[Space Journal](https://louis.uah.edu/space-journal)

Volume 1 | Number 5 Article 7

3-1-1959

Reality, Relativity, and Common Sense

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James Patrick Gardner was born in Winnipeg, Manitoba, Canada, and grew up in Granite City, Illinois. He was educated at Parks College of Aeronautical Technology of St. Louis University and at the University of Alabama. His field was aeronautical engineering. Since leaving college, he has been employed by the Missile Design Section, Future Projects Design Branch of the Structures and Mechanics Laboratory at the Army Ballistic Missile Agency.

Common sense is that layer of prejudices laid down in the mind prior to the age of eighteen.
—Albert Einstein

No individual was more aware of the inherent difficulties associated with the acceptance of a new idea than was the creator of the theory of relativity. The more basic the idea, the greater the difficulty. Probably the foremost cause of this difficulty is the tendency to confuse reality with human experience. In early childhood we begin to form positive ideas in relation to space, time and motion. Anything that challenges these fixed notions is considered a violation of common sense and therefore unreal.

Fortunately there is a way out of the dilemma if one is willing to take the necessary steps. The first step is the recognition of man's place in the world as a casual observer with rather limited equipment. The second step is the acceptance of the fact that man does not have the capacity to conceive reality in the ultimate sense. With these things in mind we are ready to re-examine our ideas of space, time and motion.

We think of everything that moves as having some sort of conveyor. A train moves along a track with some velocity relative to the track. A ship moves through the water with some velocity relative to the water. Sound waves travel through the air with some velocity relative to the air. When we say something has a velocity, we usually mean relative velocity. The importance of the relative velocity concept may be illustrated by the following example.

Suppose we have two rifles, each of which fires a bullet with a muzzle velocity of 1,000 feet per second. To simplify the experiment we will assume that sound waves travel at exactly 1,000 feet per second. The two rifles are mounted on a stationary bench and are equipped with a mechanism which will allow us to fire them simultaneously, and a metal drum is placed 4,000 feet down range to serve as a target. When the guns are fired the bullets will travel down range, strike the drum, and the impact sound will travel back to the starting point. In this case we will hear both impacts at exactly the same time, or eight seconds after we fire, since the time required for the bullets to travel to the target will be

exactly equal to the time required for the sound to travel back to the starting point.

Now let us repeat the experiment in a slightly different manner. We will mount one rifle exactly as before, but we will mount the other on an automobile which is moving toward the target with a velocity of 115 feet per second. Both rifles are fired the instant the car passes the stationary bench and again we wait for the impact sound waves to return. This time the sound waves will return approximately ½ second apart. Although both bullets left the rifles with the same muzzle velocity, they each had a different velocity relative to the ground. The bullet fired from the moving rifle had a higher relative velocity (muzzle velocity + car velocity) therefore it must arrive at the target first.

Now let us try another similar experiment. This time we will replace the rifle on the car with a horn. We will let the car travel in the same direction and with the same speed as before, and we will assume that the sound from the horn will bounce back from the target like an echo. As before, the instant the car passes the stationary bench the horn is sounded and the bullet is fired. In contrast to the previous experiment both sounds will return to the starting point simultaneously. The reason for the different result is as follows: A bullet moves independently of any medium with whatever velocity it is given unless it is acted upon by some external force. A sound wave is dependent upon some medium of transportation. In this case the sound wave is propagated by the air which may be con-

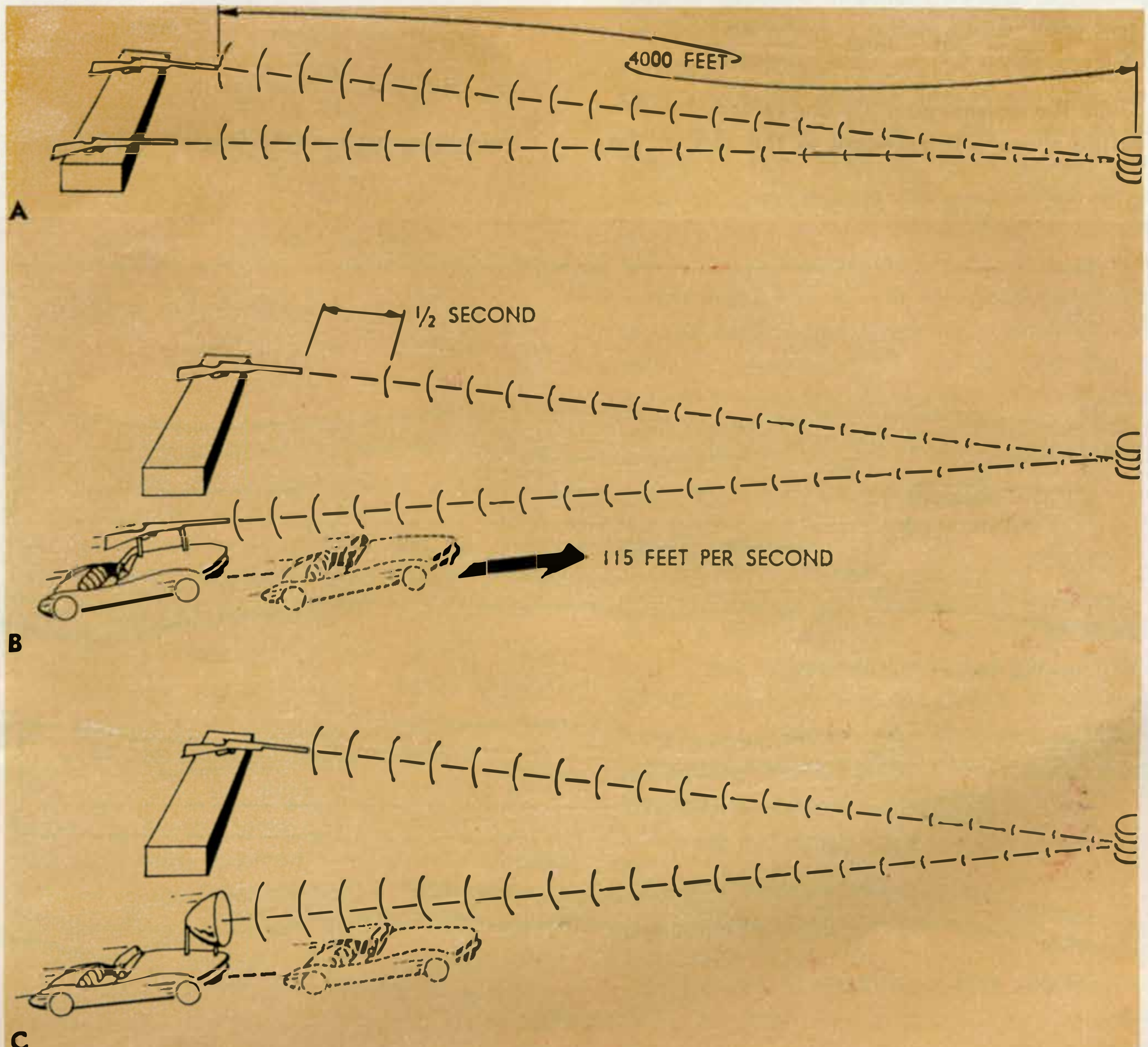


FIGURE 1

sidered at rest relative to the earth. So we find that the sound wave moves with a constant velocity relative to the air and is independent of the velocity of the source. This is an important point which will be referred to later.

We are now ready to perform an hypothetical experiment which will be helpful in explaining the Michelson experiment which opened the door to the theory of relativity.

The experiment is shown in Fig. 1, and proceeds as follows. Points A and B are located on a river 100 miles apart. We will assume that the river is flowing from A to B with a velocity of 10 miles per hour. We wish to travel by boat from A to B and back to A, and would like to calculate the time required for the trip. Our boat has a speed in still water of 20 miles per hour.

The basic equation of motion is:

$$t = \frac{d}{v} \quad \text{or} \quad \text{time} = \frac{\text{distance}}{\text{velocity}}$$

On the downstream trip our velocity relative to the shore will be equal to the sum of the velocity of the boat in still water and the velocity of the current.

$$v_{(\text{downstream})} = 20 + 10 = 30 \text{ mph}$$

$$\text{therefore: } t_{(A \text{ to } B)} = \frac{100}{30} = 3.33 \text{ hr}$$

On the upstream trip our velocity relative to the shore will be equal to the difference between the velocity of the boat in still water and the velocity of the current.

$$v_{(\text{upstream})} = 20 - 10 = 10 \text{ mph}$$

$$\text{Therefore: } t_{(B \text{ to } A)} = 100 = 10 \text{ hrs.}$$

$$t_{(B \text{ to } A)} = \frac{100}{10} = 10 \text{ hrs.}$$

The total time for the trip is:

$$10 + 3.33 = 13.33 \text{ hrs.}$$

Now let us stop the current and repeat the experiment.

$$v_{(\text{downstream or upstream})} = 20 \text{ mph}$$

$$\text{Total time} = \frac{200}{20} = 10 \text{ hrs.}$$

We have a time difference of 3.33 hrs.

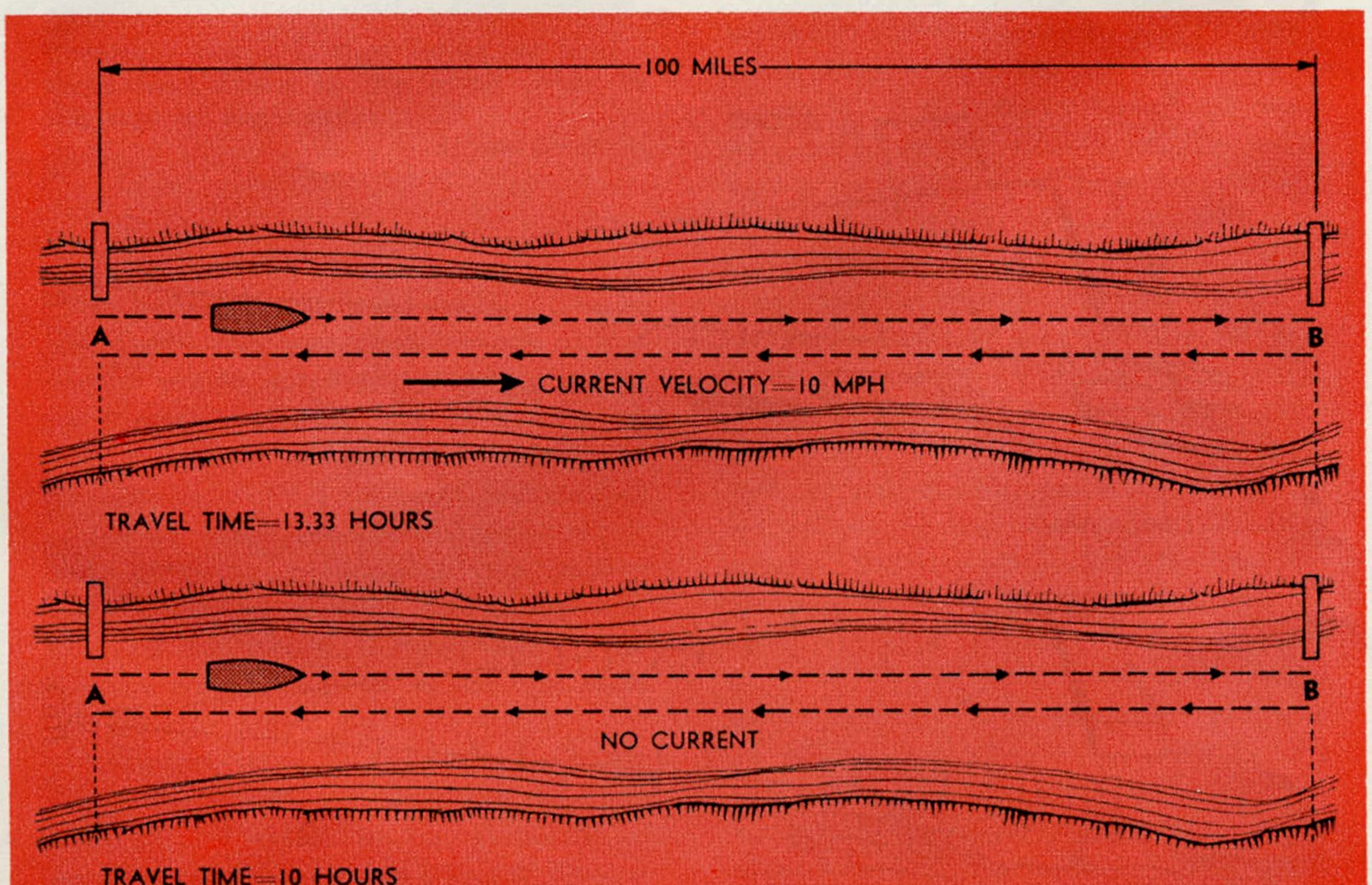


FIGURE 2

This time difference will vary proportionally to a factor involving the ratio of the current and boat velocities. By the use of some simple algebra we can derive the equation for the time shift and time shift factor.

t_1 = time downstream
t_2 = time upstream
d = distance A to B
v = boat speed in still water
c = current speed
t_t = total time for trip

$$t_1 = \frac{d}{v+c} \; ; \; t_2 = \frac{d}{v-c}$$

$$t_t = \frac{d}{v+c} + \frac{d}{v-c}$$

$$= \frac{d(v-c)+d(v+c)}{v^2-c^2}$$

$$= \frac{dv-dc+dv+dc}{v^2-c^2}$$

$$t_t = \frac{2dv}{v^2-c^2} \text{ (with current) };$$

$$t_t = \frac{2d}{v} \text{ (without current)}$$

$$\text{time shift factor} = \frac{1}{1-\left(\frac{c^2}{v^2}\right)}$$

It is clearly seen that a time shift is introduced when an experiment is performed which involves motion in opposite directions through a medium which is in motion. With this in mind we are ready to review the famous Michelson experiment.

In the last half of the 19th Century there was much speculation in regard to the method of propagation of electro-magnetic waves, or more specifically light waves. As was mentioned before, we think of everything that moves as having some sort of conveyor and it is reasonably assumed that light was no exception to the rule. It can be easily proved by experiment that light does not use air as a conveying medium. If air is not the conveyor, what is? This is essentially the problem which confronted the 19th Century physicists. They found it difficult to imagine light waves propagating through empty space, so they decided that space must be filled with some mysterious substance. The mysterious substance was called ether and was endowed with some unique characteristics. It could propagate a wave, but it could offer no resistance to motion.

The next step in the ether hypothesis was obvious. If space is filled with this ether which propagates lightwaves, and it is at rest, then it should be a simple matter to find our (the Earth's) velocity through this medium. This is what Michelson set out to do.

Since light must move through the ether much as sound moves through the air, we know from our experiment with the rifle and the horn that the wave velocity is independent of the velocity of the source. We also know from the boat experiment that velocities measured in opposite directions through a moving medium will result in a time shift. With these assumptions Michelson set out to measure the Earth's velocity through the ether. His apparatus is shown in Fig. 2, and operates as follows. Two arms of equal length are mounted perpendicular to each other on a table which may be rotated about a vertical axis. A light source is placed at S, a half mirror at the axis A, and an optical instrument is mounted at the observation point O. A mirror is placed at the end of each arm at B and C. The optical instrument at O is called an interferometer which is an instrument which can be used to measure the slightest shift in the fringe pattern resulting from two interfering light beams. For instance, if a light beam is split into two beams, allowed to travel a given distance, and then re-united, an interference pattern will be observed. If the velocity and therefore the travel time of one of the beams is slightly altered, a different interference pattern will be observed. This change is referred to as a shift in the interference fringes.

In the Michelson experiment, if we consider the Earth at rest and the ether flowing by, we have a situation similar to that in the boat experiment. We are substituting a light beam for the boat and a flowing ether for the river. The light beam starts at S and proceeds to A where it is split into two beams, one of

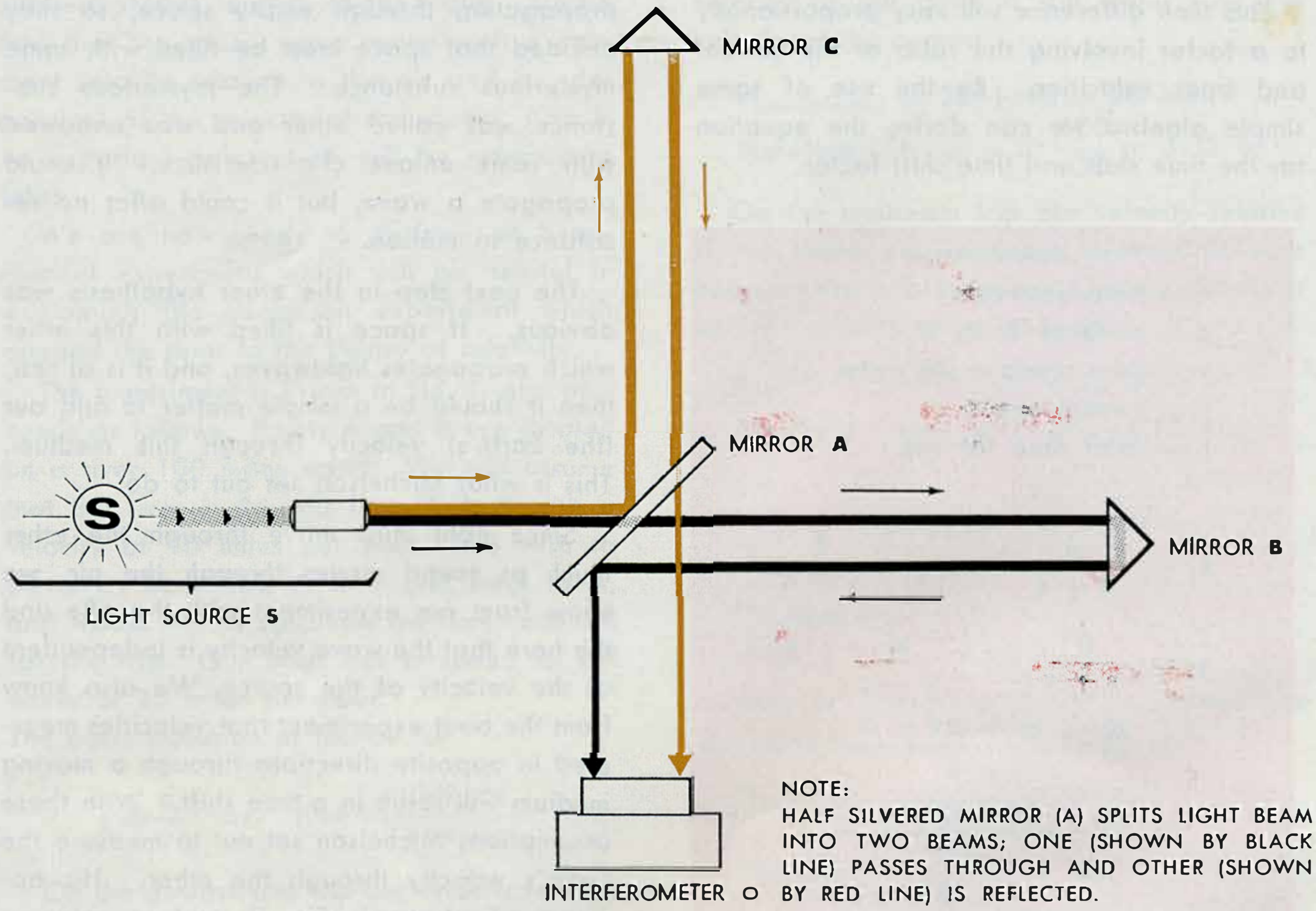


FIGURE 3

which passes through A and proceeds to B, and the other is deflected 90 degrees and proceeds to C. The two beams are reflected at B and C, re-united at A, and proceed to O where they enter the interferometer. If the entire apparatus is rotated 90 degrees so that the light beam from A to B is first moving parallel to the motion of the ether and then perpendicular to the motion of the ether, we would expect to find a time shift as we found in the boat experiment. In this case motion perpendicular to the ether stream is comparable to motion with no current in the boat experiment.

Michelson performed his experiment with extreme accuracy, and several variations were introduced to eliminate the possibility of error due to external influence. To his amazement, in each case no appreciable shift in the interference fringes was observed, and no time shift could be recorded.

The results of this experiment had a greater effect on physical science than perhaps any in history, for they cast a shadow of doubt upon existing fundamental concepts which were the very foundation of modern physics. Many leading physicists of that day took up the challenge and attempted to explain the results of the experiment by slightly modifying or extending present views, but this path usually led to further complications and contradictions. Of these attempts probably the most brilliant was made by H. A. Lorentz in the field of electro-magnetics. He showed that the negative result of the interference experiment could be explained by applying a theory previously advanced by Fitzgerald which stated that the physical dimensions of a body are altered if the body is in motion. This change in dimension is known as Fitzgerald contraction, and is described in the following manner. If a body is in motion its length measured along the line of motion will be decreased by an amount proportional to the ratio of the velocity of the body and the velocity of light. As the velocity of the body approaches the velocity of light it will gradually become shorter until at the velocity

Published by LOUIS, 1957

of light its length will become zero. If this theory is applied to the Michelson experiment, we see that the arm of the apparatus which is parallel to the Earth's motion will be shorter. When the apparatus is rotated 90 degrees, the other arm will be shorter. The equations of Lorentz show that this change of length due to velocity is the right amount to cancel out the effect of the time shift and cause the observed negative result. Lorentz believed this shrinking to be a physical reality resulting from magnetic field interactions within the atomic structure of the material. He compared this effect to that which can be observed in certain electrical phenomena involving charged bodies moving in electric fields.

The electro-magnetic theory necessitated the introduction of new hypothesis and heavy restrictions, and therefore could not be fully accepted as an explanation of the experimental results.

One other possible explanation was brought out. This was the theory that the ether moved with the Earth thereby eliminating the ether stream. This possibility was disproved by experiment.

As one attempt after another failed, the scientific world wondered what to do with these experimental results which seemed to violate every rule of science and common sense ever laid down by man.

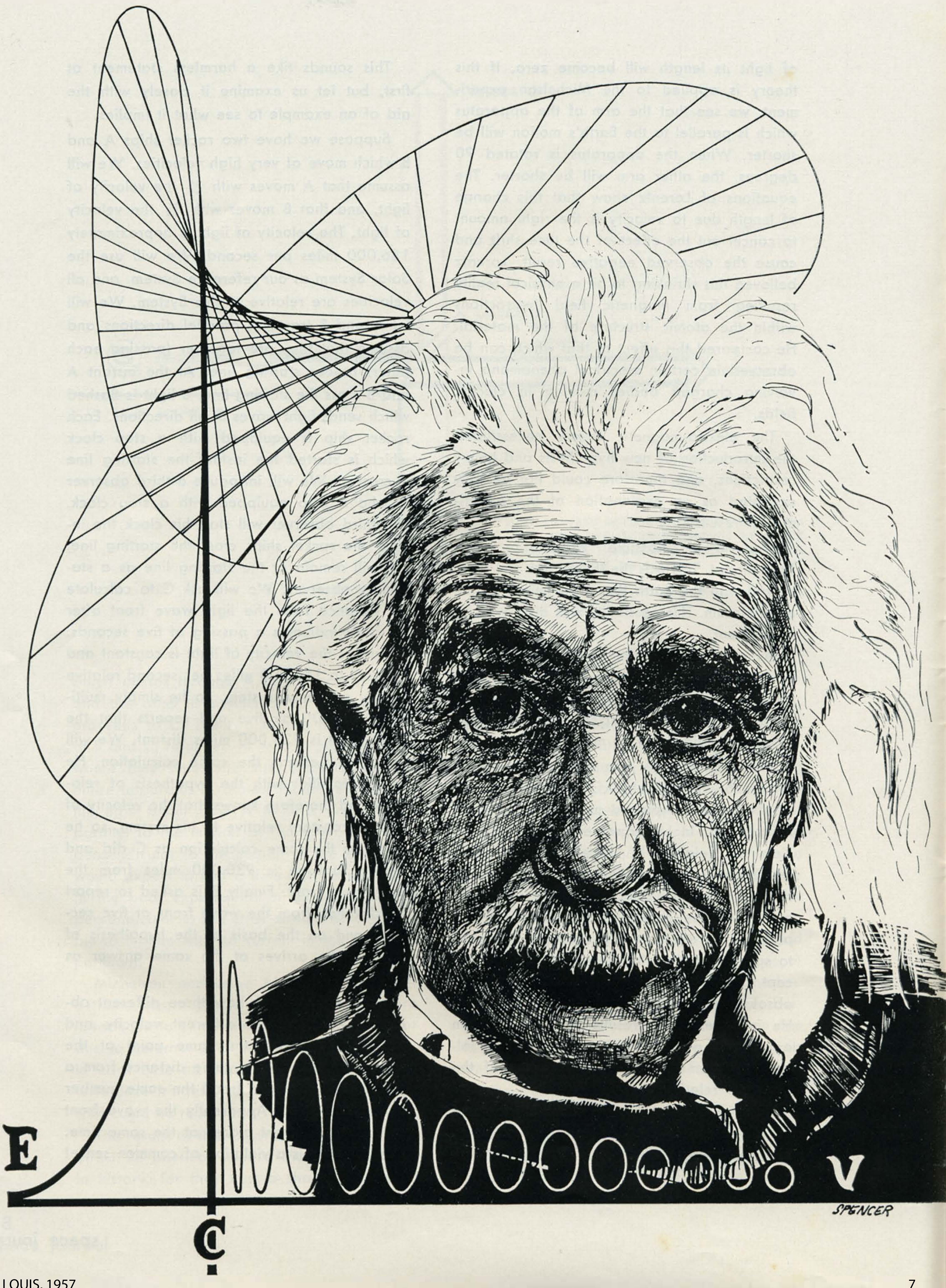
The answer came in a short paper written by a 26-year-old physicist, Albert Einstein, who was then employed as a patent clerk in Switzerland. In his paper entitled "The Principle of Relativity", Einstein introduced a whole new concept of the physical world. He showed that the difficulties encountered in explaining the results of the Michelson experiment were due to false concepts in regard to space and time. He showed that the concept of space and time as individual and absolute entities was completely meaningless. He interpreted the results of the Michelson experiment as indisputable proof of the following statement which is the basis of the theory of relativity.

"The velocity of light in vacuo is the same in all reference systems moving uniformly, relative to each other."

This sounds like a harmless statement at first, but let us examine it closely with the aid of an example to see what it implies.

Suppose we have two rocket ships A and B which move at very high velocities. We will assume that A moves with ¼ the velocity of light, and that B moves with ½ the velocity of light. The velocity of light is approximately 186,000 miles per second. We will use the Solar System as our reference System, and all velocities are relative to this System. We will let A and B travel in parallel directions and assume that they are together (passing each other) at our starting line. At the instant A and B cross the starting line, a light is flashed which sends light waves in all directions. Each rocket ship is equipped with a stop clock which is started the instant the starting line is crossed. We will introduce a third observer C who is also equipped with a stop clock. The third observer will start his clock the instant the rocket ships cross the starting line, but will remain at the starting line as a stationary observer. We will ask C to calculate his distance from the light wave front after his clock indicates a passing of five seconds. He knows the velocity of light is constant and is equal to 186,000 miles per second relative to any reference system, so he simply multiplies 186,000 by five and reports that the wave front is 930,000 miles distant. We will ask A to perform the same calculation. He is also familiar with the hypothesis of relativity and therefore knows that the velocity of light is constant relative to his system, so he performs the same calculation as C did and reports that he is 930,000 miles from the light wave front. Finally B is asked to report his distance from the wave front at five seconds and on the basis of the hypothesis of relativity he arrives at the same answer as did C and A.

Now we must ask how three different observers each with a different velocity and each starting from the same point at the same time can be the same distance from a point (the light wave front) the same number of seconds later? Apparently the wave front is in three different places at the same time. This certainly is a violation of common sense!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In search of an explanation, we are confronted with a choice. We either must accept this result and look deeper for the cause, or we can forget the hypothesis of relativity and go back to the old method of adding and subtracting velocities. The Michelson experiment has shown the disastrous results of the old method, so we will take the first choice.

We must accept the fact that the wave front is where the observers say it is since their calculations are based on the hypothesis of relativity, but we cannot accept the possibility of the wave front occupying three different positions at the same time. The answer to the puzzle lies in our concept of time which we have considered absolute, or the same, for all observers regardless of their state of motion. We are actually forced to give up the concept of absolute time and accept the fact that it is impossible to compare time measurements directly between systems which are moving relative to each other. In our rocket ship experiment we can consider the time measured by the stationary observer C as our basic time for comparison. I do not wish to give the impression that there is anything special or absolute about the time measured by C. We only use this time as a basis for comparison because we considered C to be at rest in our reference system.

Since A is moving with some velocity relative to C, we must assume that his clock runs somewhat slower than the clock at C. Since B is moving at a higher velocity than A relative to C, his clock must run slower than A's clock. So we have three observers performing an experiment based on time, and each observer has a clock which is running at a different rate. No wonder our results were ridiculous!

Actually the wave front was much closer to A and B than it was to C when C's clock showed a passage of five seconds since they were traveling at high velocities in the direction of the light wave. The clocks carried by A and B were running slower, so when they finally recorded a passage of 5 seconds the wave front was the same distance from them as it had been from C.

In the theory of relativity, time by itself has no meaning, and space by itself has no meaning. It is only the combination of the two, or the defined point at the defined time which can really describe an event. Because of this interlocking of space and time, comparisons of length, distance, and velocity cannot be made between systems which are moving relative to each other unless the laws of transformation, which were first derived by Lorentz, are applied. These laws enable us to calculate the length of a body which is in motion relative to a given reference system. These laws are in the form of equations, and are stated as follows:

$$L' = L_0 \sqrt{1 - \frac{v^2}{c^2}} \quad ; \quad t' = t_0 \sqrt{1 - \frac{v^2}{c^2}}$$

Where:

L_0 = Length of a body at rest relative to a system.

L' = Length of a body in motion relative to a system.

t' = Time lapse of a clock in motion relative to a system.

t_0 = Time lapse of a clock at rest relative to a system.

v = Velocity of a body or clock relative to a system.

c = Velocity of light in any system.

These laws which are based on the constant velocity of light as given in the hypothesis of relativity completely explain the results of the Michelson experiment. If these same equations are applied in the boat experiment, we see that the change of length and time will exactly compensate the effect of the moving current. As stated before, in this case the boat represents the light beam, and the current represents the relative velocity. If the contraction and time change equations are properly combined they result in the time shift factor which was derived in the boat experiment.

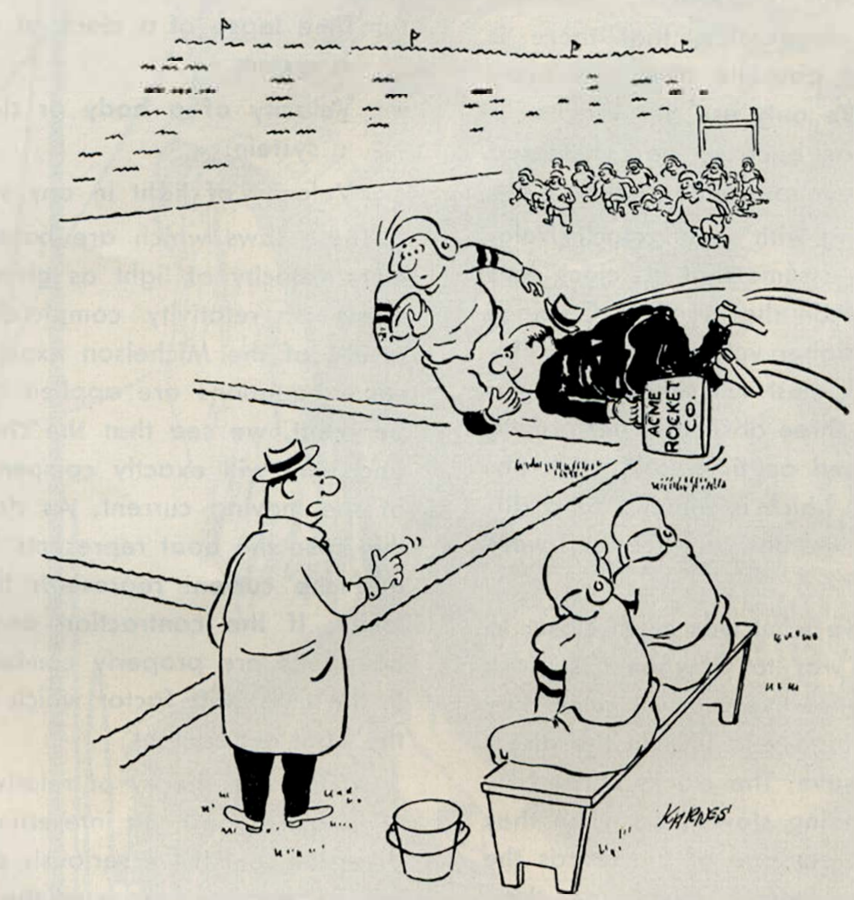
At first the theory of relativity strikes most of us as, at best, an interesting philosophical diversion, but if we seriously ponder the subject we become aware of the significance of it's implications. In certain areas these implications seem to border on the supernatural. A good example of this is the slowing down

of time. Time, which is usually taken quite for granted, is actually somewhat of an abstraction in itself. When we think of time we usually think of a clock which is a periodic mechanical device which is calibrated to the rotation of our planet. If the rotational speed of our planet should suddenly increase or decrease, we would be forced to throw away all of our clocks.

So we see from the preceding discussion that time is meaningless unless it is associated or interlocked with physical events. The theory of relativity shows that the velocity of light is the upper limit or maximum velocity with which any physical body can move since to exceed this velocity we would find ourselves dealing with negative time or clocks running backwards.

An interesting result of this time dilatation is illustrated by the classic example of the Space traveler who leaves the Earth, flies about in Space for a few weeks with a velocity near that of light, and then returns to Earth to discover that several hundred years have elapsed. During his voyage his clock was almost stopped due to his high velocity relative to the Earth. He was of course completely unaware of this slowing down of time since all of his physical and mental processes were slowed down in the same manner.

Examination of the transformation equations shows clearly that relativistic effects do not come into play unless velocities near that of light are attained. We do not experience such velocities in everyday life, but as man moved into Space such velocities must be obtained if we wish to travel to another solar system within an individual's life span.



"Doggone it! Are they THAT hard up for Space Cadets?"

EDITOR'S NOTE: Recent investigations in astronautics have resulted in a new concept which may help relate the macrocosm to the microcosm, with the tie between them being *time*.

Briefly the idea is this: in basic physics we learn that the total energy of a mass is equal to the sum of its potential energy and its kinetic energy; or, in formula $\Sigma E = E_p + E_k$. But this is true only in a state of equilibrium; for example, a satellite in orbit around Earth or one of its sister planets, the swinging pendulum of a clock, etc. But if we consider the total energy required to bring a mass into a new state of equilibrium, then this formula no longer holds true—according to the new concept of "displacement energy" or ΔE.

To illustrate, let us analyze the football quarterback who makes a "jump" pass. Before he leaps into the air, his body possesses potential energy. As he springs into the air, two things happen: time elapses and his potential energy is converted to kinetic energy. However, during the time he is moving upward, energy must also be expended to lift his energy needed to throw the ball. This, then, is the "displacement energy," and it must be accounted for in any computation of the *total* energy needed for such a pass. Thus the formula must now become: $\Sigma E = E_p + E_k + \Delta E$. The same holds true for launching a satellite into orbit around Earth, lunar probes, and interplanetary Space flights.

Within the microcosm the concept of ΔE may also have far reaching consequences. It may even impinge upon a unified concept of universal occurrences. In this respect, ΔE seems comparable to Maxwell's "displacement current," which explains, among other things, the action of a capacitor (condenser) in an electric circuit. Indeed, there is a striking similarity between the two concepts in that both involve the consideration of *time* as the essential determinant.

The discovery and formulation of this important concept was made by Helmut Hoeppner, formerly of the Army Ballistic Missile Agency and now Senior Scientist for Astronautics at the Chrysler Corporation, and his co-worker at ABMA B. Spencer Isbell, also editor of SPACE Journal. Both Hoeppner and Isbell credit Professor Hermann Oberth with assistance and encouragement during their work on ΔE.

—Mitchell R. Sharpe