Role of air pressure in the force between currents

Hamid V. Ansari
Department of Physics, Isfahan University, Isfahan, IRAN
Personal address: No. 16, Salman-Farsi Lane, Zeinabieh Street, Isfahan, Postal Code 81986, IRAN
Tel: 00989131013484, Fax: 00983112730139
E-mail: hvansari@gmail.com

November 2, 2007

Abstract

Density of lines of the magnetodynamic field arising from two parallel currents is more in the regions out of the distance between the two wires and then the molecular magnetic dipoles of air are pulled toward these regions and create a bigger pressure there which causes the two wires to be pushed (or to be attracted) toward each other. A similar reasoning applied conversely to two antiparallel currents justifies their repulsion arising from the created air pressure difference. Thus, most probably, railgun will not work very well in the absence of the air.

PACS: 41.90.+e

1 Introduction

We know that two parallel currents attract each other and two antiparallel currents repel each other. In almost all of the electromagnetic textbooks (eg see [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]) existence of these forces is justified in this form that the current in a wire creates a magnetic field at the place of the other wire, and since in this magnetic field there is an electric current (in this other wire) there will be a force exerted on this current (of this other wire). This is the same force between the two wires. It is shown here that if the experiment is performed in air (or in a medium which its molecules have magnetic dipoles) and the currents in the wires are sufficiently high, theoretically, a pressure difference in the air near around each wire (ie between the two sides of each wire: the side in the distance between the two wires, and the other side out of this distance) will be created. Because of this pressure difference, each wire is pressed, or in fact is pushed, toward the region (or side) of low pressure. It is shown that the direction of these pushes exerted on the wires is toward the inside of the distance between the two wires when the currents in the wires are parallel and is toward the outside of this distance when the currents in the wires are antiparallel.This conforms exactly with the attraction and repulsion of the two wires as predicted in the current theory of electromagnetism.

Therefore, this is quite important that firstly, if, according to the theory presented in this paper, existence of this pressure difference is acceptable theoretically, its existence be also tested experimentally, ie it be examined that when sufficiently high currents are passing through the wires and the experiment is performed in a vacuum or in a gas with molecules lacking magnetic dipoles whether or not the force between them decreases, and secondly if both the theory and experiment confirm the role of the above-mentioned air pressure difference in the force between the two wires, then it will be necessary to publicize that it is necessary that the role of this pressure difference becomes separate from the role of the electromagnetic influence of the two wires on each other; in other words, to observe and measure net electromagnetic influence of two current-carrying wires on each other the experiment must be performed in a vacuum or in a medium with molecules lacking magnetic dipoles. We should notice that SI definition of Ampere (current intensity) is based on such forces that currents exert on each other. In other words, the relevant experiments will be necessary to be performed in vacuum or in a gas having no molecular magnetic dipoles or we should contrive proper ways to deduct the role of this air pressure difference.

2 Air pressure and the force between electric currents

We can easily calculate that the magnetic field arising from two parallel currents has a magnitude in the distance between (and near) them smaller than its magnitude out of (and near to) this distance. We know that a net force is exerted on a mgnetic dipole in a gradient of magnetic field. The direction of it is toward the region having intenser magnetic field. In fact, the couple exerted on a magnetic dipole in a magnetic field makes the dipole axis coincides with the line of field in the place of the dipole, and there will be exerted a force on that pole (of the dipole) situated in the region of intenser field which its magnitude is more than the force exerted on the pole situated in the region of weaker field although the direction of these two forces are opposite to each other, and then the resultant of these two forces being exerted on the dipole is a (net) force toward the region of intenser field. Thus, the gas molecules (or molecular magnetic dipoles) are pulled toward the region of intenser field near the wires and then gas pressure in this region increases relative to the gas pressure near the wires in the distance between the two wires in which the field is weaker. In this manner the pressure difference between the two sides of each wire causes the two wires are pushed toward the distance between them, ie they are pressed toward each other.

Also, the density of lines of the magnetodynamic field of two parallel wires carrying antiparallel electric current is more in the distance between them (near them) than in the regions out of this distance (near them). So, we conclude through a reasoning similar to what presented above that the pressure difference between the two sides of each wire causes the two wires to open from each other.

Here we present an account based on calculation to show existence of such a pressure (difference) besides the above-mentioned conceptual physical justification. Let's verify just this recent case of two antiparallel currents. Consider two parallel long wires carrying antiparallel but equal currents (i). The distance between them is $2r$. Consider the right wire. The purpose is firstly comparing the magnetic fields in two opposite points on the two sides of this wire which are equidistant from it through a distance smaller than r. Call the magnitude of this distance as a. We know from the electromagnetic theory (in almost every relevant textbook) that the magnetic field in the distance d from a long wire carrying electric current i is:

$$B = \frac{\mu_0 i}{2\pi d}$$

So, for the algebraic sum of the two magnetic fields arising from the two currents, in one of the above-mentioned opposite points, being in the distance between the two wires, we have:

$$B_1 = \frac{\mu_0 i}{2\pi(r + (r - a))} + \frac{\mu_0 i}{2\pi a} = \frac{\mu_0 i}{2\pi}(\frac{1}{2r - a} + \frac{1}{a})$$

and for the algebraic sum of the two magnetic fields arising from the two currents, in the other point out of the above-mentioned opposite points, being out of the distance between the two wires, we have:

$$B_2 = \frac{\mu_0 i}{2\pi(2r + a)} - \frac{\mu_0 i}{2\pi a} = \frac{\mu_0 i}{2\pi}(\frac{1}{2r + a} - \frac{1}{a})$$

B_2 is negative, and we compare its magnitude, $-B_2$, with B_1, and we expect, as explained in the physical concept of the problem, this magnitude to be smaller than B_1. This is the case, since:

$$\frac{1}{2r - a} + \frac{1}{2r + a} > 0 \Rightarrow \frac{1}{a} - \frac{1}{2r + a} < \frac{1}{2r - a} + \frac{1}{a} \Rightarrow$$

$$\frac{\mu_0 i}{2\pi}(\frac{1}{a} - \frac{1}{2r + a}) < \frac{\mu_0 i}{2\pi}(\frac{1}{2r - a} + \frac{1}{a})$$

or $|B_2| < B_1$. In this manner we see that the magnitude of the resultant magnetic field due to two antiparallel currents in a near point out of the distance between the two wires carrying them is smaller than the resultant field due to these currents in the equidistant opposite point in this distance. Since, as seen in the above formulae, the magnitudes of these resultant fields are proportional to the current (i) passing through the wires, the difference between these magnitudes (in the two above-mentioned points) is also proportional to the current intensity i.

Magnitude of a magnetic field in a point won't be alone the cause of attraction of the magnetic dipoles toward this point, but the existence of difference between the magnetic fields in two separate points will cause the magnetic dipoles to be attracted toward the point where the magnetic field is intenser. Mathematical language of this matter is that whenever there exists gradient of magnetic field in a space (which is related to the same difference between the magnetic fields in the points of the space), there will exist a net force exerted on a magnetic dipole in this space in the direction of most increasing of the intensity of field in the point of the dipole. Electric analog of this problem is the net force exerted on an electric dipole in a gradient of electric field: If the electric dipole moment of a point electric dipole is $\mathbf{p}$, then the force exerted on this dipole in the electrostatic field $\mathbf{E}$ will be [3]:

$$(\mathbf{p}.\nabla)\mathbf{E}$$

So, where the electrostatic field is constant (eg in the space between the two plates of a capacitor), this force will be zero since the spacial alteration of it is zero. The net force exerted on a magnetic dipole in a magnetic field should be calculated similarly, and in a similar manner, where the magnetic field is constant (eg inside a solenoid) this force will be zero since the spacial alteration of it is zero while, eg, in the outside space near the opening of the solenoid, where the magnetic field has gradient, this force will be considerable and will cause attraction of the magnetic dipole toward the space inside the solenoid where the magnetic field is stronger.

Similarly, as previously reasoned for the two parallel wires carrying antiparallel currents, the field in the distance between the wires is intenser than one out of this distance and so, there exists gradient of magnetic field in the space around each of these wires and then according to the above reasoning a net force will be exerted on each magnetic dipole in this space toward the region where the field is intenser, ie the space between the two wires. Under the influence of this force, the magnetic dipoles are pulled toward this space and increase the pressure there and push the wires outwards. As shown previously, the magnitude of this net force exerted on a dipole is proportional to the field gradient which itself is proportional to the current intensity in the wires. So, the intenser the current of wires, the bigger both the force exerted on the dipoles toward the region of intenser field and created pressure due to it will be, and then this created pressure (difference) will be detectable more easily when the currents are intenser. A similar reasoning can be presented for two parallel wires carrying parallel currents.

Existence of the above-mentioned pressure differences must be measurable by a proper pressure gauge when sufficiently high currents are flowing in the wires, and this can be a criterion for the validity of the theory presented in this article. It is clear that, when high currents are flowing in a vacuum or in a gaseous medium with molecules lacking magnetic dipoles, because of noncreation of any pressure difference around the wires there won't be any due net forces exerted on them practically and then we expect that in these mediums the amount of the attraction or repulsion between the two current-carrying wires will decrease.

Railgun is an excellent case for testing what presented here. Simple mechanism of this device is a rectangular circuit which we call here one of its small edges as AB. An intense current flows through this rectangular loop anticlockwise by a powerful source. As we know (and was mentioned above) electromagnetic theory predicts that this current causes an outward force exerted on each edge of the rectangular loop (toward getting away from the center of the rectangle). Thus, if a small one of these edges, eg AB, is itself a (conductive) projectile, it will be thrown outwards (toward getting away from the loop's center) due to the exertion of this force. According to what expressed in this article, if this experiment is performed in air, outward forces exerted on these parts of the current-carrying route not only are due to the above-mentioned electromagnetic force, but also are probably rather due to the produced air pressure in the (rectangular) loop because a very intense magnetic field is produced inside the loop (in comparison with the outside magnetic field) which causes molecular magnetic dipoles of the air to be attracted strongly toward this region and produce a huge pressure in this region in comparison with the outside pressure. Therefore, if this air pressure has a considerable role in throwing the projectile in the railgun, contrary to what so far expected, we should not expect future use of this device probably on the moon or other planets lacking (magnetic) atmosphere to produce the same speed for the projectile as in the atmosphere of the earth. That this will be the case or not can be examined by firing the railgun in a vacuum or a low-pressure atmosphere or a gas atmosphere which its molecules have no magnetic dipoles and observing that whether or not the speed of the projectile decreases. Also in principle we can install a pressure gauge inside the loop and observe any probable increase in the air pressure when firing the railgun. Also, it is so notable that a firing railgun makes a muzzle blast just like a rifle (every person working with railguns and every photo or video showing a firing railgun confirm this matter). There wouldn't be any sudden strong gust of air at the muzzle of a firing railgun if the cause of throwing the projectile was exclusively due to what explained in the current theory of electromagnetism. Such a blast cannot exist without any pressure difference between the inside and outside of the loop.

It is notable that in another form of railgun instead of using a conductive projectile itself as a part of the route of the loop current (AB), a copper wire is used as this part which will melt due to the passage of the intense current of the loop. The projectile is located near this wire outside the loop. Simultaneous with the melting of the wire the projectile will be thrown outwards. The justification presented for this phenomenon is that (eg see [2]) firstly a conductive gas is produced from melting and evaporation of the copper wire, secondly the electric current continues its passing through it, thirdly an outward force will be exerted on this current-carrying gas quite like the outward force exerted on AB (when it was not to melt) due to the passage of current in the presence of magnetic field, and fourthly this expelled gas will push the projectile outwards. Such a reasoning shows clearly that hypothesis of the existence of a current-carrying medium seems necessary in order that according to the electromagnetic theory (after exertion of force on this medium) there be a force on the projectile which is not carrying current in this (alternative) experiment while no longer there exists the current-carrying wire AB (since it has melted) to exert probably force on the projectile. Details of that whether or not there exists really such a conductive gas and that according to what has been expressed to what extent its role is are no concern of this article (although it is almost clear that immediately after that the copper wire melts the current will stop and will not be increased to creat the heat necessary to evaporate the melted copper). But, it is important here that this experiment, performed by melting wire (AB), is easily justified based on the intense air pressure produced in the loop (proposed in this article), since this produced air pressure which is due to the great increase in magnetic field inside the loop (as compared with the outside) will force all objects adjacent to itself, including the projectile adjacent to AB, whether they carry current or not.

Separate from the produced air pressure difference and the electromagnetic reason (mentioned in Introduction) presented in the textbooks, another minor factor which clearly has a role very smaller than the above-mentioned pressure differences causes the attraction of two wires carrying parallel currents and the repulsion of two wires carrying antiparallel currents: In two parallel wires carrying parallel electric currents, magnetic dipoles of the substance of each wire will be oriented in the magnetodynamic field arising from the current in the other wire in such a way that eventually unlike poles of the oriented magnetic dipoles of the wires are closer to each other and then altogether the two wires attract each other while in two parallel wires carrying antiparallel electric currents like poles of the oriented magnetic dipoles of the wires are closer to each other and then altogether the two wires repel each other. This factor, which forms only a little portion the of force between the two wires, still remains after omission of the magnetic dipoles of the medium.

References

[1] Purcell E. M., Electricity and Magnetism, McGraw-Hill, 1985

[2] Halliday D., Resnick R., Walker J, Fundamentals of Physics, John Wiley & Sons, 2005

[3] Reitz J. R.& Milford F. J.& Christy R. W., Foundation of Electromagnetic Theory, Addison-Wesley, 1993

[4] Jackson J. D., Classical Electrodynamics, John Wiley & Sons, 1998

[5] Nayfeh M. H.,& Brussel M. K., Electricity and Magnetism, John Wiley & Sons, 1985

[6] Kip A. F., Fundamentals of Electricity and Magnetism, McGraw-Hill, 1983

[7] Grant I. S., Phillips W. R., Grant A. S., Electromagnetism, John Wiley & Sons, 1991

[8] Cheng D. K., Field and Wave Electromagnetics, Addison-Wesley, 1989

[9] Young H. D.& Freedman R. A., University Physics, Addison Wesley, 1996

[10] Hayt W. H. & Buck J. A., Engineering Electromagnetics, McGraw-Hill, 2001

[11] Hudson A.& Nelson R., Saunders Colledge Pub., University Physics, 1990

[12] Alonso M.& Finn E. J., Fundamental University Physics, Addison-Wesley, 1974