

Electrodynamics and Magnetism

As a preface - this article is based on these conventional and long - established facts that

- 1) Current is the rate of flow of charge – any charge, not just the flow of electrons.
- 2) This flow of charge produces a magnetic field around itself/conductor.
- 3) Classical physics is purely deterministic and that definite causes should have definite results.
- 4) Observers (who are at the same point and stationary) in the same frame of reference should agree with same or similar incidents (all parameters remaining the same).

This article has no intention to argue against the well-established theory of relativity. In fact, this is much more in concordance with the theory of relativity in keeping the facts 3) and 4) than conventional thoughts in this matter. Moreover this article is only concerned with a classical, logical and more rational attempt to eliminate a paradox in classical electrodynamics.

A humble request: - Please read this article completely, otherwise it may seem it is arguing against the theory of relativity (especially in the former part) which in turn is a disgrace to the intention of this article.

ABSTRACT

This article is concerned with:-

- 1) an attempt to explain an unexplained anomaly in classical electrodynamics,
- 2) about the results it produced thereof which are in quite agreement with existing theories of classical electrodynamics.
- 3) And finally about an experiment which should prove the above stated.

In other words, this article is an effort to give a classical explanation for the anomaly arising in identical situations -where a test charge experience different forces -when it is at rest with respect to one kind of charge (say positive) and is in motion with respect another kind of charge (say negative). Here basically the test charge is at under exactly similar conditions but experience different force on it. This anomaly is explained producing results which are consistent with and are precursors to the existing theories of classical electrodynamics.

INTRODUCTION

In science, definite causes should have definite results and classical theory of electrodynamics should not be an exception - and this article is an attempt to

eliminate the following discrepancy in classical electrodynamics where a charged particle which is at rest with one kind of charge and in motion with respect to the opposite kind of charge experience different forces. This attempt in trying to eliminate this discrepancy resulted in something quite consistent with the rules and equations as we already have now or in other words resulted in no deviation from the present scenario in describing the magnitude of magnetic field and forces – and hence creating the necessity for this article, the relevance of the following experiment and finally to share your valuable opinion regarding this. *(Please consider this article as if it was something that was written at around early 1900 or so - at the time when the theory of magnetism was just evolving, this should help in the proper understanding of this article and the following experiment.)*

The Anomaly:-

Consider the setup - AB is an infinitely long current carrying conductor carrying current I . let CD be a metal strip positioned near to the conductor.

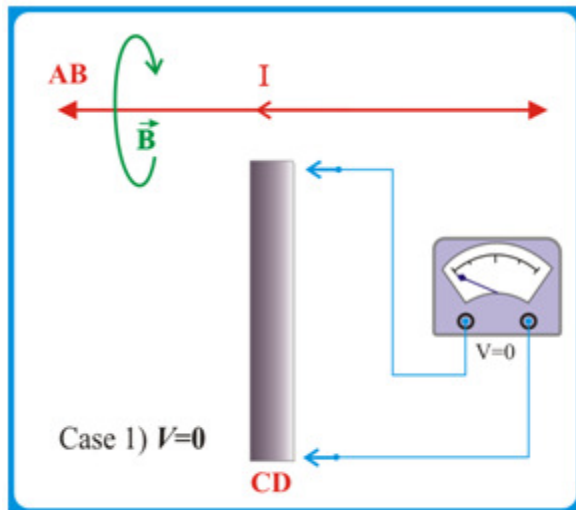


Fig 1A

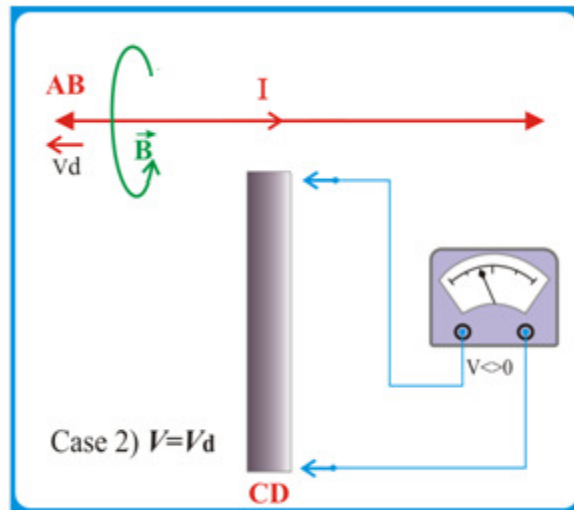


Fig 1B

Case 1) The conductor AB is at rest with respect to the metal strip CD (fig 1A)

Here there will be a magnetic field in and around the metal strip CD, but there won't be any potential developed across it (since there is no magnetic force acting on the electrons). The strength of this magnetic field is given by the equation

$$dB = \mu I / (2\pi r)$$

Case 2) the potential applied to AB is reversed (so drift velocity is negative), and the conductor is moving with a positive drift velocity – i.e., here essentially Q is at rest with the conducting electrons in AB and moving with respect to non

conducting charges. Here too, there will be a magnetic field given by the above equation and there will be magnetic force acting on the conducting electrons of the metallic strip which is given by the equation

$$dF = dB e V_d$$

This causes a potential to be developed across the metallic strip CD.

Even though the potential developed in the two cases are different, it can be seen that in both cases the metal strip is exactly under similar conditions as shown in Fig 2- it is stationary with respect to one kind of charges in AB and is moving with respect to the other (opposite) kind of charge. In case 1) the metallic strip CD sees a current due to the flow of electrons in the conductor AB and in case 2) the metallic strip CD sees a current due to the flow of nuclear positive charge in conductor AB. This anomaly (different result for identical situation) is explained conventionally by saying that in case 1 the metallic strip is not moving but in case 2, it is. This classical explanation is not satisfactory because –

- 1) It keeps double standard (from the atomic point of view –its still similar situation producing different results- if electrons and protons are regarded as mere charged particles, the only difference between the two cases is the flow of neutrons, but this is not a parameter in describing the force.)
- 2) Its converse is true –charges moving under similar magnetic fields always produce the same effect.
- 3) It is ultimately the motion between the charges that creates these effects and its relative velocity is not taken into consideration and for these reasons this explanation is not according to the true spirit of science.
- 4) Trying to explaining these by taking their absolute relative velocity into consideration (besides correctly answering this question) resulted in no deviation from the present scenario. This also finally resulted in an equation for magnetic field strength B which is proportional to the current I and force acting on the charged particle proportional to the velocity with which it is moving (not the relative velocity) and other rules which is very much consistent

with what we already have now and this greatly support in favor of this explanation.

(As mentioned earlier this article has no intention or is not arguing against the theory of relativity -it's only an attempt to eliminate the above said discrepancy in a classical and rational way).

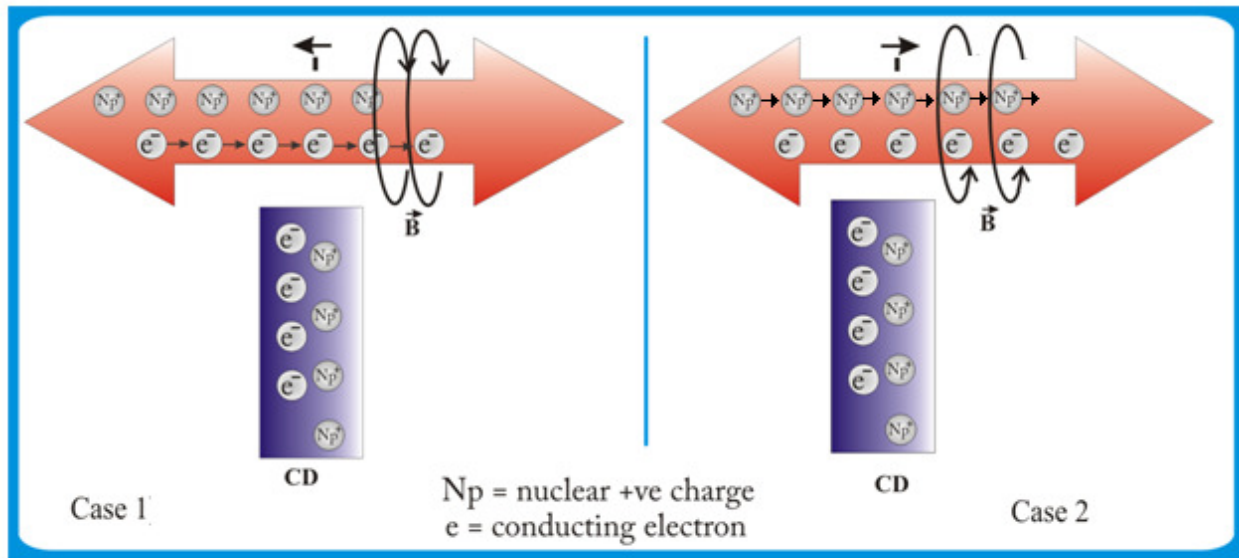


Fig 2

Now the above phenomenon can be explained in this way, since in case 2 there is a potential developed across the strip CD there (has to be) is a potential developed in case 1 also (identical situation producing identical phenomenon). The reason why the potentiometer didn't detect any voltage in case 1 is due to the facts that

- 1) The magnetic field which acts on the metallic strip CD is also acting on the probes of the potentiometer (Fig 3) which develops the same potential across it (i.e., the probes of the wire that are equi-distant from the wire AB are at equi -potential and hence the potentiometer reads zero potential. This creates a situation where the voltage developed can't be measured directly.
- 2) The calculated potential developed in case 2) is of the order of Pico-volts (for a few amps) and this clubbed with the above fact (1) makes it even harder to detect.

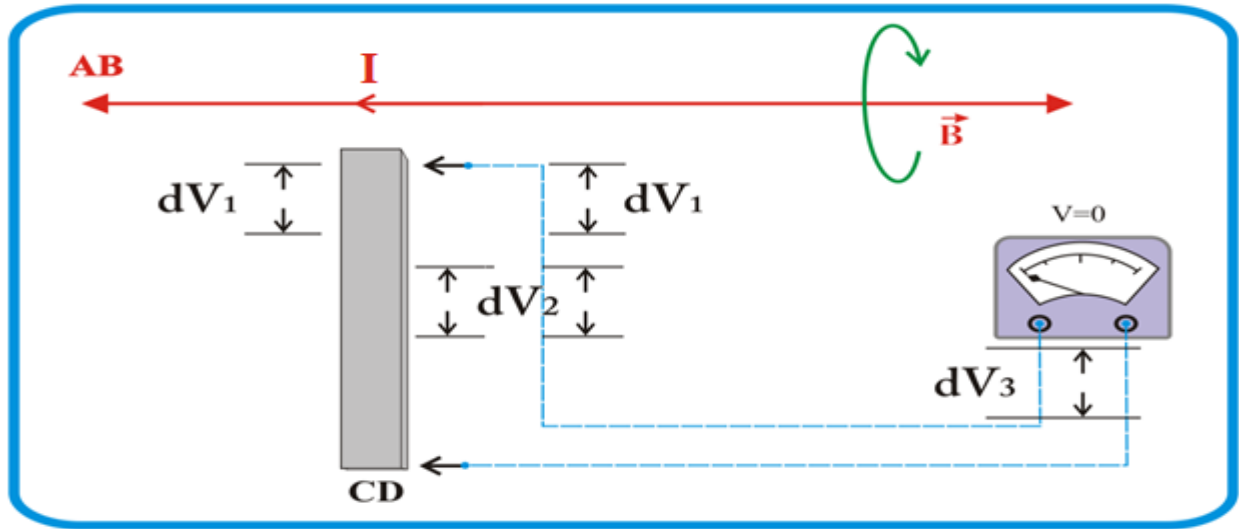


Fig 3 $V=0$

Moreover, assuming that there is an undetected potential developed in case 1) also and proceeding on that line of thought resulted in:-

- 1) An equation for magnetic field which is directly proportional to the current flowing in the conductor {B proportional to I } and
- 2) An equation for the magnetic force experienced by the electrons in the metallic strip which is proportional to the relative velocity between the conductor AB and the metallic strip CD {F proportional to V, { not (V+Vd) } which is consistent with the present scenario giving more solidity for the above concept. [In relation to fig-3, the measured potential is proportional to V and not (V+Vd)].
- 3) the derivation of Other rules of charges in motion that are precursor to the laws of magnetism which again is in agreement with what we have now and this also strongly supports this
- 4) In giving a good “picture” on the idea of magnetic South and North poles and magnetic lines of forces etc.

The Derivations:-

Now the potential calculated in case 2 is given by the equation

$$dE = dBV_d \quad \text{which is also the potential developed in case 1.}$$

And the magnetic force that is acting on the electrons in the metallic strip CD which is at a distance r from the conductor AB is given by

$$F = B e V_d$$

Where $B = \mu I / (2\pi r)$ and $I = n A e V_d$

I = the current flowing in the conductor AB

n = No. of conducting electrons per unit volume

A = Area of cross-section of the conductor AB

e = electronic charge

V_d = drift velocity of electrons in conductor AB

I.e.

$$\Rightarrow F = \mu n A e^2 V_d^2 / (2\pi r)^*$$

(* It should be noted that force between charges in motion are not always related to square of their relative velocities, which is mentioned in the later part of this article**).

From these equations it can be seen that the force acting on the electrons is proportional to the square of the drift velocity (which is the relative velocity) between them. Moreover attempting to generalize this with other velocities resulted in (as stated earlier)-

- 1) *An equation for magnetic field which is proportional to the current flowing in the conductor {B proportional to I }*
- 2) *An equation for the magnetic force experienced by the electrons in the metallic strip which is proportional to the relative velocity between the conductor AB and the metallic strip CD {F proportional to V, { not (V+V_d)} which is consistent with the present scenario giving more solidity for the above concept. [In relation to fig 3, the measured potential is proportional to V and not (V+V_d)].*
- 3) *the derivation of Other rules of charges in motion that are precursor to the laws of magnetism which again is in agreement with what we currently have now and this also strongly supports in favor of this.*

Case 3) when the relative velocity between the conductor and the strip CD is greater than the drift velocity of electrons as shown in the figure4. (here in the picture below, CD moves to the right with respect to AB.

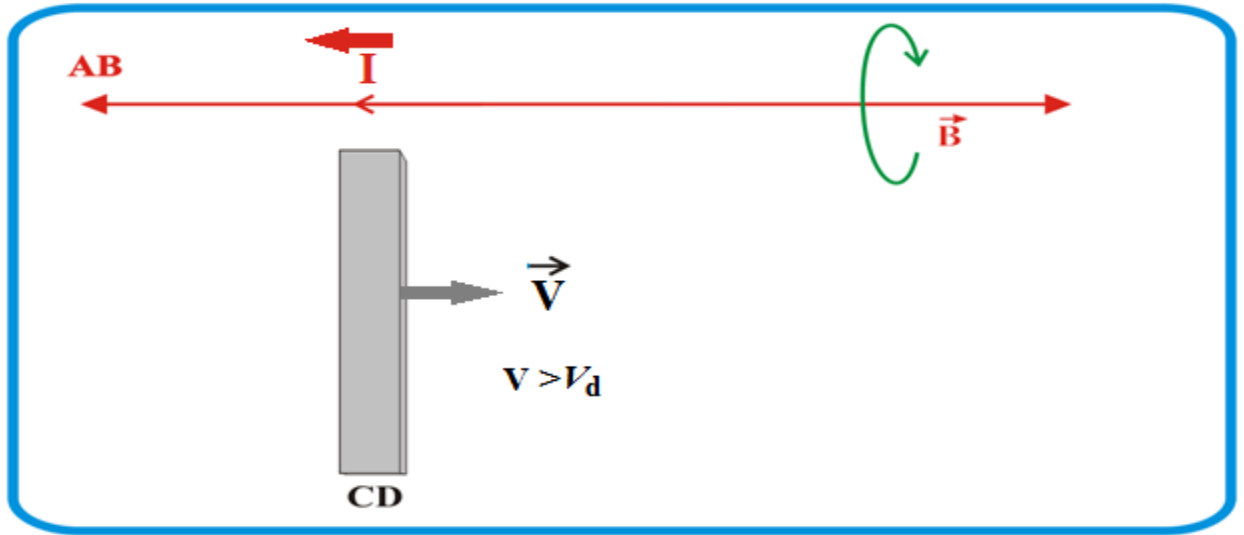


Fig 4

This is similar to case 2) or case 1) except that the metallic strip CD is now on the magnetic field caused by three types of current in place of one as shown in fig5. They are due to current caused by the movement of

- 1) Conducting electrons flowing towards the left or $(-X)$ axis with a velocity $(V-V_d)$, I_1
- 2) Non conducting electrons flowing towards the left with a velocity V , I_2
- 3) Non conducting nuclear positive charge flowing towards the left with a velocity V , I_3

The potential developed in CD is due to the net result of the effect of these currents. The magnetic field caused by flow of conducting electrons, non conducting electrons and nuclear positive charges is given by the equations

$$dB_1 = \mu I_1 / (2\pi r)$$

$$dB_2 = \mu I_2 / (2\pi r)$$

$$dB_3 = \mu I_3 / (2\pi r)$$

(This shouldn't be hard to imagine as it is true in the case of masses and charges where one mass/charge particle affect every surrounding mass/charge particle –then why not with moving charges. Moreover, this is more logical).

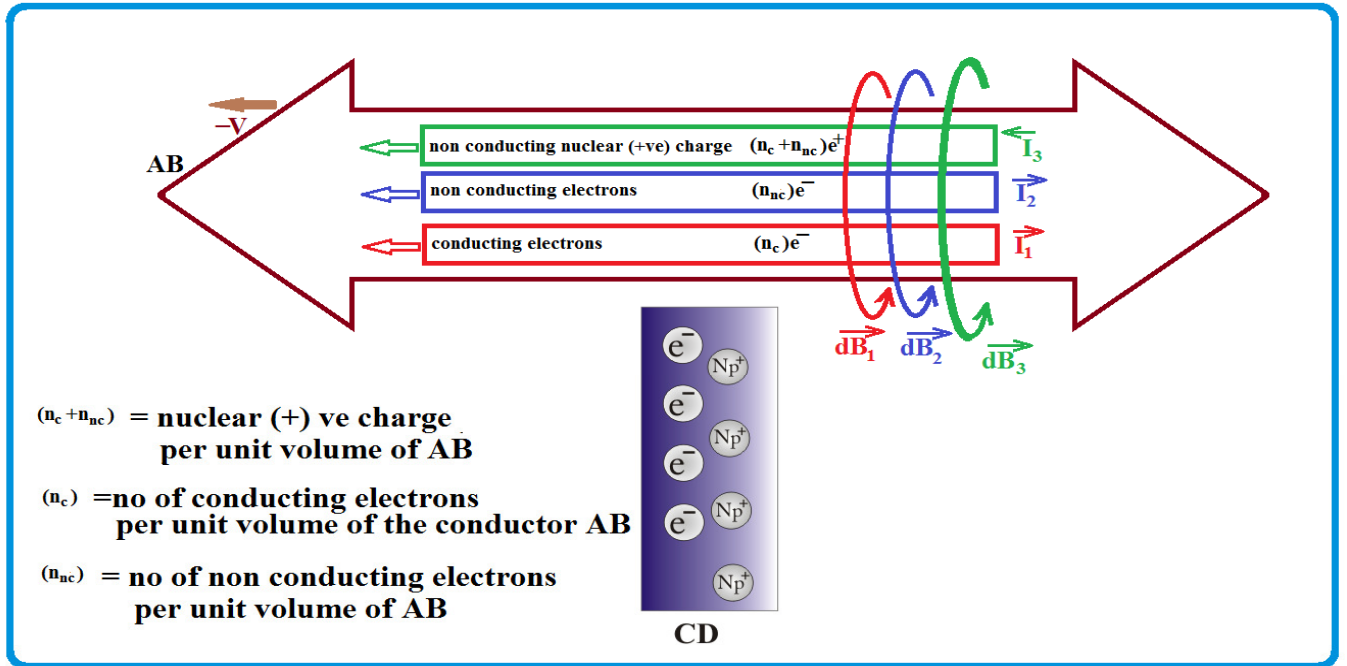


Fig 5

Summing the above equations gives the magnetic field produced by the current carrying conductor AB on CD.

$$dB = \mu(I_1 + I_2 + I_3) / (2\pi r)$$

$$I_1 = -n_c Ae(V - V_d)$$

$$I_2 = -n_{nc} AeV$$

$$I_3 = -(n_c + n_{nc}) Ae^+ V$$

$$= (n_c + n_{nc}) AeV$$

$$= k \{ [n_c Ae(V_d - V)] - [n_{nc} AeV] + [(n_c + n_{nc}) AeV] \} / r$$

$$k = \mu / (2\pi)$$

$$dB = k (n_c AeV_d) / r$$

$$dB = \mu I / (2\pi r)$$

$$\text{since } n_c = n \text{ and } I = n AeV_d$$

And this is in accordance with the conventional equation.

Derivation of the force acting on the electrons of CD:-

In case2) the metal strip sees a current flowing to the right due to the flow of net positive charges and the force acting on the electrons of CD is given by:-

$$dF = C n A e^2 V_d^2 / r \quad (\text{where } C = \text{a constant})$$

In case3) since there are three sets or types of current (as shown in fig5), three set of force acts on the electrons of CD.

- 1) F_1 force due to the flow of conducting electrons to the left
- 2) F_2 force due to the flow of non conducting electrons to the left.
- 3) F_3 force due to the flow of non conducting nuclear positive charge flowing to the left.

The net effect is due to the sum of these three forces. (A constant C is incorporated in this equation which is usually given a value after experimental verification)

$$dF_1 = C n_c A [e (V - V_d)]^2 / r \quad \rightarrow \text{repulsive in nature}$$

$$dF_2 = C n_{nc} A [e V]^2 / r \quad \rightarrow \text{repulsive in nature}$$

$$dF_3 = C (n_{nc} + n_c) A e e^+ V^2 / r \quad \rightarrow \text{attractive in nature}$$

$$\begin{aligned} dF &= dF_1 + dF_2 + dF_3 \\ &= C A e^2 [\{n_c (V - V_d)\}^2 + (n_{nc} V^2) - \{(n_{nc} + n_c) V^2\}] / r \\ &= C A e^2 n_c (-2 V V_d + V_d^2) / r \end{aligned}$$

If $V_d \ll V$ can be neglected.

(it can be seen that the value of $C = \mu / (4\pi)$ when calculated this way)

$$= C \cdot 2 I e V$$

$$= B \text{ eV}$$

And hence we still have an equation for force which is proportional to both B and V as in the present case scenario}

And this constant sign should be reincorporated into case 1 and case2 equations. From these it can be seen that interpreting magnetism in this way is in complete agreement with the conventional theory of magnetism.

The Experiment:-

Experimental set up like these will prove that there is magnetic force acting as described above.

Consider a straight long tube CD which on conduction electro-deposition of copper takes place at the cathode (-). The cathode is in contact with a long piece of wire AB (as shown in fig 5B) which is connected to the negative terminal of the battery and the anode is connected to the positive terminal. PQRS is a piece of wire or a metal plate shaped as shown and is placed near this (AB – CD) arrangement. On the tube, the carriers of current are the positive ions whereas in the wire; it is the electrons that conduct electricity. On conduction, the conducting electrons in AB repel electrons in PQ away from it whereas the moving cations on the tube attract electrons in RS towards it. This causes a potential to be developed across PS and this can be measured directly. (Here the length of QP/RS has to be much smaller than the length of AB and CD preferably $QP=1\text{cm}$ and $QR=200\text{cm}$).

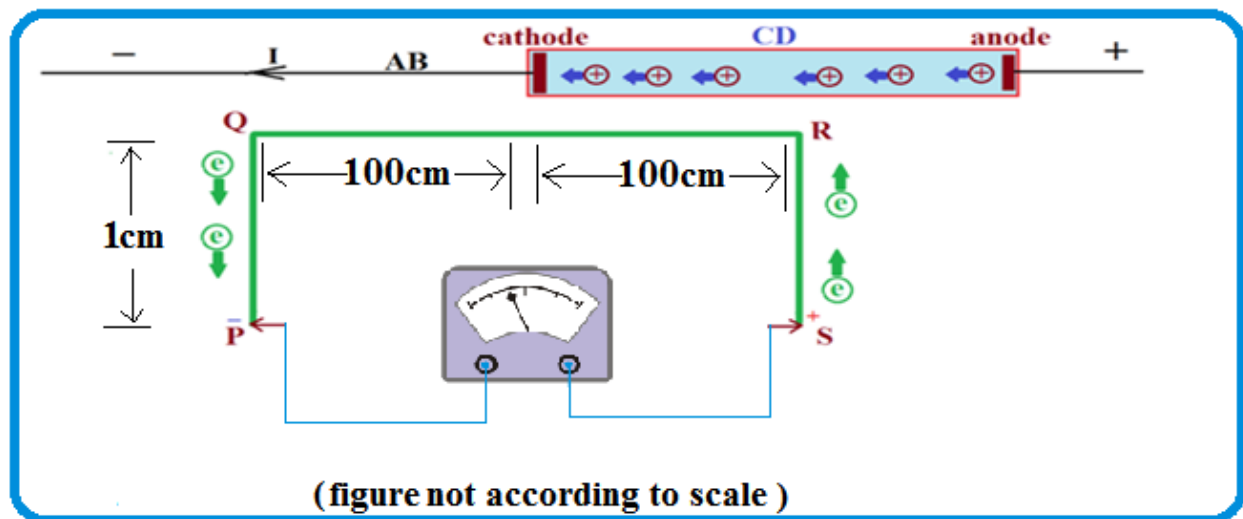


Fig 5B

As we have derived earlier, the force acting on the electrons in QP (part of PQRS) due to the conducting electrons in AB is given by (the force between conducting charges in CD and QP is negligible and is omitted).

$$dF = C n A e^2 V_m^2 / r$$

This force is repulsive in nature and similarly the force acting on the electrons in RS due to the conducting positive ions in CD is attractive in nature.

Now the incremental potential developed in PQ/RS is given by the equation

$$dV = B v dl$$

where V is the potential developed,

B = the strength of the magnetic field, $dB = \mu I / (4\pi r)$

v = drift velocity of the conducting charge.

l = length of PQ or RS

Substituting in the above equation, we have

$$V = \int_{r_1}^{r_2} \frac{\mu I}{(4\pi r)} dr V_e + \int_{r_1}^{r_2} \frac{\mu I}{(4\pi r)} dr V_p$$

where r_1 and r_2 are the distance of P and Q from AB (or S and R from CD) respectively.

The potential developed across PS can be calculated and is of the order of Pico volts for a few amperes of current.

In the above experiment, in place of AB and CD, n-type and P-type semiconductors can be used which should develop much more voltage across PS (of the order of nano-volts) since the drift velocity of electrons in semiconductors is much greater.

** Consider a straight long wire AB carrying current I and a charge Q is moving perpendicular to it with a velocity V as shown in the figure 5C. Here as the particle moves, it can be seen that its “ r ”, the distance between AB and Q that varies and hence the magnitude of the magnetic field changes and thus, it is magnetic induction that plays here and is very different from the above case.

$$V = dr/dt$$

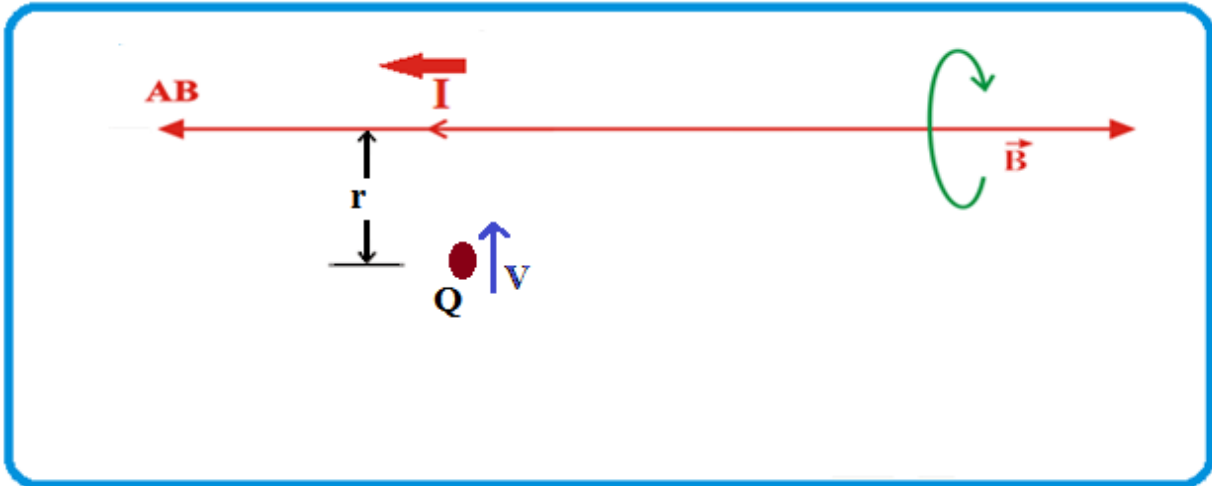


Fig 5C

Here clearly the equation for the force take the form $F = BQV$ which is independent of the square of their relative velocities.

From Biotsarvats law we have (fig 6)

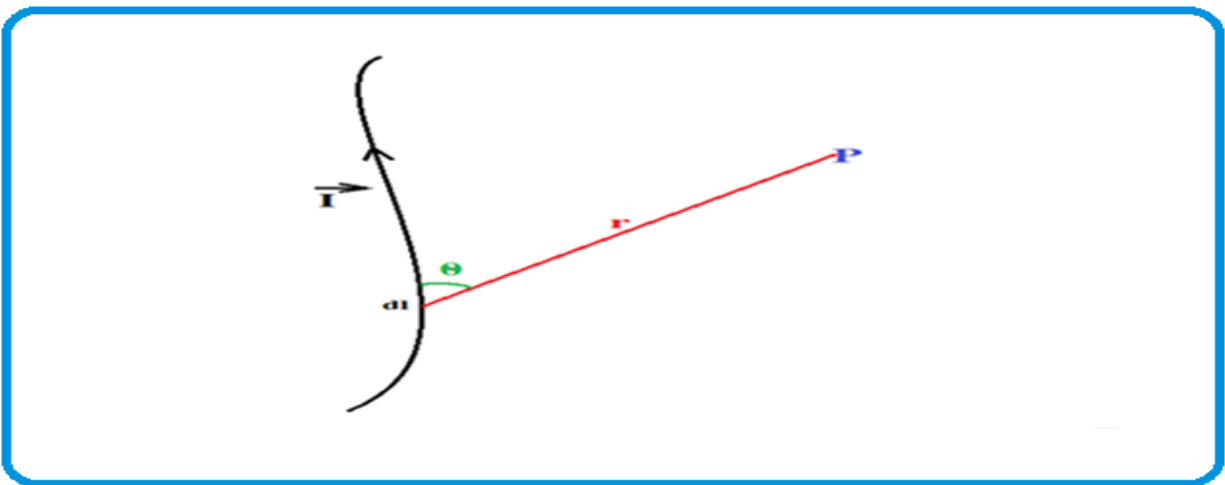


fig 6

The magnetic field produced by a current element at any point p is proportional to the current I, elementary length dl, $\sin\theta$ and $1/r^2$

$$dB = \mu I dl \sin\theta / (2\pi)r^2$$

Now consider a stream of electrons flowing through a conductor or in free space, (but in a straight line) the current $I = nAeV_d$ can be regarded as $q_l V$ where q_l = charge in elementary length dl, V is the drift velocity of electrons.

Therefore, the magnetic field on the charged particle q_2 at point P due to the motion of charged particles on elementary length dl is given by

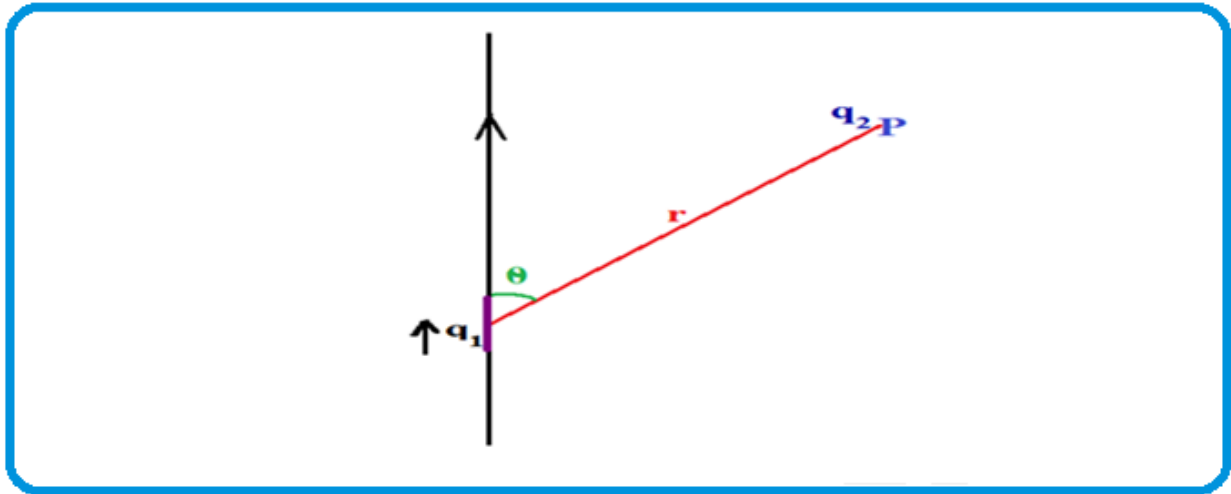


fig 7

$$dB = K q_1 V \sin\theta / r^2 \quad \text{where } K \text{ is a constant} = \mu / (2\pi)$$

θ is the angle q_1 makes with q_2 and velocity vector V

Then from the above explanation we have the force acting on Q_2 due the charge on elementary length dl moving with the velocity V with respect to q_2 can be rewritten as

$$dF = C q_1 q_2 V^2 \sin\theta / r^2 \quad \text{where } C \text{ is a constant} = \mu / (4\pi)$$

and when the magnetic field is caused by a straight live conductor carrying current I and let a charged particle Q moves with a velocity U , then the net magnetic field and force experienced by it (not by the flowing electrons alone but due to net effect of the various charges on the conductor as a whole) can be derived from the above equation and is given by

$$dB = k I dl \sin\theta / r^2 \quad \text{where } K = \mu / (2\pi) \text{ and}$$

$$dF = dB Q U$$

It can be seen from the equation ($dF = Cq_1q_2 V^2 \sin\theta/r^2$) that,

- 1) this magnetic force will be attractive in nature if the charges are opposite and if they are like charges they will repel one another
- 2) the direction of the velocity (to or against) with which the charged particle is moving relative to one another is not a factor in deciding the direction of the force (attractive or repulsive in nature).

This explains, in the case why the magnetic force on the charged particle is reversed on reversing the direction of motion of the charged particle (when the magnetic field is caused by the current carrying wire and the like). Moreover this is the precursor to concepts like magnetic north and south poles and rules like Right Hand Thumb rule (why like poles repel and unlike poles attract and why a magnet takes a circular path from head to tail around a live conductor) etc, - since these can be derived from this equation. Had the force been independent on the square of the relative velocities - then these can never be derived or explained.

However as stated earlier (going back with reference to fig 5C), when the charged particle Q is moving towards the conductor, then the force acting on Q is due to magnetic induction (where the motion of the charged particle causes a change in magnetic field) and not due to the force that we have described above. Here the magnetic force is not dependent on the square of the velocity.

RESULTS -

Interpreting the phenomenon in this way not only resulted in eliminating the anomaly of different forces experienced by charged particles under similar situations but also explained other properties of charges which are precursor to the formation of magnetic north and south poles and lines of charge and is very much consistent with existing theories of classical electrodynamics.

CONCLUSION- Even though this article describes magnetism in a way a bit different from conventional magnetism, it is in complete agreement with conventional magnetism and it successfully eliminates the anomaly of different effects produced by charges moving under similar conditions. Moreover this has a more rational and logical approach towards the concept of magnetism.

(Please send your valuable suggestions and opinions regarding these to abhilashsidhakodu@gmail.com)

Thank You and welcome.

Abhilash J Pillai.