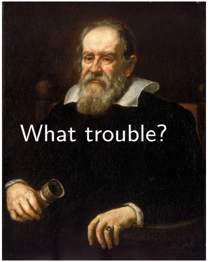
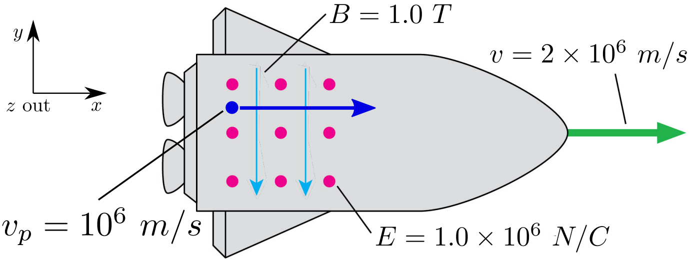
# Filling out the Card

1. List which physics and math courses you have had especially Math Methods, Quantum Mechanics, Electricity and Magnetism.
2. Do you have experience with *Mathematica*?
3. What are your pronouns?

A rocket flies past the Earth at a velocity $v = 2 \times 10^6\ m/s$ (in green) as shown in the figure. The astronauts on board have set up electric and magnetic fields on the rocket. A proton (in blue) is injected into the field region with the velocity $v_p = 1.0 \times 10^6\ m/s$ as measured by the astronauts on the ship. What is the force on the proton as measured by the astronauts? What is the force on the proton as measured by someone on the Earth? Does this make sense?



Physics is the same in all inertial reference frames (hopefully).

| Galilean |
| --- |
| $x' = x - vt$ |
| $y' = y$ |
| $z' = z$ |
| $t' = t$ |
| $v'_x = v_x - v_O$ |
| $v'_y = v_y$ |
| $v'_z = v_z$ |

primes refer to the frame moving with velocity $v_O$.

$v_O$ - velocity of moving/Other/B frame.

$v_i$ - $i^{th}$ component of the velocity in the stationary/Home/A frame.

$v'_i$ - $i^{th}$ component of the velocity in the moving/Other/B frame.

# The Galilean Transformations (GT) - 1 

| Galilean |
|---|
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| $v'_x = v_x - v_O$ |
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**Are Newton's Laws consistent with the Galilean transformations?**

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| Galilean |
| --- |
| $x' = x - vt$ |

**Are Newton's Laws consistent with the Galilean transformations?**

**Yes! The laws of physics are the same in all inertial frames.**

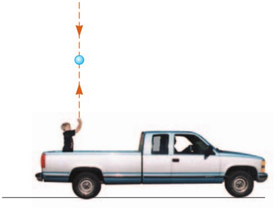
primes refer to the frame moving with velocity $v_O$.

$v_O$ - velocity of moving/Other/B frame.

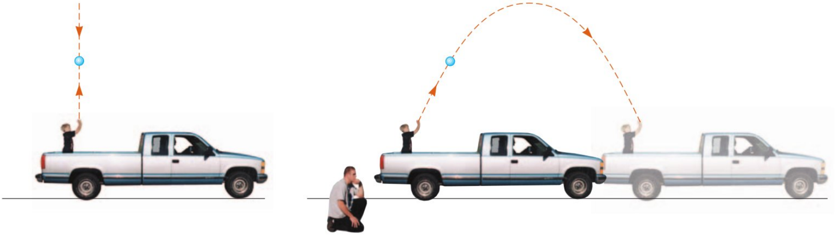
$v_i$ - $i^{th}$ component of the velocity in the stationary/Home/A frame.

$v_i'$ - $i^{th}$ component of the velocity in the moving/Other/B frame.

What changes in the trajectory of a tossed ball between the Home frame and the Other frame?



What changes in the trajectory of a tossed ball between the Home frame and the Other frame?



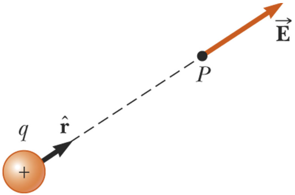
A person who can swim at a speed $c$ in still water is swimming in a river with a current of speed $v_O$ where $c > v_O$. Suppose the person swims upstream a distance $L$ and returns to the starting point. What is the time for this round trip? Compare this with the time it takes to swim the same distance $L$ across the river and back. Note: The swimmer returns to the same point each time.

Ira Gershenhorn swims the Hudson River near 104th St in New York City (NYT 7/11/2018).

| Galilean Transformation |
|---|
| $x' = x - vt$ |
| $y' = y$ |
| $z' = z$ |
| $t' = t$ |
| $v'_x = v_x - v_O$ |
| $v'_y = v_y$ |
| $v'_z = v_z$ |

Coulomb's Law

$$d\vec{E} = k_e \frac{dq\hat{r}}{r^2} = \frac{1}{4\pi\epsilon_0}\frac{dq\hat{r}}{r^2}$$



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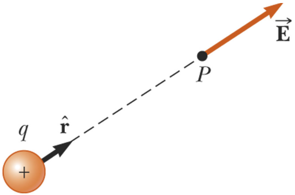
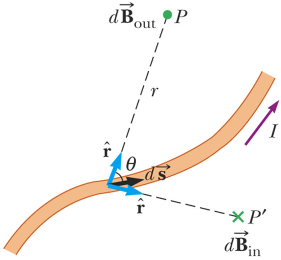



Biot-Savart Law

$$d\vec{B} = k_m \frac{Id\vec{s}\times\hat{r}}{r^2} = \frac{\mu_0}{4\pi}\frac{Id\vec{s}\times\hat{r}}{r^2}$$
$$= k_m \frac{q\vec{v}\times\hat{r}}{r^2} = \frac{\mu_0}{4\pi}\frac{dq\,\vec{v}\times\hat{r}}{r^2}$$



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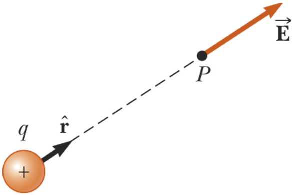


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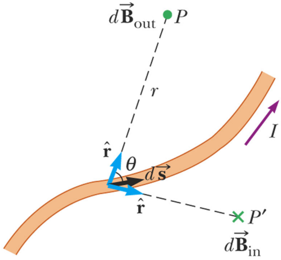
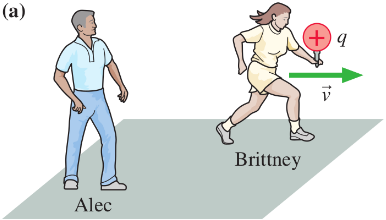



Electromagnetic Force Law

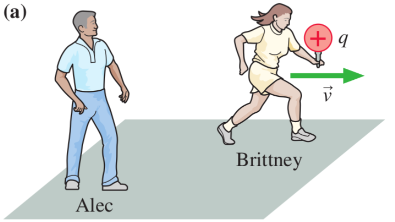
$$\vec{F} = q\vec{E} + \vec{v}\times\vec{B}$$

# The Trouble With Galileo - 2

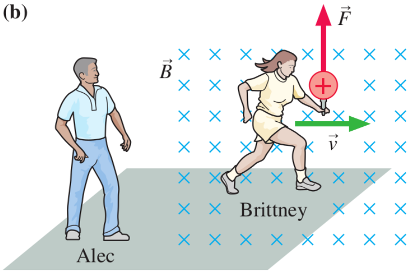



Charge $q$ moves with velocity $\vec{v}$ relative to Alec.

Apply Galilean relativity to electric and magnetic fields.

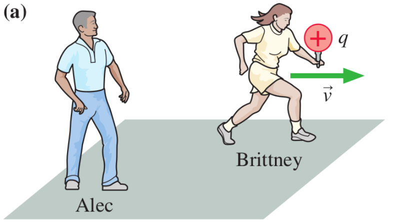



Charge $q$ moves with velocity $\vec{v}$ relative to Alec.




Charge $q$ moves through a magnetic field established by Alec.

Apply Galilean relativity to electric and magnetic fields.



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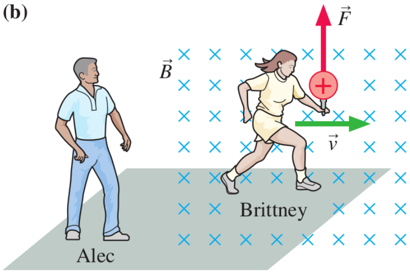
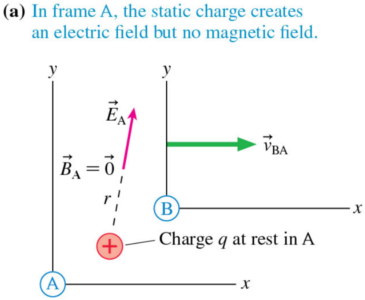


Charge $q$ moves through a magnetic field established by Alec.

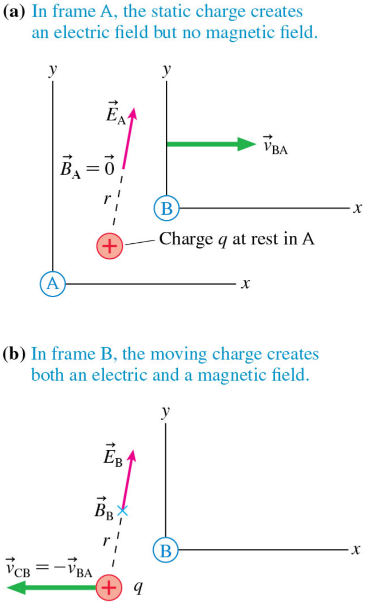
Apply Galilean relativity to electric and magnetic fields.

$$\vec{E}_B = \vec{E}_A + \vec{v}_{BA} \times \vec{B}_A$$

$$\vec{v}_{BA} = \vec{v} \qquad \vec{B}_A = \vec{B}$$

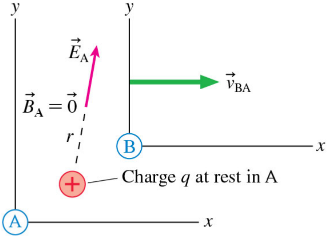



Apply Galilean relativity to electric and magnetic fields.

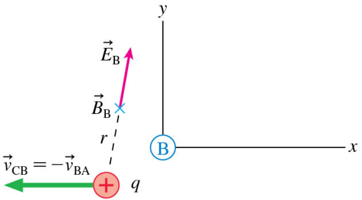



Apply Galilean relativity to electric and magnetic fields.

(a) In frame A, the static charge creates an electric field but no magnetic field.

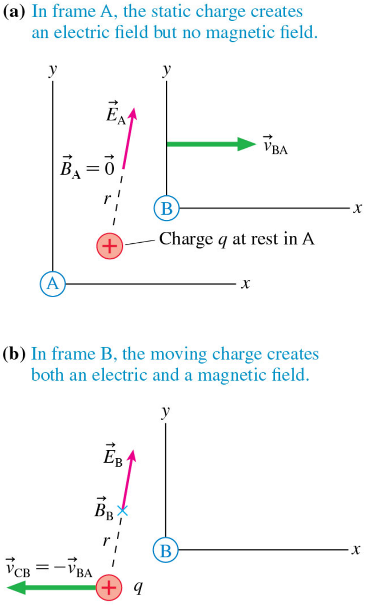



(b) In frame B, the moving charge creates both an electric and a magnetic field.




Apply Galilean relativity to electric and magnetic fields.

$$\vec{B}_B = \vec{B}_A - \mu_0 \epsilon_0 \vec{v}_{BA} \times \vec{E}_A$$



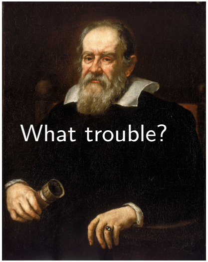

Apply Galilean relativity to electric and magnetic fields.

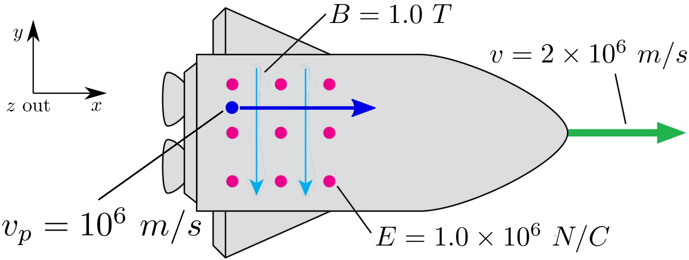
$$\vec{B}_B = \vec{B}_A - \mu_0\epsilon_0\vec{v}_{BA} \times \vec{E}_A$$

$$\vec{E}_B = \vec{E}_A + \vec{v}_{BA} \times \vec{B}_A$$

**Galilean Field Transformations**

A rocket flies past the Earth at a velocity $v = 2 \times 10^6\ m/s$ (in green) as shown in the figure. The astronauts on board have set up electric and magnetic fields on the rocket. A proton (in blue) is injected into the field region with the velocity $v_p = 1.0 \times 10^6\ m/s$ as measured by the astronauts on the ship. What is the force on the proton as measured by the astronauts? What is the force on the proton as measured by someone on the Earth? Does this make sense?

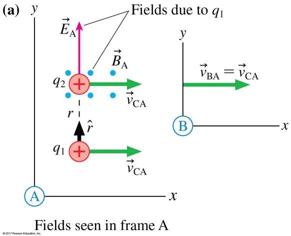


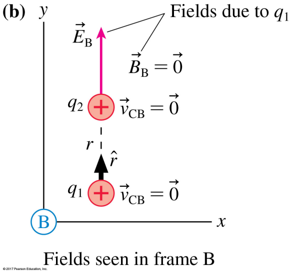



Consider Figure a. Two positive charges are moving side-by-side through frame $A$ with velocity $\vec{v}_{CA}$. The fields of charge $q_1$ at the position of charge $q_2$ are the following.

$$\vec{E}_A = \frac{1}{4\pi\epsilon_0}\frac{q_1}{r^2}\hat{j} \qquad \vec{B}_A = \frac{\mu_0}{4\pi}\frac{q_1 v_{CA}}{r^2}\hat{k}$$

The B/Other frame is moving with the same velocity as the two charges. What is $\vec{E}_B$ at the position of $q_2$?



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The B/Other frame is moving with the same velocity as the two charges. What is $\vec{E}_B$ at the position of $q_2$?