RELATIVITY

1. Special Relativity
2. Time Dilation
3. Doppler Effect
4. Length Contraction
5. Twin Paradox
6. Electricity and Magnetism
7. Relativistic Momentum
8. Mass and Energy
9. Energy and Momentum
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ELECTRICITY AND MAGNETISM

The connection between electricity and magnetism was puzzling to Einstein…

One of the triumphs of special relativity is that it clarified the nature of this connection…

HOW???

ELECTRICITY AND MAGNETISM

First let's think…

• Does moving charges (such as electrons) have speeds close to the speed of light?

• Should there be a relativistic effect in the motion of charge?

• What about the strength of electric forces?

ELECTRICITY AND MAGNETISM

- Electric attraction between the electron and proton in H atom is 10^{39} times greater than the gravitational attraction between them.

- A small change in the character of these forces due to relative motion has large consequences.

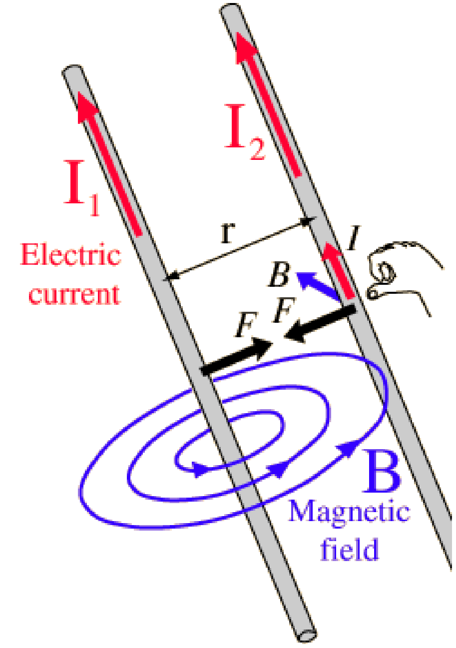
- Although the effective speed of an electron in a current-carrying wire is < 1mm/s, there are 10^{20}/cm or more moving electrons in a wire, so the total effect is considerable.

ELECTRICITY AND MAGNETISM

- How relativity links electricity and magnetism is mathematically complex.

- We will only look at one aspect that is easy to appreciate.

The magnetic force between two parallel currents.



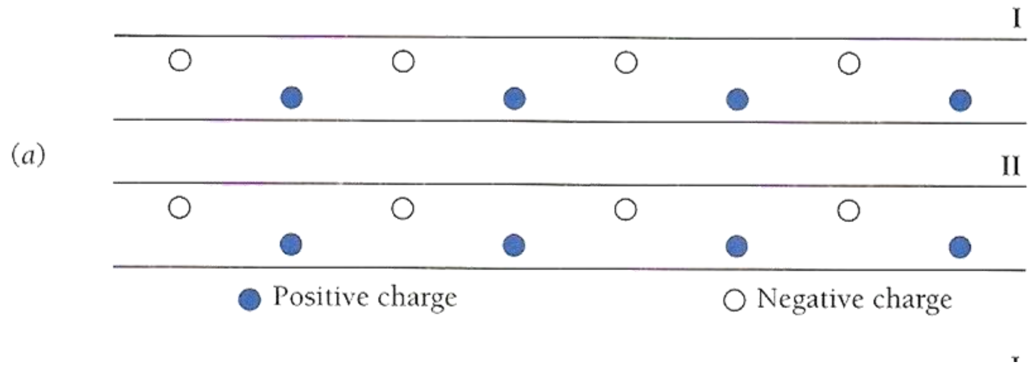
ELECTRICITY AND MAGNETISM

Like the speed of light..

Electric charge is relativistically invariant..

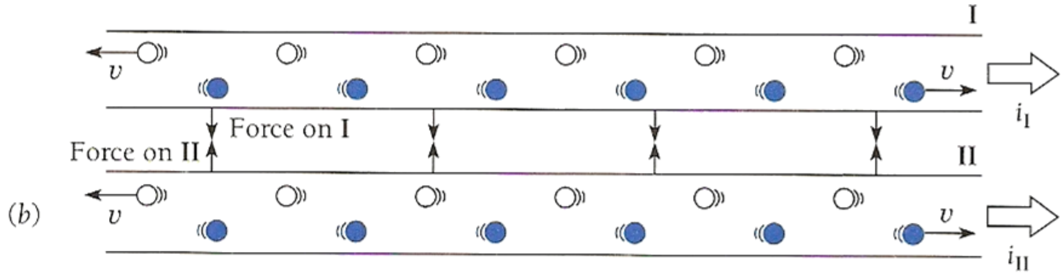
A charge with magnitude Q in one frame of reference is also Q in all other frames.

ELECTRICITY AND MAGNETISM



- They contain equal numbers of positive and negative charges at rest that are equally spaced.
- The conductors are electrically neutral.
- There is no force between them.

ELECTRICITY AND MAGNETISM



- Conductors carry currents i_I and i_{II} in the same direction.
- Positive charge move → and negative charges move ←, both with the same speed υ *as seen from the laboratory frame of reference*.
- Charges are moving $\Rightarrow$ their spacing is smaller than before by a factor $\sqrt{1-\upsilon^2/c^2}$
- Will the conductor remain neutral?
- Since υ is the same for both sets of charges, their spacing shrink by the same amount for an observer in the laboratory.

The conductors now attract each other. WHY?

ELECTRICITY AND MAGNETISM

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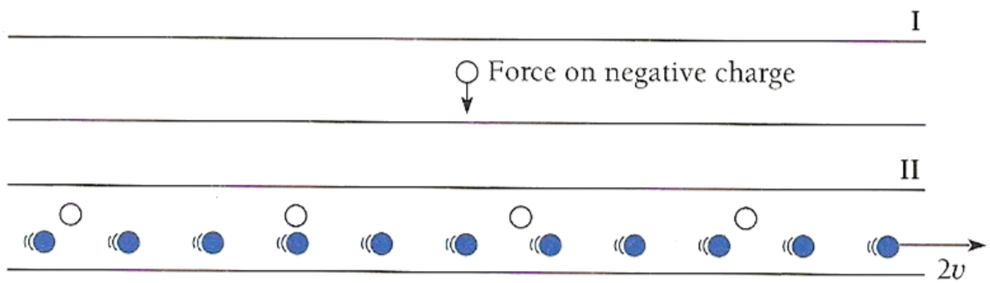
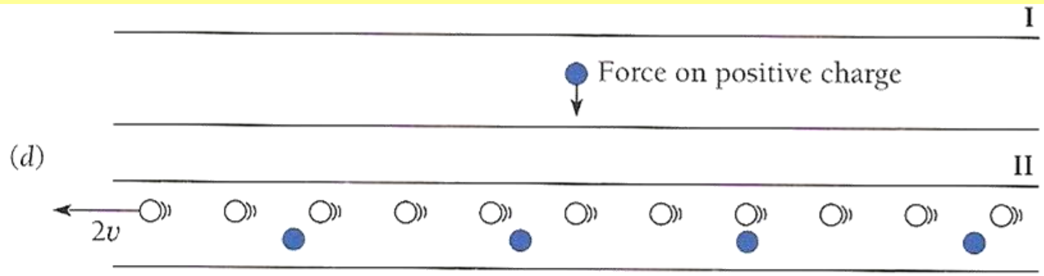


Let us look at conductor II from the frame of reference of one of the negative charges in conductor I…

- Negative charge in II appear at rest in this frame ← their spacing is not contracted.
- Positive charges in II have velocity 2υ ← spacing contracted more than in laboratory frame.
- Conductor II appears to have a net positive charge.
- An attractive force acts on the negative charge in I.

ELECTRICITY AND MAGNETISM

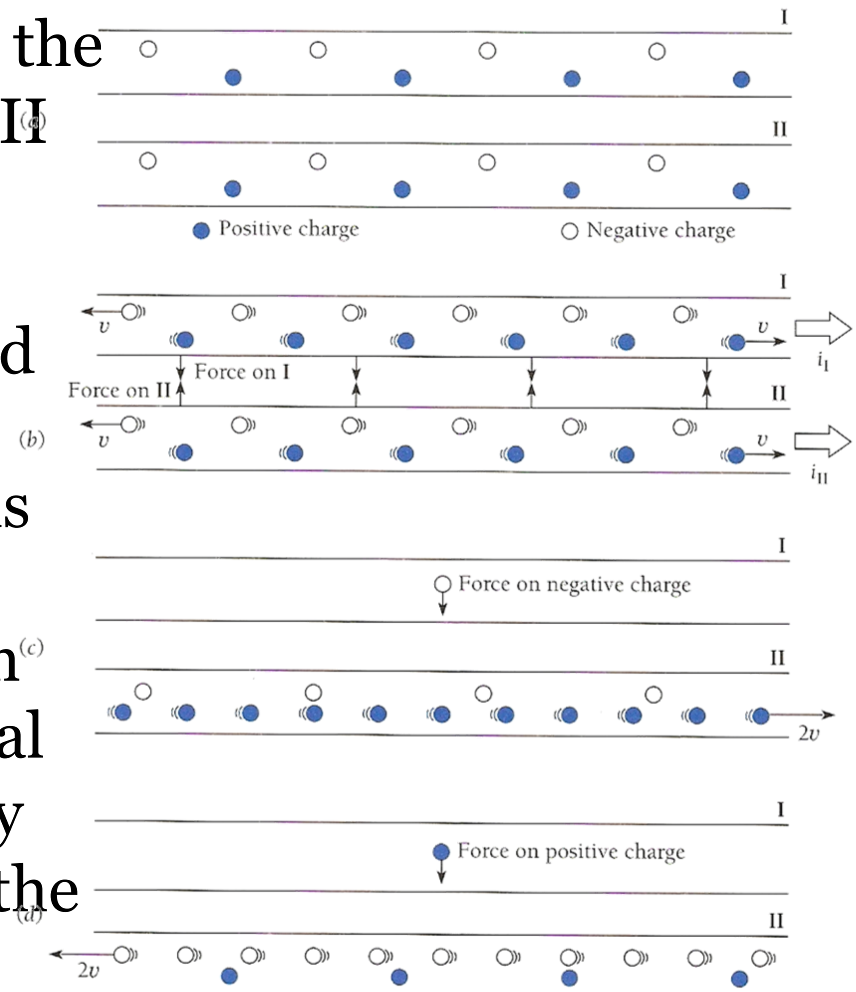


Let us look at conductor II from the frame of reference of one of the positive charges in conductor I…

- Positive charge in II appear at rest in this frame ← their spacing is not contracted.
- Negative charges in II have velocity 2υ ← spacing contracted more than in laboratory frame.
- Conductor II appears to have a net negative charge.
- An attractive force acts on the positive charge in I.

ELECTRICITY AND MAGNETISM

• Identical arguments show that the negative and positive charges in II are attracted to I.
• All charges in each conductor experience forces directed toward the other conductor.
• To each charge, the force on it is an ordinary "electric" force.
• From the laboratory frame both conductors are electrically neutral and the attraction is explained by "magnetic" interaction between the conductors.



ELECTRICITY AND MAGNETISM

A current-carrying conductor that is electrically neutral in one frame of reference might not be neutral in another frame.

How can this observation be reconciled with charge invariance?

ELECTRICITY AND MAGNETISM

How can this observation be reconciled with charge invariance?

-We must consider the entire circuit of which the conductor is a part.

- For every current element in one direction that a moving observer finds to have positive charge, there must be another current element in the opposite direction which the same observer finds to have negative charge.

- Magnetic forces act between different parts of the same circuit, even though the circuit as a whole appears electrically neutral to all observers.

ELECTRICITY AND MAGNETISM

All magnetic phenomena can also be interpreted on the basis of Coulomb's law, charge invariance, and special relativity.

ELECTRICITY AND MAGNETISM

Remember…

Relativity is the bridge between electricity and magnetism…