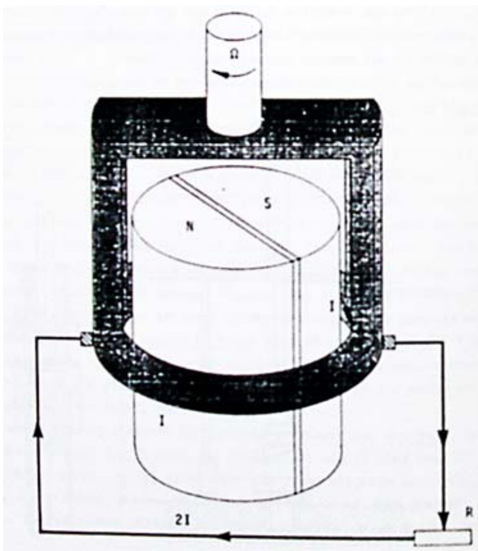
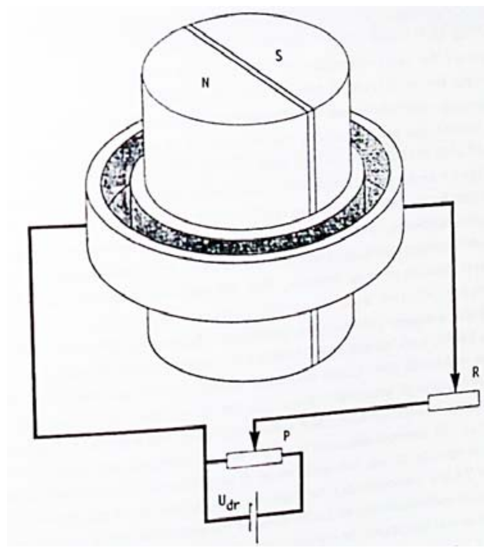
1 Problem

In 1993, Marinov, p. 248 of [1],[1] used non-Maxwellian arguments to propose a paradoxical motor, which he claimed would be a perpetual-motion machine. His sketches from [1] are shown below.





Marinov's proposals involve use of two half-cylindrical magnets, axially polarized in opposite directions,[2] surrounded by a solid (left figure) or liquid (right figure) annular conductor that is connected at two diametrically opposite points to a battery (via sliding contacts in case of the sold ring conductor which is free to rotate about its axis).

Marinov was unable to make his proposed motor work, and committed suicide in 1997. But within months of this tragic event the motor was shown to work in [3],[3] which included the figure on the top left of the next page. Most likely, the apparatus used in [3] was similar to that in the top right figure on the next page (from [13]), in which two axially, oppositely magnetized stacks of disk magnets were joined by two "keepers" to form an approximation to a toroidal magnet.

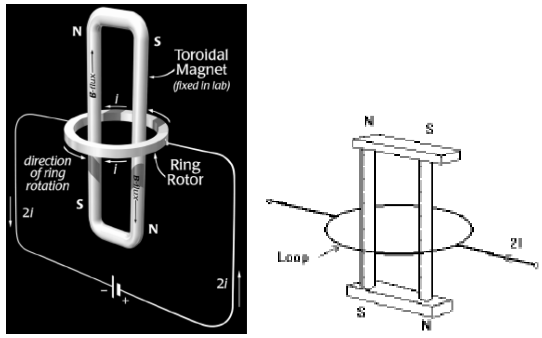
The Maxwellian view is that the magnetic field is zero outside a toroidal magnet, so it is paradoxical that a torque could be exerted on the ring rotor to drive the motor.

[1]See also [2].

[2]While magnets of this type could be manufactured, they do not seem to be commercially available. There is a YouTube video, https://www.youtube.com/watch?v=frHOpzMDqSg&t=38s, that implies use of such magnets in the righthand configuration above, and reports very peculiar results. I am skeptical that it actually used magnets of the type desired by Marinov.

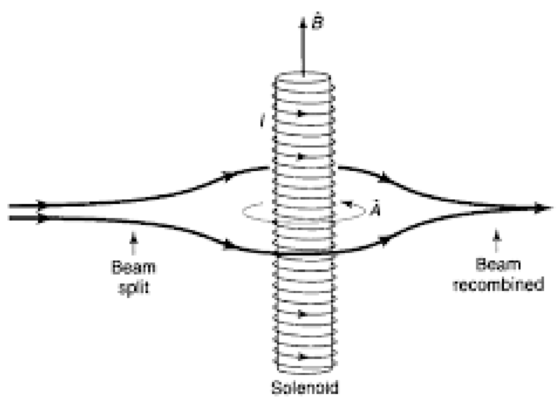
[3]See also [4]-[16].

Should the Maxwellian view be abandoned given the successful operation of the Marinov motor?



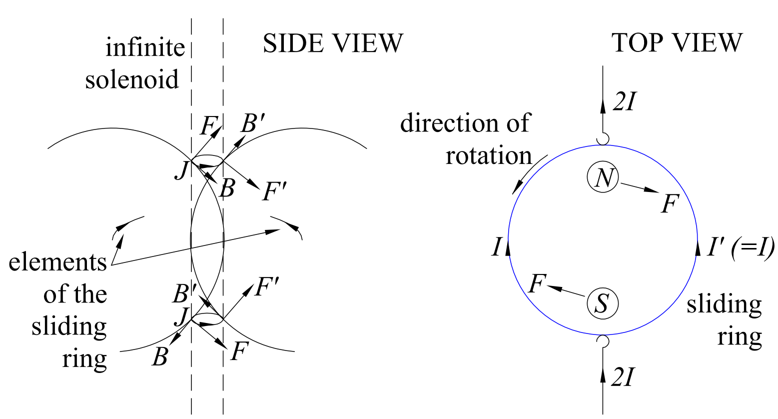
2 Solution

Aharonov and Bohm [17, 18] argued that there exists a quantum effect on electrons passing outside a long/infinite solenoidal magnet, where classically the magnetic field is "zero".



The Marinov motor seems to be a purely classical example of such an effect.

As in the Aharonov-Bohm effect, it is useful to consider the effect of the passing electron (currents in the ring rotor) on the currents in the solenoidal magnet (toroidal magnet). First we consider the effect of the magnetic field of the currents in the two halves of the sliding ring on circular loops of current in one of the two long/infinite solenoids inside the sliding ring, as sketched below.



The Biot-Savart ($\mathbf{J} \times \mathbf{B}$) force on these current loops due to the current in the left half of the sliding ring is strongest on the left side of the current loops, while the force due to the current in the right half of the sliding ring is strongest on the right side of the currents loops. Hence the net force on such a current loop is to the right, for the sense of the current loops shown in the figure.

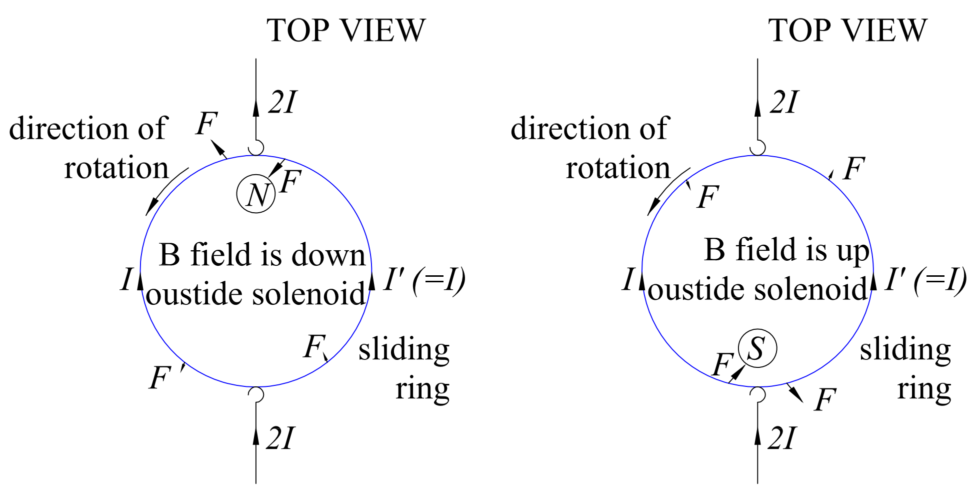
This argument is a small elaboration of Ampère's observation [19] that parallel currents (in the same direction) attract.[4]

Conversely, for the current loops in the other long/infinite solenoid is to the right. Hence, as seen in a top view, there is a net clockwise torque on the two infinite solenoid due to the currents in the two halves of the sliding ring.

Now, we know that the Biot-Savart force law (as well as Ampère's original force law) between two closed circuits predicts that the forces are equal and opposite. Thus, there must be forces/torques on the currents in the sliding ring[5] due to the currents in the infinite solenoids that are equal and opposite to those discussed above.

In particular, there is a torque on the sliding ring the makes it rotate in the direction shown in the right figure at the bottom of the previous page, in agreement with the experiment result (shown a the top of the previous page).

We can also argue more directly for the realistic case of finite-length solenoids, which have small magnetic fields outside them, generally in the opposite direction to the field inside the solenoids. Then, the $\mathbf{J} \times \mathbf{B}$ forces on the currents in the sliding ring, due to the N solenoid are as in the left figure below, and lead to a net counter-clockwise torque on the sliding ring. Likewise, the $\mathbf{J} \times \mathbf{B}$ forces on the currents in the sliding ring, due to the S solenoid are as in the right figure below, and also lead to a net counter-clockwise torque on the sliding ring.

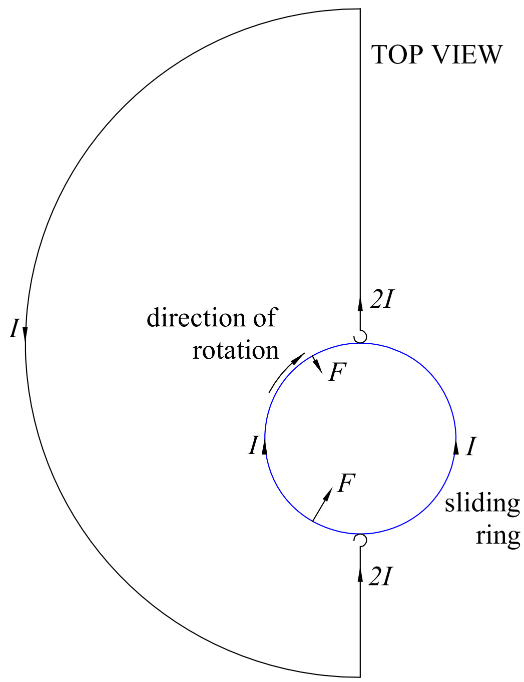


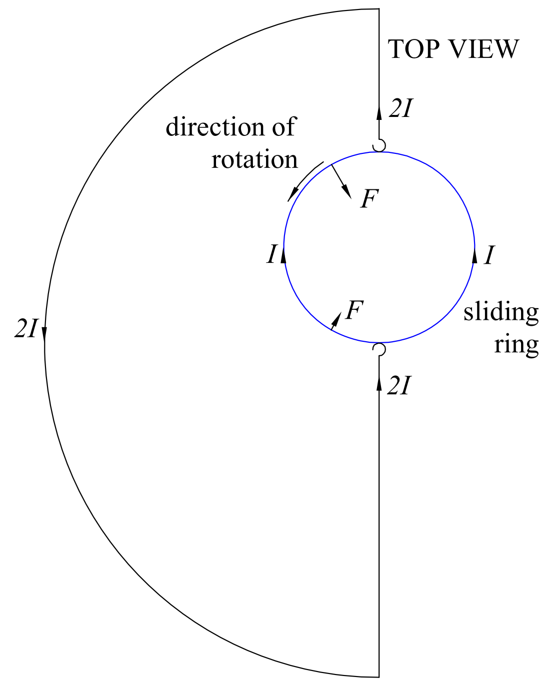
But, the magnetic fields due outside the two finite solenoids are very weak at points on the sliding ring, and perhaps could not lead to the observed rotation of the latter.

So, we also consider the effect of the rest of the circuit on the sliding ring. The figure below shows two possibilities for of the routing of the "return" wire (which ignores the toroidal magnet/infinite solenoids).

[4] *Deux courans électriques s'attirent quand ils se meuvent parallèlement dans le même sens; ils se repoussent quand ils se meuvent parallèlement en sens contraire.*

[5] Strictly, these forces could be anywhere in the electric circuit that includes the sliding ring, and do not act solely on the latter.





In both configurations, the current in the "return" wire has the opposite sense to that in the nearer half of the sliding ring, so the forces on the sliding ring point inwards as sketched.

In the left configuration, the inward force is greater on the lower portion of the sliding ring, so the net torque on the sliding ring due to the return current makes the ring rotate in a counterclockwise sense.

That is, Marinov's motor can work even if there is zero magnetic field inside the toroidal magnet/infinite solenoids!

And, in the right configuration, the net torque on the sliding ring due to the return current makes the ring rotate in a clockwise sense.

If we add back the toroidal magnet/infinite solenoids, and they are free to rotate about the axis of the sliding ring, the toroidal magnet will rotate in a clockwise sense as discussed above.

Thus, it can be arranged (by suitable routing of the "return" wire), that sliding ring of the Marinov motor rotates in either direction, and the sliding ring and the toroidal magnet/infinite solenoid can rotate in either the same or the opposite directions.[6]

Do we still need to worry whether the toroidal magnet/infinite solenoid exerts a torque on the sliding ring (which is expected to be zero if the magnetic field of the toroid is entirely inside it)?

A Appendix: Wesley

In [4], Wesley gave an explanation of the Marinov motor based on a force law on a moving charge related to the external vector potential $\mathbf{A}$.

He seems not to have noticed that his analysis (his eq. (18)) predicts the rotation of the sliding ring to be opposite to that reported in [3] (although I now believe that the Marinov

[6] There are poorly documented reports of such behavior.

motor can be made to rotate in either direction for a given sense of the electric current).

Wesley's force law, his eq. (5), was considered by Maxwell on p. 64 of his first paper on Faraday's lines of force [20], but which he deftly avoided in his subsequent studies, eventually arriving somewhat tentatively at the Lorentz force law (as reviewed in secs. A.28.1.7, A.28.2.6, A.28.3.7 and A.28.4.7 of [21]).

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