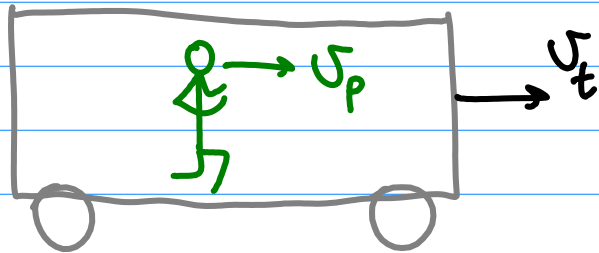


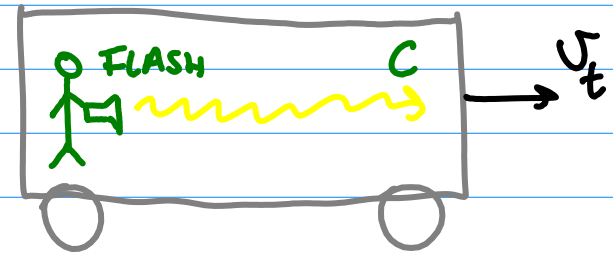
LECTURE 5
CHAPTERS 8, 10, 11

PHY 100. SPECIAL RELATIVITY. MAGNETISM

GALILEO



EINSTEIN



OBSERVER MEASURES:

$$v_p^{obs} = v_p + v_t$$



OBSERVER DOES NOT MEASURE:

$$v_{light}^{obs} \neq c + v_t$$
$$v_{light}^{obs} = c$$

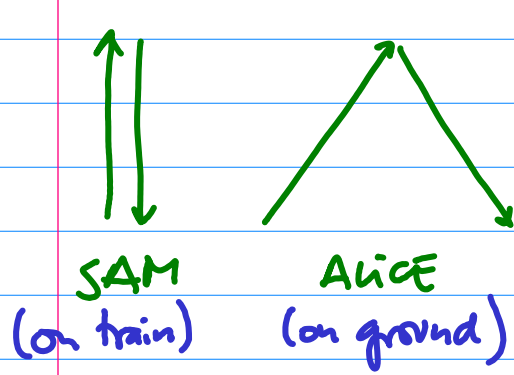
EINSTEIN SPECIAL RELATIVITY:

- 1) THE LAWS OF PHYSICS ARE THE SAME IN ALL INERTIAL FRAMES
- 2) THE SPEED OF LIGHT IS INVARIANT (THE SAME FOR ALL OBSERVERS)

non-accelerating

$$c = 186,000 \text{ mph}$$

DISTANCE LIGHT TRAVELS DEPENDS ON THE POINT OF VIEW
FRAME OF REF.



↓
 LIGHT TRAVEL TIMES DIFFER

TIME IS RELATIVE

$$t_{\text{ALICE}} = \frac{1}{\sqrt{1 - \left(\frac{v}{c}\right)^2}} t_{\text{SAM}} = \gamma > 1$$

TIME DILATION: $\Delta t = \gamma \Delta t'$ or as in book: $t = \gamma t_0$

TIME IS SHORTER IN THE FRAME
 OF REF. WHERE THE "EVENT"
 IS AT REST → PROPER REF. FRAME

proper time

SAME APPLIES TO SPACE → LENGTH CONTRACTION

SPACE IS RELATIVE

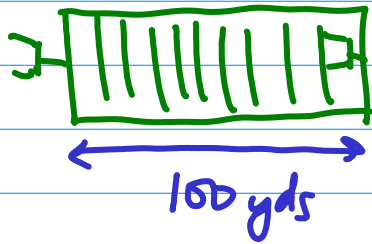
$$\Delta x' = \gamma \Delta x \quad [L_0 = \gamma L]$$

PROPER LENGTH

EXAMPLE:

HOW LONG IS FOOTBALL FIELD AS MEASURED BY ALIENS IN SPACECRAFT?

 $v = 0.98c$ $\Delta x' = 100 \text{ yds} \equiv$ IN REST FRAME OF FIELD



$\Delta x =$ REST FRAME OF ALIENS

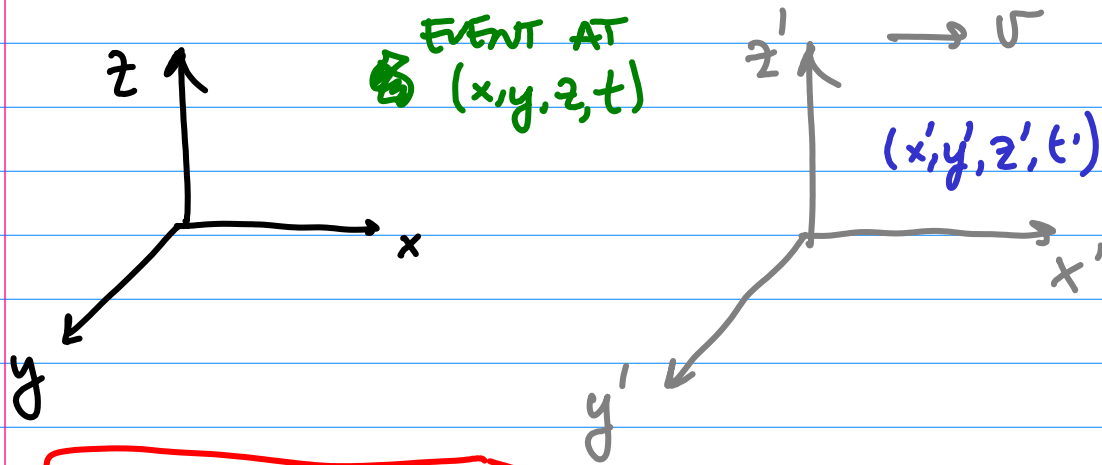
$$\gamma = \frac{1}{\sqrt{1 - \left(\frac{0.98c}{c}\right)^2}} \approx 5$$

$$\Delta x' = \gamma \Delta x \rightarrow \Delta x = \frac{\Delta x'}{\gamma} \rightarrow \Delta x = \frac{100}{5} = 20 \text{ yds}$$

100 yds

ALIENS SEE FOOTBALL FIELD AS 20 yds LONG!

LORENTZ TRANSFORMATION



HOW ARE (x, y, z, t)
RELATED TO (x', y', z', t') ?

VERY IMPORTANT IN
PHYSICS.

$$x = \gamma (x' + vt')$$

$$y = y'$$

$$z = z'$$

$$t = \gamma \left(t' + \frac{v x'}{c^2} \right)$$

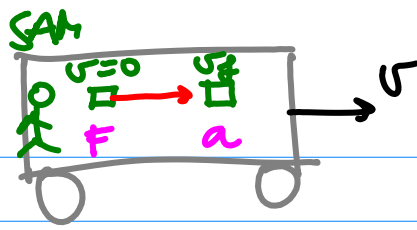
SPACE AND TIME GET ALL MIXED UP
WHEN WE RELATE OBSERVATIONS MADE FROM
DIFF. POINTS OF VIEW!

COMPARE TO GALILEO:

$$x = x' + vt \quad (\text{ASSUMES } t = t')$$

WE TALK ABOUT SPACETIME.

SPACE ITSELF IS CONTRACTED INSIDE THE SPACESHIP AS SEEN FROM OUTSIDE, IT'S NOT JUST THE SPACESCRAFT. AS SEEN FROM THE INSIDE ALL IS "NORMAL".



SAM INSIDE TRAIN THROWS BASEBALL WITH A FORCE F . THE BASEBALL ACCELERATES (FROM $v=0$ TO v_f).

ALICE

SAM WILL MEASURE A VALUE FOR THE ACC: a_S

BUT ALICE (AT REST ON THE GROUND) WILL MEASURE A SMALLER VALUE a_A BECAUSE:

$$a_A < a_S \quad \left\{ \begin{array}{l} \Delta x_A < \Delta x_S \\ \Delta t_A > \Delta t_S \end{array} \right. \quad \text{AND} \quad a \sim \frac{x}{t^2}$$

WHAT ABOUT THE FORCE? THE FORCE HAS TO BE THE SAME IF MEASURED BY ALICE OR SAM

NOW, IF FORCE ($F = ma$) IS THE SAME, THE MASS OF THE BASEBALL HAS TO COMPENSATE, BECAUSE $a_A < a_S$:

$$m_A > m_S$$

SO THE MASS IS ALSO RELATIVE TO THE OBSERVER: $m_A \sim \gamma m_S$

THIS EXPLAINS WHY YOU CANNOT ACCELERATE OBJECTS TO LIGHTSPEED!
YOU CANNOT ACCELERATE OBJECTS TO LIGHT SPEED. THEIR MASS BECOMES ∞

DERIVATION OF $E = mc^2$

$$\gamma = \frac{1}{\sqrt{1 - \left(\frac{v}{c}\right)^2}} \approx 1 + \frac{1}{2} \left(\frac{v}{c}\right)^2 \quad m_A = \gamma m_S$$

$$m_A \approx \left(1 + \frac{1}{2} \left(\frac{v}{c}\right)^2\right) m_S = m_S + \frac{1}{2} \frac{m_S v^2}{c^2} \rightarrow$$

$$m_A c^2 \approx m_S c^2 + \boxed{\frac{1}{2} m_S v^2} \rightarrow \text{KINETIC ENERGY}$$

MASS SEEN BY ALICE MASS SEEN BY SAM + KE

"proper mass"

$$E_A = m_A c^2$$

$$E_S = m_S c^2$$

$$E = mc^2$$

↑ MASS OF INERTIA

INERTIA IS THE PROPERTY THAT MAKES MOTION CONTINUE OR RESIST ACCELERATION ($F = ma$: MORE m MEANS MORE F ; IT'S HARDER TO ACCELERATE A TRUCK THAN A CAR WITH A GIVEN F) →

EINSTEIN SAYS THIS MASS IS A FORM OF ENERGY

MAGNETISM



MAGNETIC FORCE IS CAUSED BY A MAGNET ON ANOTHER MAGNET.

REPEL



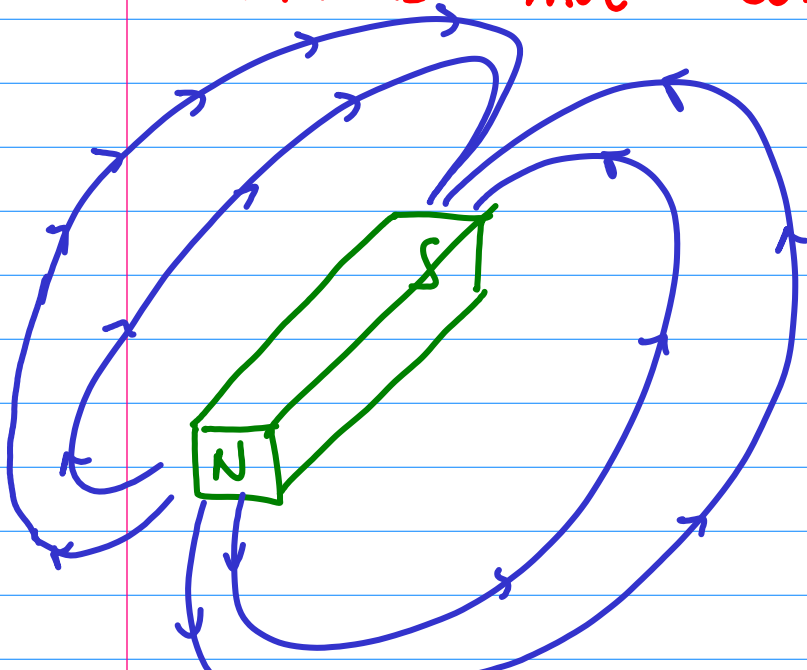
ATTRACT



WHY N&S? → EARTH HAS A MAGNETIC FIELD

MAGNETIC FORCE IS DIFFERENT FROM ELECTRIC FORCE:
THE TWO ENDS OF A MAGNET ARE NOT ELECTRICALLY CHARGED.

MAGNETS HAVE BOTH CHARGES (UNLIKE EL. OBJECTS)



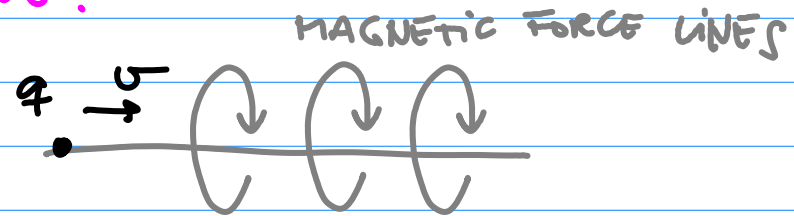
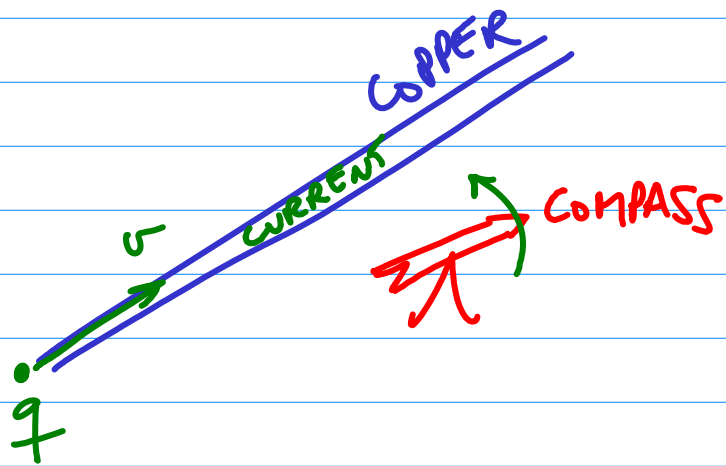
MAGNETIC FIELD (VERY SIMILAR TO ELECTRIC FIELD)

CONDITION IN SPACE THAT WOULD CAUSE A SMALL MAGNET TO BECOME ORIENTED

→ THINK COMPASS.

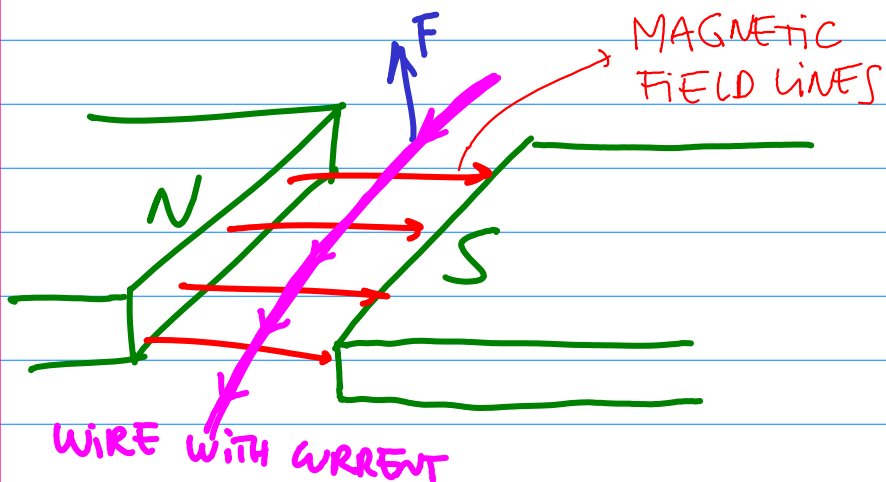
BUT ELECTRIC AND MAGNETIC FIELDS ARE RELATED.

ELECTRIC CURRENT (CHARGE MOVING) CAUSES COMPASS TO MOVE.



MOVING ELECTRIC CHARGE CREATES A MAGNETIC FIELD.

MAGNETIC FIELD EXERTS FORCE ON MOVING CHARGE.

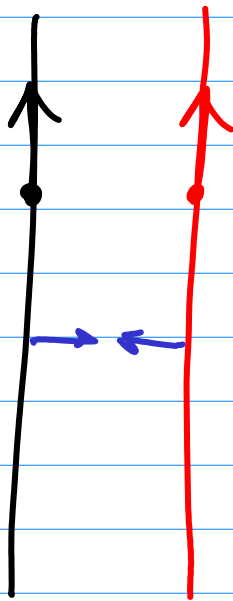


PUT CURRENT IN WIRE INSIDE MAG. FIELD → IT MOVES!

MAGNETIC FIELD EXERTS FORCE ON MOVING CHARGE

SOURCES OF MAGNETIC FIELDS:

- 1) ELECTRICAL CURRENT (MOVING CHARGES)
- 2) MAGNETIC DIPOLE.
- 3) CHANGING ELECTRIC FIELD



TWO CURRENTS
IN SAME DIRECTION
ATTRACT WIRES

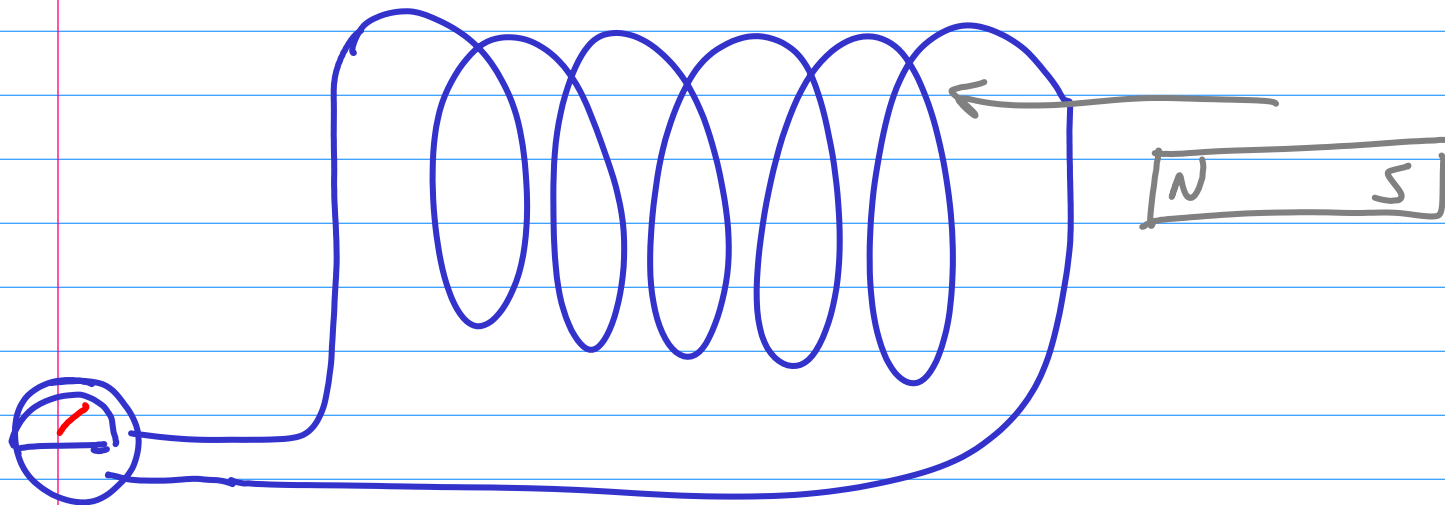


TWO CURRENTS
IN OPPOSITE DIRECTION
REPEL WIRES

SO MOVING ELECTRICITY CAN MAKE MAGNETISM.

AND VICEVERSA : CHANGE IN A MAGNETIC FIELD PRODUCES
A CURRENT

PRINCIPLE OF DYNAMO : ELECTRICAL POWER IS GENERATED
BY MOVING MAGNETS.



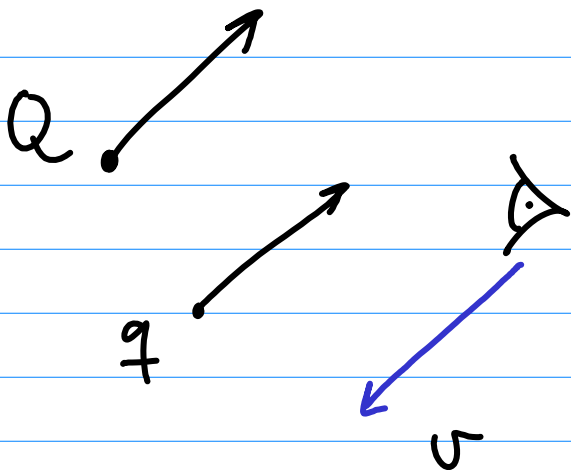
FINAL TWIST (LINK WITH RELATIVITY)

Q •



OBSERVER SEES FORCE BETWEEN STATIC CHARGES \Rightarrow ELECTRIC

q •



NOW IF THE OBSERVER IS MOVING BY, THE CHARGES WILL LOOK LIKE THEY ARE MOVING (CURRENTS) \rightarrow THE FORCE IS NOW SEEN TO BE MAGNETIC (IN PART)

WHAT WE PERCEIVE AS ELECTRIC OR MAGNETIC FIELD IS RELATIVE!