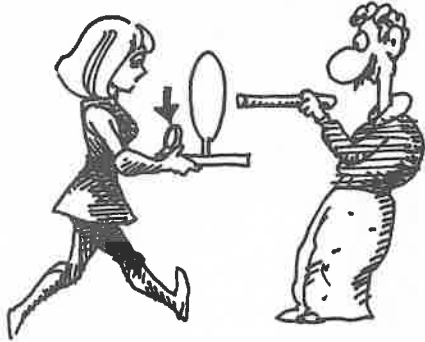


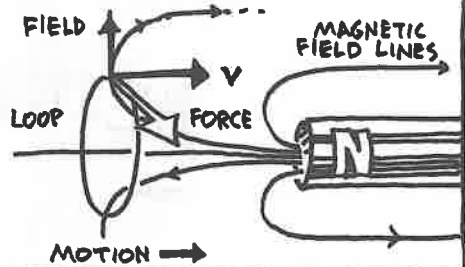
♦ CHAPTER 20 ♦  
**RELATIVITY**



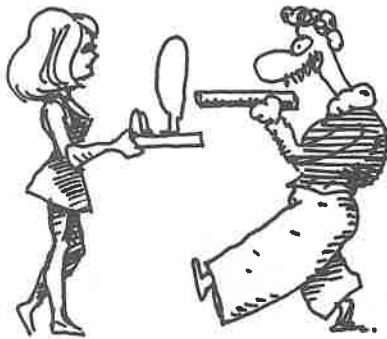
LET'S THINK THROUGH THE FARADAY EXPERIMENT AGAIN. I HOLD THE LOOP, RINGO THE MAGNET. WHEN I MOVE, SO DOES THE GALVANOMETER NEEDLE.



THIS IS EASILY UNDERSTOOD. THE WIRE HAS CHARGES. WHEN THEY MOVE, THEY FEEL THE SIDWAYS MAGNETIC FORCE WHICH DRIVES THEM AROUND THE LOOP.



BUT WHAT ABOUT WHEN RINGO MOVES AND I STAND STILL?



UM,  
AH, ER,  
EH,  
DUH...



WE KNOW THAT A CURRENT IS INDUCED, BUT BY WHAT? THE CHARGES ARE NOT INITIALLY MOVING, SO HOW CAN THE MAGNET AFFECT THEM?

IF ONLY MAGNETIC AND ELECTRIC FIELDS CAN MOVE CHARGES, THERE MUST HAVE BEEN AN ELECTRIC FIELD, TOO?

**BRAVO!**

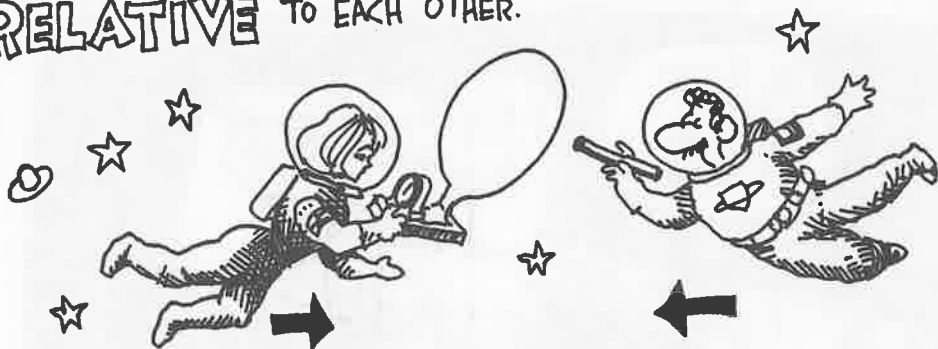


RINGO HAS DEDUCED WHAT IT TOOK EINSTEIN TO REALIZE. EINSTEIN SAW THAT, DEPENDING ON WHO WAS MOVING, THE CURRENT IS SOMETIMES DUE TO A MAGNETIC FIELD AND SOMETIMES TO AN ELECTRIC FIELD.



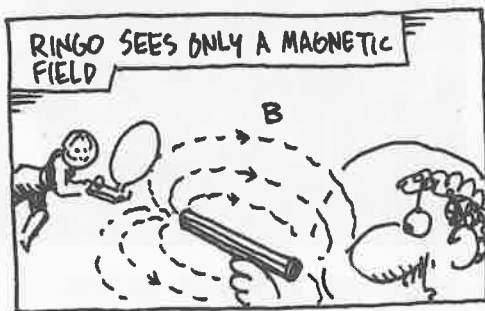
CHANGING MAGNETIC FIELDS CAUSE ELECTRIC FIELDS !!

NOW AGAIN... ONE MORE TIME... WE'LL DO THE FARADAY EXPERIMENT... BUT THIS TIME IN OUTER SPACE, SO WE CAN'T TELL WHO IS "REALLY" MOVING. WE KNOW ONLY THAT WE ARE MOVING **RELATIVE** TO EACH OTHER.



I THINK I AM STATIONARY, AND RINGO IS MOVING. I DETECT A MAGNETIC FIELD, BUT IT CAN'T MOVE THE CHARGES, SO THERE MUST BE AN ELECTRIC FIELD ALSO, CAUSED BY THE CHANGING MAGNETIC FIELD.

RINGO THINKS HE IS STATIONARY AND I AM MOVING. HE DETECTS ONLY A MAGNETIC FIELD AND MOVING CHARGES, WHICH ACCOUNT FOR THE INDUCED CURRENT.

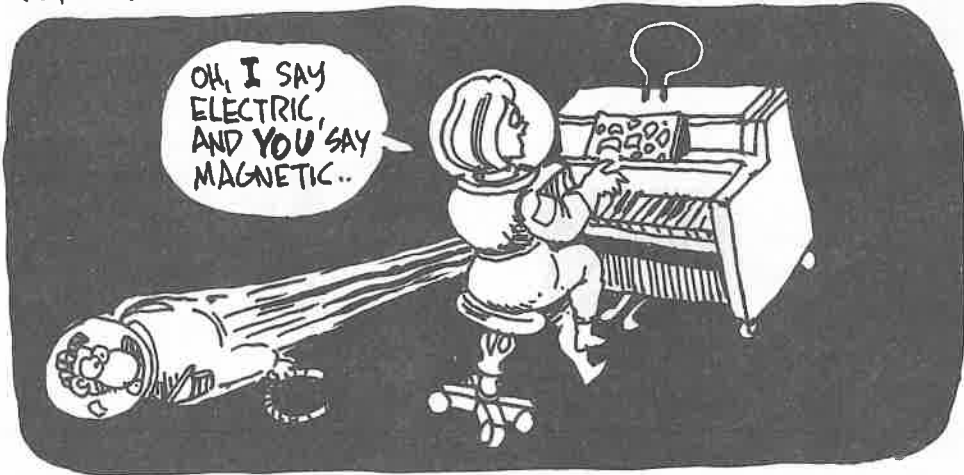


PHYSICISTS USE B FOR MAGNETIC FIELDS.

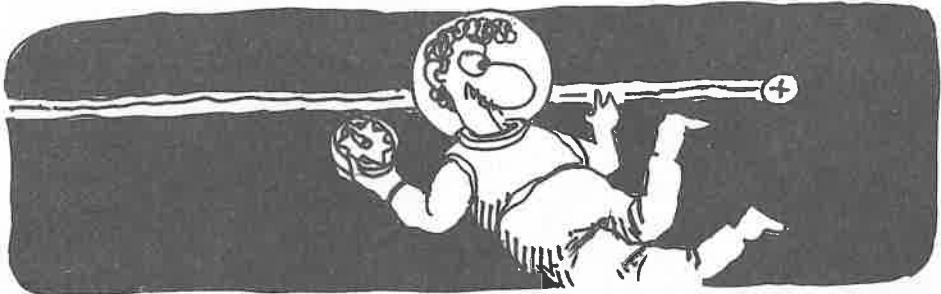
**RINGO AND I DISAGREE ON WHAT FIELDS ARE PRESENT!**



THIS IS THE HALLMARK OF RELATIVITY THEORY: TWO OBSERVERS, LIKE RINGO AND ME, IF THEY ARE MOVING WITH RESPECT TO EACH OTHER, WILL DISAGREE ON THEIR MEASUREMENTS OF KEY PHYSICAL QUANTITIES OF THE UNIVERSE!

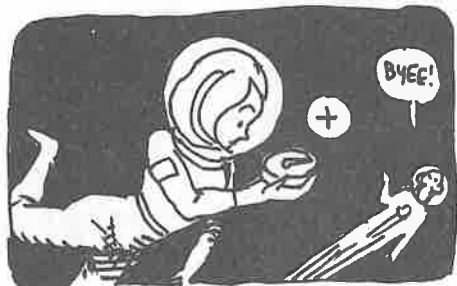
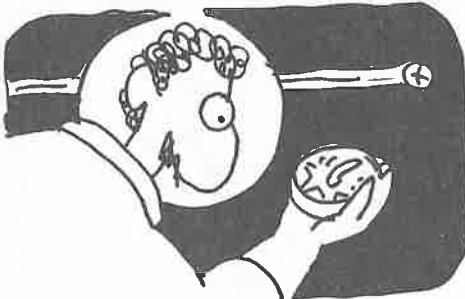


HERE'S AN EVEN SIMPLER ILLUSTRATION: A SINGLE CHARGE ZIPS THROUGH SPACE PAST RINGO:

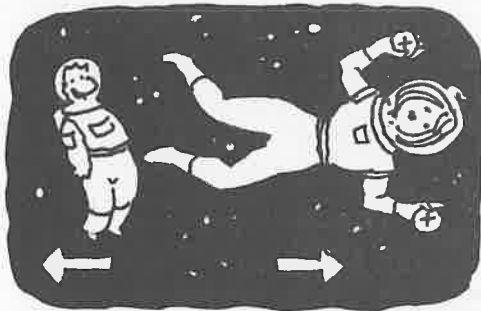


RINGO SEES A MOVING CHARGE — A CURRENT THAT GENERATES A MAGNETIC FIELD. THE NEEDLE OF RINGO'S COMPASS DEFLECTS!

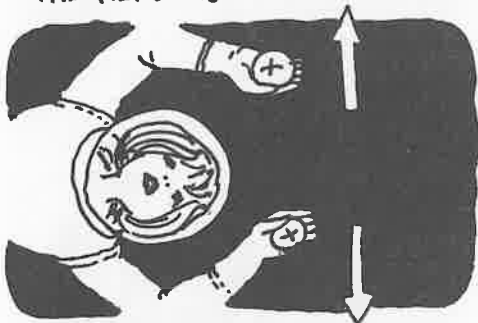
BUT IF I AM MOVING WITH THE CHARGE, I SEE IT AS STATIONARY. THERE IS NO MAGNETIC FIELD, AND MY COMPASS IS NOT AFFECTED!



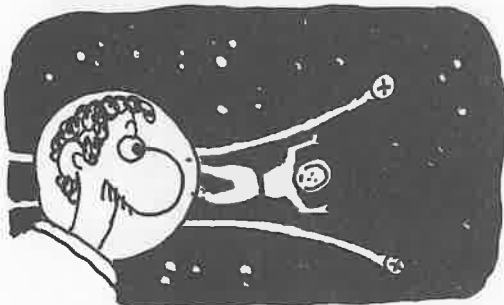
HERE'S THE FINAL DEMONSTRATION:  
WATCH CAREFULLY! I NOW CARRY  
**TWO** CHARGES SIDE BY SIDE  
PAST RINGO.



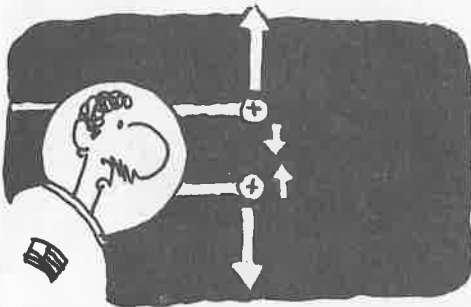
BUT TO ME, THE CHARGES ARE  
STATIONARY, SO I SEE ONLY  
THE REPULSION.



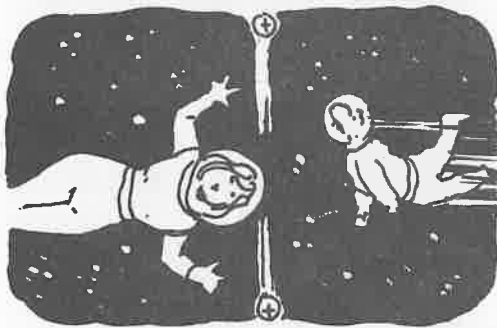
NOW THE STRANGE PART: RINGO  
SEES AN ATTRACTIVE MAGNETIC  
FORCE BETWEEN THE CHARGES,  
WHICH PARTLY OFFSETS THE  
REPULSIVE ELECTRIC FORCE —  
SO RINGO SEES THE CHARGES  
MOVE APART MORE SLOWLY  
THAN I DO!



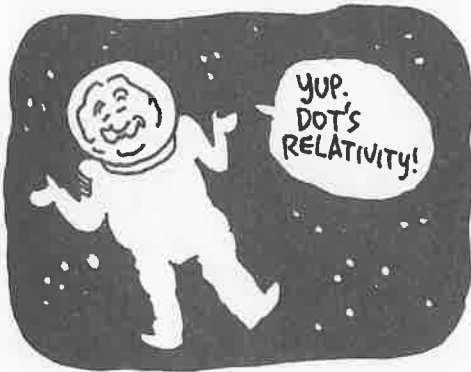
THEY REPEL EACH OTHER  
ELECTRICALLY — BUT RINGO  
SEES THEM MOVING: TWO  
PARALLEL CURRENTS, WHICH  
ATTRACT MAGNETICALLY!



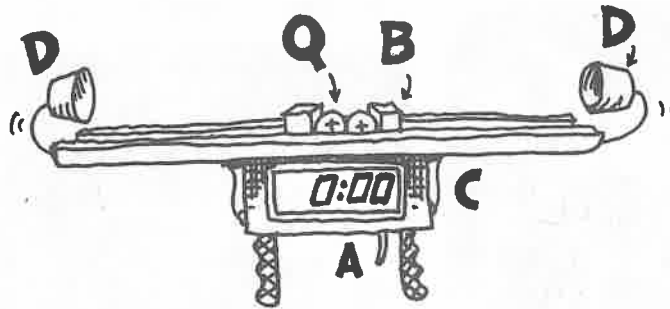
NOW I LET GO OF THE CHARGES.  
THEY FLY APART.



GOT THAT? RINGO, WHO IS  
MOVING WITH RESPECT TO ME,  
MEASURES THE CHARGES' OUTWARD  
VELOCITY TO BE **SLOWER**  
THAN I MEASURE IT!!

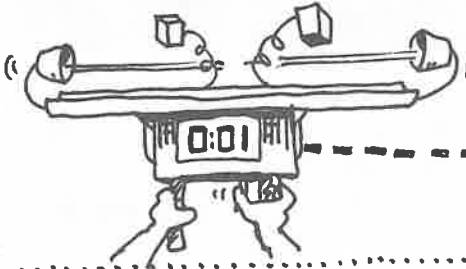


HERE IS AN APPARATUS FOR MEASURING HOW FAST THE CHARGES FLY APART.

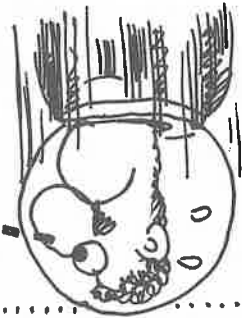


PULLING TRIGGER **A** RELEASES BLOCKS **B**, STARTING CLOCK **C** AND ALLOWING CHARGES **Q** TO FLY APART. CHARGES STRIKE CUPS **D**, STOPPING CLOCK **C**.

WITH THE THING AT REST IN FRONT OF ME, THE CHARGES FLY APART QUICKLY, SAY IN 0.01 SECONDS.



BUT, AS WE JUST SAW, THE SPEEDING RINGO SEES A MAGNETIC ATTRACTION THAT DELAYS THE CHARGES' FLYING APART.



RINGO MEASURES A **LONGER TIME** THAN I DO—SAY 0.02 SEC., FOR THE CHARGES TO FLY APART! HE ALSO NOTICES THAT MY CLOCK TICKS OFF ONLY 0.01 SEC. IN THE TIME IT TOOK HIS CLOCK TO REACH 0.02 SECONDS. CONCLUSION?

WHAT IS RINGO TO THINK?  
AS I SPEED BY, HE SEES MY  
CLOCK TICK OFF 0.01 SECONDS,  
WHILE HIS TICKS OFF TWICE AS  
MUCH. THERE IS ONLY ONE  
THING HE CAN CONCLUDE.  
RINGO DECIDES THAT—

MY RAPID MOTION  
CAUSED MY TIME TO  
SLOW DOWN!!

EITHER THAT, OR  
MY SPACESUIT  
HAS SPRUNG A  
LEAK...



THAT IS JUST ONE OF THE WEIRD CONCLUSIONS OF  
RELATIVITY THEORY. AND THERE ARE MORE. ACCORDING  
TO EINSTEIN, A STATIONARY OBSERVER SEES THE  
FOLLOWING EFFECTS ON RAPIDLY MOVING OBJECTS:

- \* TIME SLOWS DOWN
- \* LENGTHS DECREASE  
(IN THE DIRECTION OF MOTION)
- \* MASSES INCREASE

IN OTHER WORDS—

SOME OF OUR MOST  
CHERISHED IDEAS ABOUT  
SPACE AND TIME ARE  
RELATIVE, NOT ABSOLUTE!



WE SAW THAT THE EFFECT OF TIME DILATION IS DERIVED FROM BASIC, OBSERVED FACTS ABOUT ELECTRICITY AND MAGNETISM. THE PHYSICISTS OF THE LATE NINETEENTH CENTURY ALREADY KNEW THAT THEIR E.M. EQUATIONS DID NOT AGREE WITH NEWTON'S MECHANICS, AND MOST OF THEM THOUGHT THE ANSWER WAS TO MODIFY THE EQUATIONS IN SOME WAY...

PERHAPS USING AN ERASER...



... BUT ONLY EINSTEIN SAW THAT THE ANSWER WAS TO REVISE THE VERY CONCEPTS OF SPACE AND TIME...

KEY!

