
Special Relativity and Magnetism in an Introductory Physics Course

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Too often, students in introductory courses are left with the impression that Einstein's special theory of relativity comes into play only when the relative speed of two objects is an appreciable fraction of the speed of light (c). In fact, relativistic length contraction, along with Coulomb's law, accounts quantitatively for the force on a charged particle as it moves relative to a current-carrying wire. That force, which in the reference frame of the wire we call "magnetic," is measurable and important even at relative speeds on the order of $10^{-12}c$. This paper offers a straightforward way of introducing students to the connection between magnetism and special relativity and provides references to more in-depth treatments, especially those of E.R. Huggins¹ and of E.M. Purcell as simplified by D.V. Schroeder.²

The Short Version

Suppose a conventional (positive) current flows in a wire that is stationary in the laboratory reference frame. To us the wire is electrically neutral, the numbers of positive and negative charges per unit length of wire being equal. But what does the wire "look like" to a positively charged particle moving in the same direction and at the same speed as the charge moving in the wire? To such a particle, the positive charges in the wire are stationary while the negative charges are moving. To the particle, is the wire still neutral?

Einstein's special theory of relativity tells us that relative motion causes a shortening (contraction) of space along the direction of motion.³ Thus, in the ref-

erence frame of the moving positively charged particle, the average distance separating negative charges in the wire is smaller than the average distance separating positive charges. Consequently, in the reference frame of the moving particle, the wire is negatively charged. The resulting Coulombic attraction is what we in the lab frame normally refer to as the magnetic force.

This simple, qualitative explanation should provoke a number of questions. Why, for example, doesn't the relative motion of positive and negative charges cause the wire to appear charged in the laboratory frame? Moreover, the drift speed with which charge moves along a wire is a tiny fraction of the speed of light. Can we really account for magnetic forces on the basis of what must be a truly minute relativistic effect?

What follows is intended to answer these questions and to encourage teachers to include Einstein's explanation of magnetism in introductory physics courses.⁴ More in-depth treatments are of course available, to which the present author is greatly indebted.⁵

One Step at a Time

Suppose a wire, stationary in the laboratory reference frame, carries a steady electric current. The net linear charge density along the wire (λ) is the algebraic sum of the linear densities of positive and negative charges, which we write as

$$\lambda = (e'L^+ - e'L^-)_0. \quad (1)$$

In this equation, e is the elementary charge ($1.60 \times$

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