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1. The Problem

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1. The Problem

Abstract

Newton's laws of motion and their associated definitions encountered their first difficulty near the middle of the nineteenth century.

Newton had designed his theory to describe the behavior of matter in space and time by inventing a relationship between the force on a body and the resulting change in motion of the body. Such a description of nature came to be called mechanical, and a large part of physicists' efforts were directed toward reducing all aspects of physics to mechanics. These efforts were rewarded magnificently in the fields of heat, electricity, and sound, in addition to astronomy and other more obviously mechanical areas. But they were far short of success in describing the various phenomena of light. [*excerpt*]

Keywords

Contemporary Civilization, Physics, Quantum Mechanics, Light Waves, Wave Vibrations, Transverse Waves, Ether

Disciplines

History of Science, Technology, and Medicine | Physics

Comments

This is a part of Section XX: Meaning in the Physical Sciences. The Contemporary Civilization page lists all additional sections of *Ideas and Institutions of Western Man,* as well as the Table of Contents for both volumes.

More About Contemporary Civilization:

From 1947 through 1969, all first-year Gettysburg College students took a two-semester course called Contemporary Civilization. The course was developed at President Henry W.A. Hanson's request with the goal of "introducing the student to the backgrounds of contemporary social problems through the major concepts, ideals, hopes and motivations of western culture since the Middle Ages."

Gettysburg College professors from the history, philosophy, and religion departments developed a textbook for the course. The first edition, published in 1955, was called *An Introduction to Contemporary Civilization and Its Problems*. A second edition, retitled *Ideas and Institutions of Western Man*, was published in 1958 and 1960. It is this second edition that we include here. The copy we digitized is from the Gary T. Hawbaker '66 Collection and the marginalia are his.

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1. The Problem

Newton's laws of motion and their associated definitions (see Chapter VIII, pp. 53-65) encountered their first difficulty near the middle of the nineteenth century.

Newton had designed his theory to describe the behavior of matter in space and time by inventing a relationship between the force on a body and the resulting change in motion of the body. Such a description of nature came to be called mechanical, and a large part of physicists' efforts were directed toward reducing all aspects of physics to mechanics. These efforts were rewarded magnificently in the fields of heat, electricity, and sound, in addition to astronomy and other more obviously mechanical areas. But they were far short of success in describing the various phenomena of light.

Many experiments had led to the conclusion that light was a wave of some sort, with the wave's vibrations being perpendicular to the direction of travel of the wave. Such waves are called transverse waves. Water waves are a familiar example of transverse waves, the vibrational motion of the water taking place up and down in the vertical direction, while the wave itself moves horizontally. A plucked string also carries transverse waves.

For those imbued with the mechanical viewpoint, it was an obvious next step to assume the existence of a medium to transmit the light waves. This medium was called the ether, and it was imagined to permeate all the universe. Light was thought to travel through the ether much as vibrations travel through a bowl of jelly. But any such ether would need unusual and at times contradictory properties. Its elastic properties would be extreme indeed. For example, green light has a frequency of about 6×10^{14} (6 followed by fourteen zeroes) vibrations per second, so that the ether would need to be able to sustain that many vibrations each second. No material known could do any such thing.

Further, the ether must offer no resistance to the motion of material bodies -- say, as air offers to a thrown ball. Surely any such resistance to the motion of the planets would have been observable, but none was noticed. Thus the ether, able to sustain exceedingly high frequencies, must be rarified indeed, at least when compared to the earth's atmosphere.

Also, it was known that light has different velocities as it travels through different materials such as glass and water.

Some observable data that didn't fit. caused men to start hunting.

This was perplexing. If there was no interaction between matter and the ether, and if the ether was to sustain light's vibration, it was difficult to understand why the wave should have different velocities in different materials.

At this stage two Englishmen, Michael Faraday (1791-1867), an experimental physicist, and Clerk Maxwell (1831-1879), a theoretical physicist, were able to give a more complete description of light. Maxwell invented some equations to account for the results of Faraday's experiments. These equations, originally cast to describe electric and magnetic phenomena, suggested that light was an electro-magnetic wave. Further, they seemed to indicate that all electro-magnetic waves, regardless of frequency, traveled with the same velocity in a vacuum.

A simple example may illustrate what Maxwell's equations predicted. As we know, two like charges repel each other. Suppose two like charges were suspended by fine threads separated by some distance, as shown in Figure I. Each would experience a force due to the other's presence. Or in Faraday's and Maxwell's language, each would be in the field of the other.

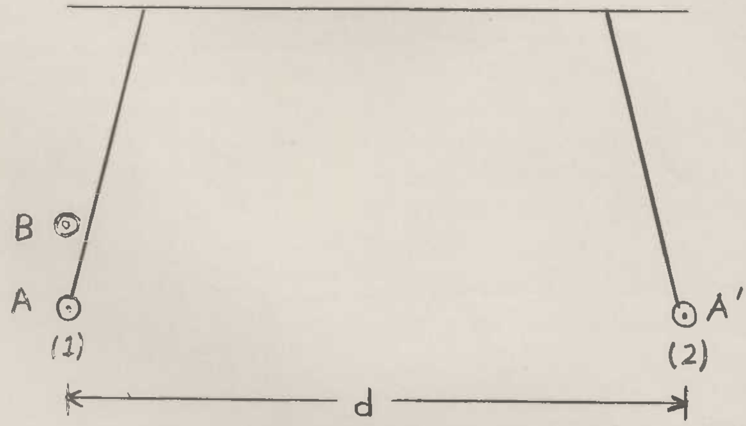

Figure I. An Experiment with Electromagnetic Forces.

Originally the charges are at A and A'. Now suppose we were to move charge (1) at A quickly to the position B. How much time would elapse after we began moving (1) before the charge (2) at A' would experience a different force due to the new position of (1)? Maxwell predicted that this time would be the same as the time needed for light to travel through the distance d. In other words, he predicted that the disturbance in the field would travel with the velocity of light.

The experiment described here would be difficult to perform, but Heinrich Hertz (1857-1894) did perform a completely equivalent experiment in 1888 that verified Maxwell's prediction exactly. In fact, Hertz's experiment formed the basis for radio transmission, radio waves also being electromagnetic waves with

Gave ether the qualities that nothing else had. Started to load the substance. Sometimes very contradictory.

frequencies lower than our eyes can detect. If we were to oscillate the charge in our thought-experiment 6 x 10^{14} times a second, it would radiate green light. If we were to reduce the frequency steadily, it would successively radiate yellow, orange, red, infrared, and radio waves. If we were to increase the frequency, it would radiate successively blue, violet, ultraviolet, and x-ray frequencies. Collectively, these constitute the electromagnetic spectrum.

In one sweep Maxwell had unified the theories of electricity, magnetism, and light. In addition, he showed that force fields (here electric and magnetic) were propagated with a finite velocity. This is in contrast to the earlier view that such forces made themselves felt instantly at all points, a view called "action at a distance." We are not surprised that this effect was not recognized earlier, when we remember that light travels with a velocity of about 186,000 miles per second.

While Faraday and Maxwell had found new insights into the vast realms of nature, they required a no less strange ether to carry their electromagnetic waves than had been needed before them. Physicists were still occupied with efforts to learn more about the embarrassing ether. Before they were through, the embarrassment would become much keener.

The possible existence of the ether did offer the chance to learn something important about the earth's absolute motion. Newton had stated his three laws of motion (Chapter VIII, pp. 61-62) to be valid when the coordinate system (frame of reference) in which the forces and accelerations were measured was at absolute rest or moving with uniform velocity relative to the system at rest. All such systems were called inertial coordinate systems. Since Newton's law involved acceleration (time rate of change of velocity), no mechanical experiment could tell anyone whether he was at absolute rest or moving with uniform velocity.

For example, if one were in an elevator either ascending or descending with uniform velocity, a dropped orange would reach the floor of the elevator in the same time that it would take were the elevator at rest. The result would be the same no matter what the elevator's velocity was. This is true, because the orange would partake of the velocity of the elevator, no matter what that velocity might be. Or imagine we are in a train. If the train's velocity is not changing (that is, the acceleration is zero), then our orange will strike the floor directly below the point from which it is dropped. Such would not be the case were the train to be speeding up or slowing down (that is, when the acceleration is not zero). This explains why we are conscious of the elevator's and train's motion only when their velocities are changing. If the train were moving with uniform velocity, it would be impossible to devise a mechanical experiment wholly within the train that would tell us the train's velocity. Galileo knew this. In his *Dialogue Concerning The Two World Systems*, he had Salviati try

How would you know that a point was fixed? tautology - circular argument to convince Simplicio of this fact by using the example of a stone dropped from the mast of a moving ship (see Chapter VIII, p. 29 ff.)

Physicists had been asking themselves for some time, "Where is the reference system at absolute rest?" As we saw above, Newton's laws gave them no hope of finding that system. Thus, in actual practice, an inertial system was simply a system in which Newton's laws worked, predicted the right answers. A system which worked well was one at rest with respect to the apparent positions of the "fixed" stars. This was a bit embarrassing. Newton's laws worked in inertial systems, and inertial systems were those in which Newton's laws worked. The argument was too circular for comfort, and everyone would have been very pleased to find an independent way to identify inertial systems.

tautolog

But a system at rest in the ether would be an inertial system. Albert Michelson (1852-1931) and Edward Morley (1838-1923) designed an ingenious and elaborate experiment to measure the earth's velocity relative to the ether. They performed the experiment in 1887. Their reasoning can be understood with the help of the following analogy.

Suppose that we are in a boat traveling in a circle on the surface of a lake. And suppose that the water waves are moving on the lake's surface with a constant velocity V relative to the still, deep water. How could we determine the speed of our boat relative to the still water, taking only measurements from the boat? Assume further that we cannot see the shore. Figure II will help us to see how the question can be answered.

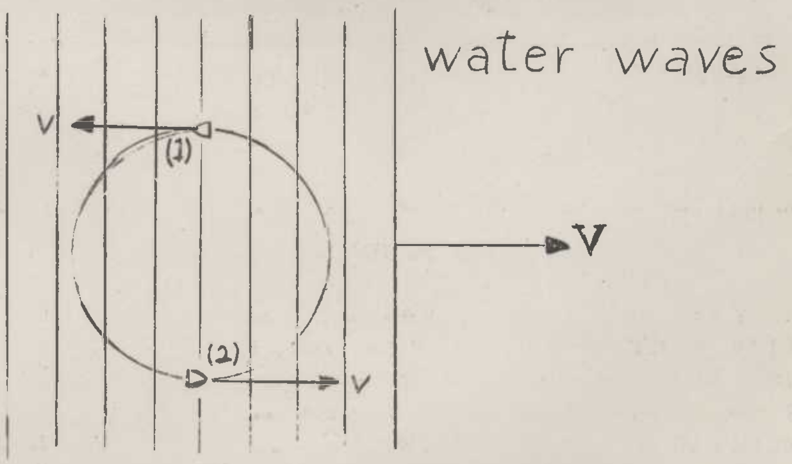

Figure II. Analogy to Michelson-Morley Experiment

We can measure the velocity of the waves, that is, the velocity with which the waves pass our moving boat. This will give us the velocity of the waves relative to the boat. At one point in our circular path (1), our measurement will give us a maximum value v_1. At another point (2), we will get a minimum value v_2. It is easy to see that

$$v_1 = V + v \qquad \text{and} \qquad v_2 = V - v$$

These equations say simply that at point (1) we are adding our velocity, v, to that of the waves, and at point (2) we are subtracting our velocity from that of the waves. If we are assured that the velocity of the waves, V, has not changed while we moved from (1) to (2), then these two equations tell us that

$$v = 1/2\ (v_1 - v_2)$$

Then we need only measure v_1 and v_2, take the difference between them, and divide that result by two.

This problem is exactly analogous to the problem facing Michelson and Morley. The lake becomes the ether, the water waves become light waves, and the boat becomes the earth. The light waves, being vibrations of the ether, would surely move with constant velocity relative to the ether. If Michelson and Morley could measure the velocity of light reaching the earth while the earth moves first toward and then away from the source of light, then they could calculate the earth's velocity with respect to the ether. And a coordinate system fixed in the ether would be the long sought-for inertial system.

To the surprise of all, and to the chagrin of many, Michelson and Morley found no difference whatever in their measured velocity of light while moving toward and away from the light source. In fact, they found that their motion, of whatever kind, relative to the source made not the slightest difference in their measured value of the velocity of light. This was as though one were to learn that the number of water waves passing the boat in a given interval of time was completely independent of the boat's motion on the lake. The inertial system which seemed finally within grasp disappeared at the last moment, leaving behind only another puzzle.

Surely the velocity of a wave in a medium (here light in the ether) depends only upon the properties of the medium. How can this be reconciled with the Michelson-Morley result?

Further, these results seemed to contradict the well-established rule for adding velocities. Suppose someone were riding on the back of a truck, the truck moving with a uniform velocity V. Now if he throws two balls with the same velocity, v, relative to the truck, one forward in the direction of the truck's motion and one backward, then a man standing at rest on the roadside would measure the balls' velocities as (V + v) and (V - v) respectively. The relation between velocities (or any other quantities) in two coordinate systems moving at constant velocity relative to each other is called a transformation. In our little problem, we have used what is called the Galilean transformation of velocity, which is a result of what is called Galilean relativity.

Light acts like bullets, or waves. But how do you describe it itself?

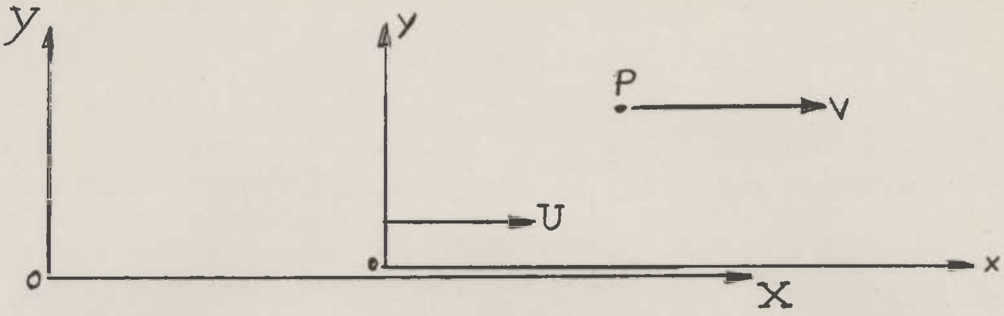

Figure III. Galilean Transformation.

The essence of a Galilean transformation is shown in Figure III. Let the xy-system be moving with uniform velocity U relative to the XY-system as shown. Let some body at P have the coordinates (x, y) in the one system and (X, Y) in the other, and let the body's velocity in the xy-system be v in the direction shown. Then we get

$$X = X_o + x$$

where X_o is the location of the origin o of the xy-system as measured in the XY-system. Further

$$V = U + v$$

where V is the velocity of the body when measured in the XY-system. If the body is accelerating (changing its velocity), the acceleration measured in the two systems will be the same.

These transformations of position, velocity, and acceleration between the two systems constitute the Galilean transformations. They had, up to the time of the Michelson-Morley experiment, adequately met the needs for all transformations of these quantities. Further, they seemed to be common-sense relations. Why did they not work when one of the velocities (here v) was the velocity of light, in which case the same velocity was measured in both systems?

A number of physicists had a try at answering the question. None was completely successful until Albert Einstein offered his solution in 1905. In the meanwhile Hendrik Lorentz (1853-1928) showed what transformation equations were demanded by the Michelson-Morley result. Yet the justification for these new and surprising transformations within a general theory had to await Einstein. This was somewhat analogous to the wait for Newton to justify Kepler's laws of planetary motion, although the wait for Einstein was much shorter.