

## ELECTRIC AND MAGNETIC FORCES IN TWO CHARGED WIRES

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Reference: Griffiths, David J. (2007) Introduction to Electrodynamics, 3rd Edition; Prentice Hall - Problem 5.12.

The electric field a distance  $d$  from an infinite line of charge (linear charge density  $\lambda$ ) is

$$E = \frac{1}{4\pi\epsilon_0} \frac{2\lambda}{d} \quad (1)$$

For positive charge, this field points radially outwards from the wire.

Now if we move this line of charge at speed  $v$ , thus creating a current  $I = \lambda v$ , it will produce a magnetic field

$$B = \frac{I\mu_0}{2\pi d} \quad (2)$$

$$= \frac{\lambda v \mu_0}{2\pi d} \quad (3)$$

The field will circle the line in a direction determined by the right-hand rule.

Now suppose we place an identical line of charge, moving at the same speed, a distance  $d$  from the first one. Since both lines carry the same sign of charge, the electric force between them is repulsive. From the Biot-Savart law and the right hand rule, we can see that the magnetic force is attractive. Can we adjust  $v$  so that the electric and magnetic forces balance each other?

For a unit length of wire, the electric force is

$$F_E = \frac{1}{4\pi\epsilon_0} \frac{2\lambda^2}{d} \quad (4)$$

and the magnetic force is

$$F_B = \frac{(\lambda v)^2 \mu_0}{2\pi d} \quad (5)$$

Setting these two equal to each other, we get

$$v = \frac{1}{\sqrt{\epsilon_0 \mu_0}} \quad (6)$$

$$= \frac{1}{\sqrt{(8.85418782 \times 10^{-12}) (1.25663706 \times 10^{-6})}} \quad (7)$$

$$= 2.997924 \times 10^8 \text{ m s}^{-1} \quad (8)$$

This happens to be the speed of light, so it's not possible to get the charge moving fast enough for the magnetic force to balance the electric force.

It's not a coincidence that  $\frac{1}{\sqrt{\epsilon_0 \mu_0}} = c$ ; in fact this quantity comes out of Maxwell's equations as the speed of electromagnetic waves, and is what led Einstein to postulate that  $c$  is a universal constant and thus create his theory of special relativity. We'll get to this eventually.

#### PINGBACKS

Pingback: Force between two sheets of current