From electron to magnetism

6. Showing tangential magnetic force by experiment

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Abstract: Theoretical explanation of tangential magnetic force and the experiment of rotating coil.

1. Does tangential force exist?

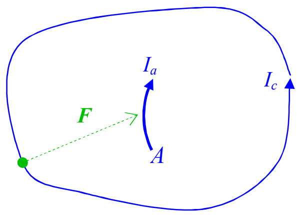

Figure 1

Tangential magnetic force is tangent to the current on which it acts. For the classical theory this force does not exist. In 1825, André-Marie Ampère determined by experiment that tangential magnetic force was zero. The principle of his experiment is shown in **Figure 1** where the closed loop current I_c acts the magnetic force $\boldsymbol{F}$ on the current I_a of the wire A in the form of an arc. Despite of being free to move, the wire A stayed immobile for whatever shapes the current I_c was put into. Then André-Marie Ampère concluded that closed loop current acted zero tangential magnetic force, see «Ampère's Electrodynamics» A. K. T. Assis and J. P. M. C. Chaib, Chapter "10.4 The Case of Equilibrium of the Nonexistence of Tangential Force". Later, Lorentz force law defined that elementary magnetic force was perpendicular to current, then tangential magnetic force was definitively claimed not to exist at all.

However, my experiment « Continuous rotation of a circular coil experiment » showed that a round coil rotated when a current passed in it. Perpendicular to the round coil Lorentz force does not drive the rotation. So, a force tangent to the current must be there. The video of this experiment is on YouTube, https://youtu.be/9162Qw-wNow. If tangential magnetic force exists, why was it not detected in almost 200 years?

2. Why was tangential force never detected?

For answering this question, we use Coulomb magnetic force law which is derived in «Coulomb magnetic force». Take the Coulomb magnetic force $d\boldsymbol{F}_{cm}$ that current element $d\boldsymbol{I}_b$ exerts on current element $d\boldsymbol{I}_a$. Equation (1) shows that $d\boldsymbol{F}_{cm}$ equals the elementary Lorentz force $d\boldsymbol{F}_{Lorentz}$ plus the Cross-force-A $d\boldsymbol{F}_a$. $d\boldsymbol{F}_a$ is proportional to $d\boldsymbol{I}_a$ and thus, parallel to $d\boldsymbol{I}_a$. So, Cross-force-A is a tangential magnetic force. Below, we will refer to tangential magnetic force simply as tangential force.

In «Coulomb magnetic force» I have shown that the integral of Cross-force-A over a closed loop current is zero. In consequence, the Coulomb magnetic force exerted by a closed loop current results in a Lorentz force, see (2).

$$d\boldsymbol{F}_{cm} = d\boldsymbol{F}_{Lorentz} + d\boldsymbol{F}_a$$
$$\text{with } d\boldsymbol{F}_a = \frac{1}{4\pi\varepsilon_0 c^2 r^3} d\boldsymbol{I}_a(\boldsymbol{r}\cdot d\boldsymbol{I}_b) \qquad (1)$$

$$\oint d\boldsymbol{F}_a = 0 \Rightarrow \oint d\boldsymbol{F}_{cm} = \oint d\boldsymbol{F}_{Lorentz} \qquad (2)$$

Figure 2 shows how tangential force disappears in experiment. We have 2 perpendicular wires in which circulate currents I_a and I_b. The current element $d\boldsymbol{I}_1$ exerts on $d\boldsymbol{I}_a$ the Coulomb magnetic force $d\boldsymbol{F}_1$. The current element $d\boldsymbol{I}_2$ is symmetric to $d\boldsymbol{I}_1$ with respect to I_a and exerts $d\boldsymbol{F}_2$ on $d\boldsymbol{I}_a$. $d\boldsymbol{F}_1$ and $d\boldsymbol{F}_2$ are expressed in (3) using (1), their sum $d\boldsymbol{F}_m$ is expressed in (4) and shown in **Figure 2**.

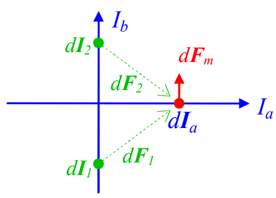

Figure 2

The 2 Cross-force-A $d\boldsymbol{F}_{a1}$ and $d\boldsymbol{F}_{a2}$ are tangent to the current element $d\boldsymbol{I}_a$, so their integrals $\int_{-\infty}^{0} d\boldsymbol{F}_{a1}$ and $\int_{0}^{\infty} d\boldsymbol{F}_{a2}$ are the tangential forces from the lower part and the upper part of the vertical current. The integral of the Cross-force-A over the whole vertical current equals the sum of $\int_{-\infty}^{0} d\boldsymbol{F}_{a1}$ and $\int_{0}^{\infty} d\boldsymbol{F}_{a2}$, see (5) and **Figure 2**.

$$d\boldsymbol{F}_1 = d\boldsymbol{F}_{Lorentz1} + d\boldsymbol{F}_{a1}, d\boldsymbol{F}_2 = d\boldsymbol{F}_{Lorentz2} + d\boldsymbol{F}_{a2} \qquad (3)$$

$$d\boldsymbol{F}_m = d\boldsymbol{F}_1 + d\boldsymbol{F}_2$$
$$= d\boldsymbol{F}_{Lorentz1} + d\boldsymbol{F}_{Lorentz2} + d\boldsymbol{F}_{a1} + d\boldsymbol{F}_{a2} \qquad (4)$$

dF_{a1} and dF_{a2} are expressed in (6). Because the scalar products in (7) have opposed values, the sum of dF_{a1} and dF_{a2} is zero and the integral of Cross-force-A over the whole vertical current is zero too, see (8). However, dF_{a1} and dF_{a2} are not individually zero and $\int_{-\infty}^{0} d\boldsymbol{F}_{a1}$ and $\int_{0}^{\infty} d\boldsymbol{F}_{a2}$ are not zero either, see (9). But they cancel out each other and the total tangential force on dI_a becomes zero.

In the same way, for the experiment of André-Marie Ampère, if we split into 2 halves the integral of Cross-force-A over the closed loop current I_c, each half-integral is the tangential force from each half of the current I_c and is nonzero, while the whole integral is zero, see (10) and (11). It is because the 2 tangential forces completely canceled out each other that André-Marie Ampère found no tangential force in his experiment.

$$\int_{-\infty}^{\infty} d\boldsymbol{F}_a = \int_{-\infty}^{0} d\boldsymbol{F}_{a1} + \int_{0}^{\infty} d\boldsymbol{F}_{a2} \qquad (5)$$

$$d\boldsymbol{F}_{a1} = \frac{1}{4\pi\varepsilon_0 c^2 r^3} d\boldsymbol{I}_a (\boldsymbol{r}_1 \cdot d\boldsymbol{I}_1) \qquad d\boldsymbol{F}_{a2} = \frac{1}{4\pi\varepsilon_0 c^2 r^3} d\boldsymbol{I}_a (\boldsymbol{r}_2 \cdot d\boldsymbol{I}_2) \qquad (6)$$

$$\boldsymbol{r}_1 \cdot d\boldsymbol{I}_1 = -\boldsymbol{r}_2 \cdot d\boldsymbol{I}_2 \qquad (7)$$

$$d\boldsymbol{F}_{a1} + d\boldsymbol{F}_{a2} = 0 \Rightarrow \int_{-\infty}^{\infty} d\boldsymbol{F}_a = 0 \qquad (8)$$

$$\int_{-\infty}^{0} d\boldsymbol{F}_{a1} = -\int_{0}^{\infty} d\boldsymbol{F}_{a2} \neq 0 \qquad (9)$$

$$\oint d\boldsymbol{F}_a = \int_{0}^{½} d\boldsymbol{F}_a + \int_{½}^{1} d\boldsymbol{F}_a = 0 \qquad (10)$$

$$\int_{0}^{½} d\boldsymbol{F}_a = -\int_{½}^{1} d\boldsymbol{F}_a \neq 0 \qquad (11)$$

Since electric current does not exist other than in closed loop, tangential force cancels out in all experiments and are undetectable. So, we have to find a way to break closed loop current in experiment to observe tangential force.

3. How to reveal tangential force?

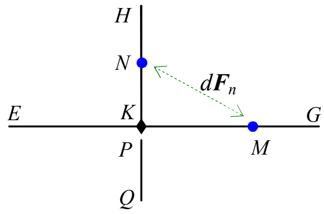

Figure 3

In fact, it is impossible to split electrically closed loop current. But we can cut the wire while passing the current through a sliding contact. For example we cut the vertical wire of **Figure 2** at the crossing point of the 2 wires to make the wire system in **Figure 3**. The upper wire is HK and the lower wire PQ. The vertical current can pass from point P to point K through sliding contact while P and K can move separately.

The upper wire HK is rigidly attached to the horizontal wire EG such that HK and EG form a rigid structure named EGH. But HK is electrically insulated from EG such that the vertical and horizontal currents circulate separately, see **Figure 4**. The structure EGH is sufficiently rigid that no deformation will occur for the studied forces.

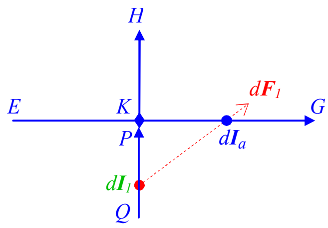

Figure 4

$$d\boldsymbol{F}_1 = d\boldsymbol{F}_{Lorentz1} + d\boldsymbol{F}_{a1} \qquad (12)$$

$$d\boldsymbol{F}_t = \int_{Q}^{P} d\boldsymbol{F}_{a1} \neq 0 \qquad (13)$$

$$\boldsymbol{F}_t = \int_{E}^{G} d\boldsymbol{F}_t \neq 0 \qquad (14)$$

Suppose that a compressed spring is installed between the points M and N of **Figure 3** and pushes M with the force dF_n and N with $-dF_n$. The resultant force on the whole structure EGH is zero because $dF_n - dF_n = 0$. So, dF_n is a force internal to the structure EGH and the compressed spring cannot put the structure EGH in motion even if EGH is free to move.

If N and M are electric charges, dF_n is Coulomb force, if N and M are current elements, dF_n is magnetic force. But in both cases dF_n is internal to the structure EGH and thus, has no effect on the motion of EGH. If ever EGH moves, this indicates that a force external to EGH is pushing the structure, for example, a force from the lower wire PQ.

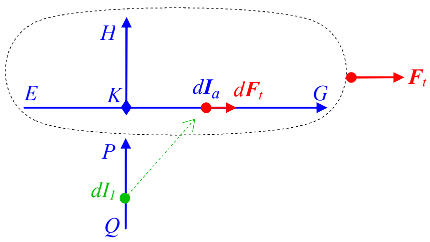

Figure 5

This force can be the magnetic force dF_l exerted by the current element dI_l on dI_a, as **Figure 4** shows. dF_l is computed in equation (12) using (1), where dF_{al} is the Cross-force-A and is parallel to dI_a. The integral of dF_{al} from Q to P is the tangential force that PQ exerts on dI_a and is denote by dF_t. dF_t is not zero because PQ is not a closed loop current, see (13). The integral of dF_t from E to G is the total **tangential** force F_t on the wire EG, which is parallel to EG and nonzero, see (14). EGH is free to move. Then, the structure EGH will move in the direction of the tangential force F_t, see **Figure 5**.

So, by cutting mechanically a system of current, we can make a structure move in the direction of the tangential force and thus, revealing experimentally the action of tangential force. This is what I have done with my experiment.

4. My experiment

The setup of my experiment is composed of a round coil C and a straight external lead PQ, see **Figure 6**. The current is connected to the coil C by PQ through a sliding contact. After several turns, the current passes through the central lead L to exit the system from the center O.

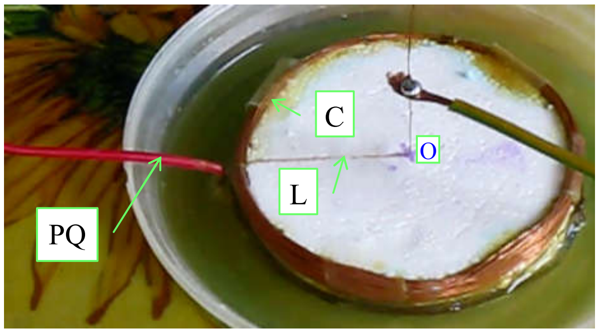

Figure 6

As **Figure 7** shows, the central lead L is fixed on the coil C to create the rigid structure C-L. The magnetic force $\boldsymbol{F}_i$ that the points A and D act on each other is internal to the structure C-L and does not rotate it.

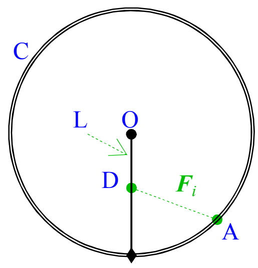

Figure 7

Someone has argued with me that the current in the coil created a magnetic field $\boldsymbol{B}$ which induced a Lorentz force on the central lead which drove the structure C-L to rotate. This is equivalent to say that the Lorentz force on the central lead is created by C and the structure C-L drives itself by acting a force on itself. This is of cause wrong. The fact that the coil C creates a Lorentz force without proper reaction force on C does not prove that the structure C-L can drive by itself, but rather shows that Lorentz force violates Newton's third law.

So, the magnetic force $\boldsymbol{F}_i$ in **Figure 7** is not the driving force. Since the structure C-L really rotates in the experiment, there must be an external force driving the structure C-L. This force comes from the external lead PQ. Like for the structure EGH in **Figure 5**, this force is the Cross-force-A which is tangent to the current of C.

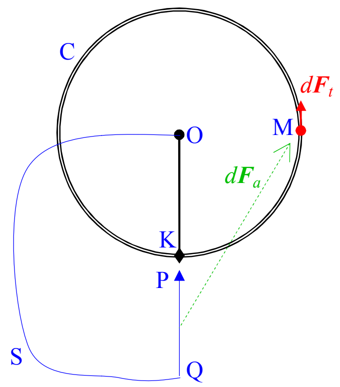

Figure 8

Figure 8 shows how tangential force works. $d\boldsymbol{F}_t$ is the Cross-force-A on the point M, so $d\boldsymbol{F}_t$ is tangent to the current at M. $d\boldsymbol{F}_t$ equals $d\boldsymbol{F}_a$ integrated over the external circuit OSQP which is not a closed loop current, thus $d\boldsymbol{F}_t$ is not zero. Because M can be any point of C, there is a tangential force on every point of C. All these tangential forces push the coil C in the same direction, then C rotates. This way, tangential force is revealed by the rotation of C driven by the non closed loop current OSQP.

For comparison, **Figure 9** shows the same system of current than that of **Figure 8** except that the wire OQ is not cut apart, which makes the circuit OSQ a closed loop. In this case, Cross-force-A is canceled out and the magnetic force on point M is the Lorentz force $d\boldsymbol{F}_l$. So, no tangential force exists and the coil C will not rotate.

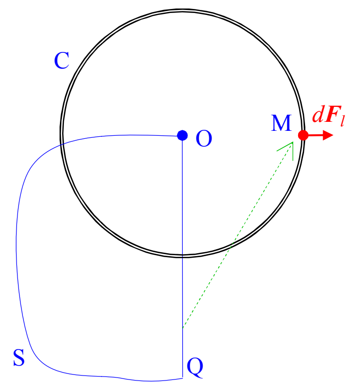

Figure 9

This comparison shows clearly that the central lead OK creates the non closed loop current OSQP which rotates C, while the closed loop current OSQ creates Lorentz force and does not rotates C.

5. Comment

Section 2 explains why tangential force was not detected until now: closed loop current cancels Cross-force-A out. Section 3 presents the insightful method for breaking closed loop current, which allowed me to design my experiment. Section 4 explains in detail the working of this experiment. So, Coulomb magnetic force law has correctly predicted tangential force and successfully guided me in the experiment.

Note that in the article « Continuous rotation of a circular coil experiment » I explained my experiment using Ampere's original formula because Coulomb magnetic force law was not ready at that time.

Lorentz force law can predict correct experimental facts because it is based on experimental observations. So, it is only an empirical mathematical model without the knowledge of the physics behind magnetic force. This is why it is unable to predict undetectable phenomena such as tangential force or space force in Tokamak which I presented in «Plasma under Coulomb magnetic force». I hope that among the 45 or so working Tokamak today, there are teams audacious enough to test the electron injection method or positively charged coils method to prevent the plasma biting into the wall and to increase the duration of plasma confinement.

In the contrary, Coulomb magnetic force law is derived from the motion of electrons which is the physics behind magnetic force. This is why this law not only gives correct predictions, but is also more powerful in predicting phenomena never seen before, which may give new insight into physics.

Coulomb magnetic force law compared with Lorentz force law is a little like Copernicus' heliocentric model compared with Ptolemy's geocentric model. Ptolemy's model is based on observation and can predict correct position of the planets. But without knowing the physics behind the motion of the planets, the geocentric model was doomed. Copernicus has discovered the physics behind the motion of the planets: the solar system. So, his model not only gave correct predictions, it had also inspired Johannes Kepler and Isaac Newton in founding modern physics.