Lecture

5/3/05

The Eighteenth Century – Newton
The Mechanical World is Understood!

The Nineteenth Century – Maxwell
The Electromagnetic World is Understood!

PHYSICS IS COMPLETE!

Well, not quite!

Welcome to the Twentieth Century!

That's the century during which physics, and our understanding of the universe, was totally transformed.

According to Maxwell (and his equations), electromagnetic waves (including visible light waves) propagate with a velocity

$$c = 1/\sqrt{\varepsilon_o \mu_o}$$

In what medium do such waves propagate?

Recall that mechanical waves (e.g., waves on a string, water waves, sound waves in fluid or solid media) generally have wave velocities determined by

$$v = \sqrt{(\text{elastic property})/(\text{inertial property})}$$

By analogy, it was once thought that the medium in which electromagnetic waves (e.g., light waves) propagate must behave similarly. But the speed of light is very high, so that medium (called the "luminiferous ether") must be enormously rigid and have nearly zero density (or mass). It must pervade all of space, because light can propagate everywhere, even in a "vacuum." And yet, it seems to have no discernable effect on the behavior (motion) of common physical objects.

How can that be?

PUZZLE

Imagine you were a late nineteenth century physicist. What would you do to answer that question?

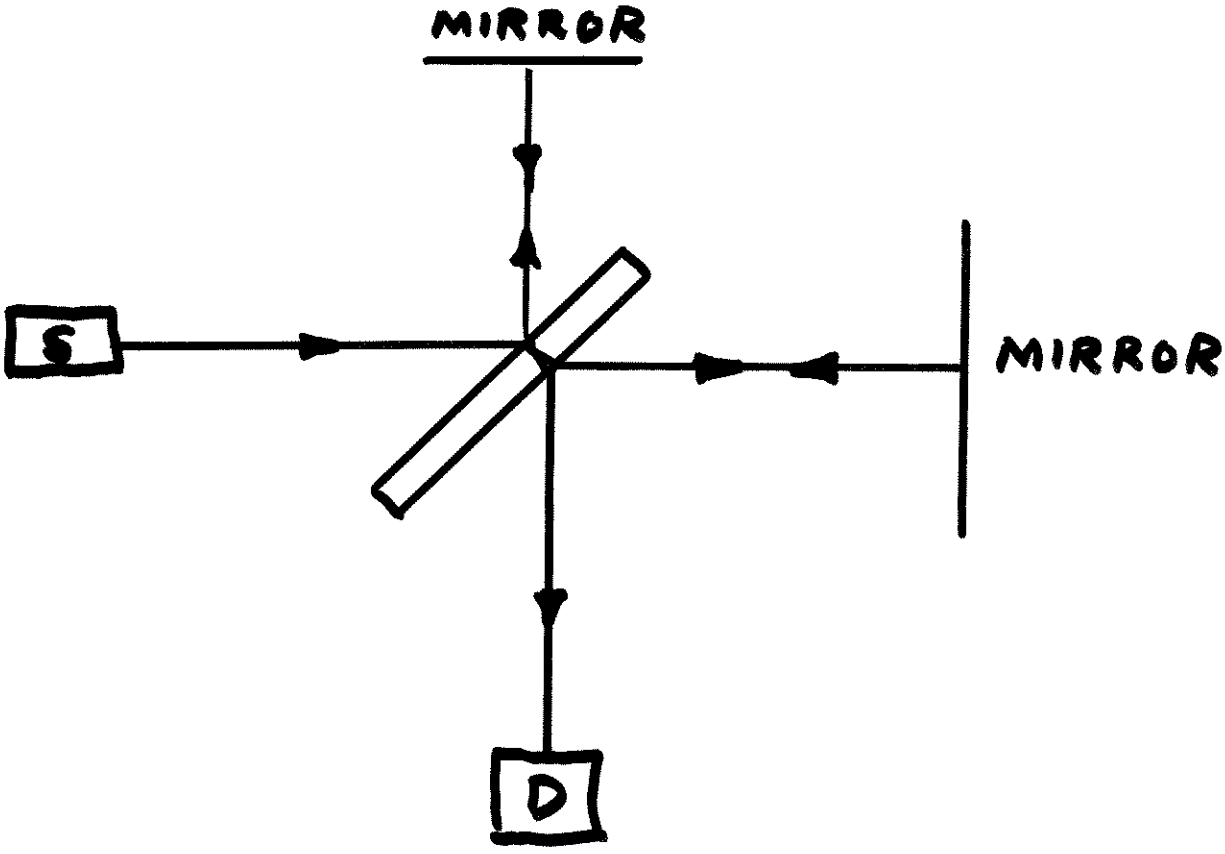
1. Just accept it as one of those inexplicable mysteries of nature.

2. Try to figure out how you might do an experiment to detect the effects of the ether.

3. Assume the ether doesn't really exist and think through what the consequences of that might be.

4. Give up and go into selling used cars. (N.B. Karl Benz didn't invent the automobile until 1885.)

Albert Michelson (later with Edward Morley) tried answer 2. First, he invented the Michelson interferometer.



Michelson-Morley's answer: The ether doesn't exist!

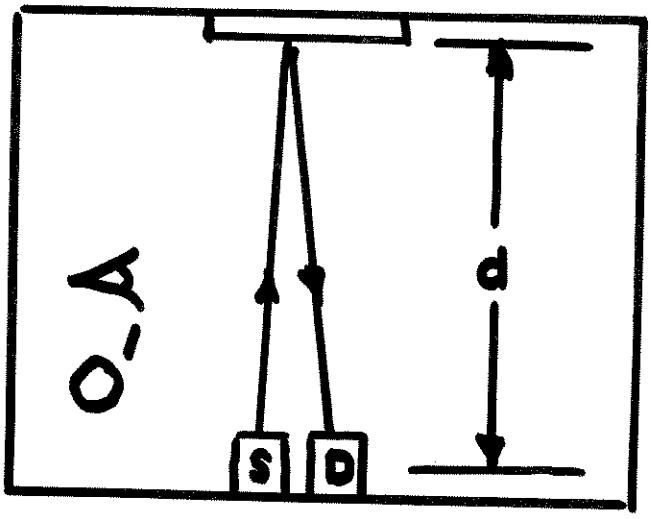
Albert Einstein tried answer 3. He didn't do any real experiments. He did *Gedanken* experiments, "thought" experiments. With the aid of these Gedanken experiments and a little eighth-grade algebra, he derived results that he published exactly 100 years ago (in 1905) and that revolutionized the way we understand our world.

He began with two fundamental postulates:

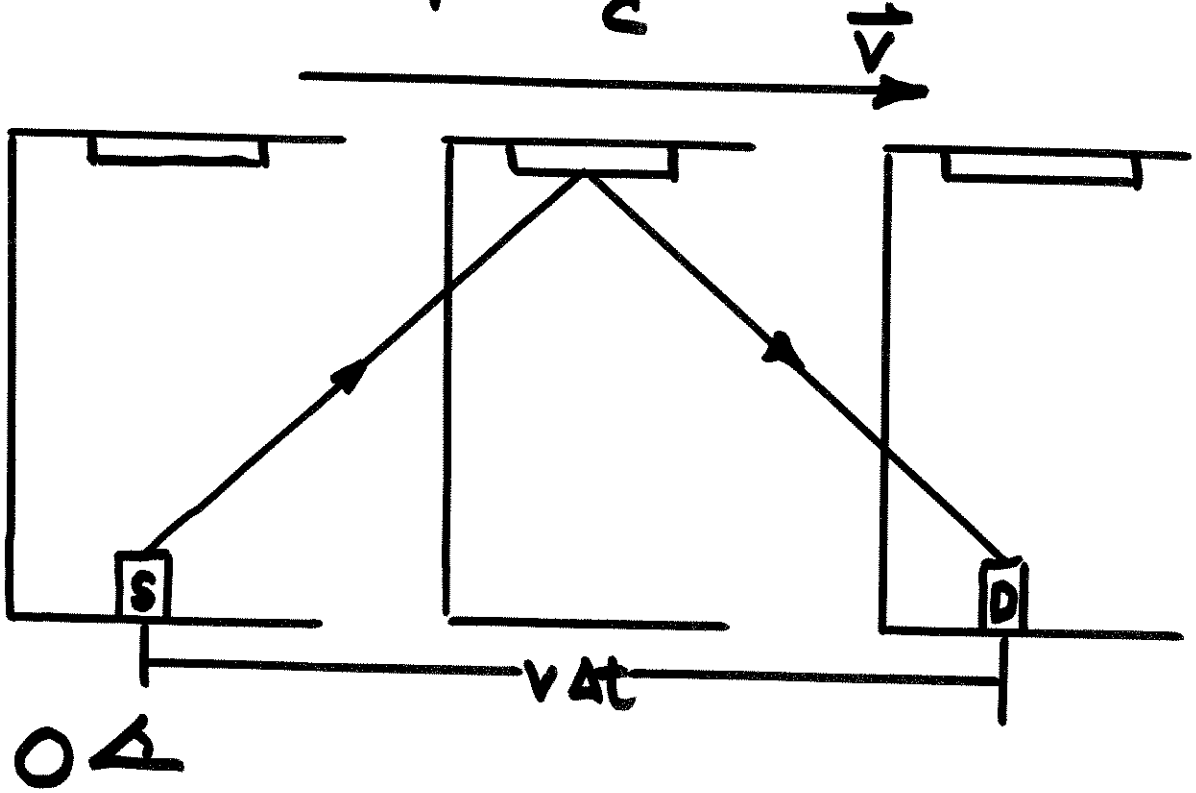
1. All laws of physics are the same in every inertial frame of reference (**The Relativity Postulate**).

2. The speed of light ("c") is the same in all inertial reference frames, regardless of the velocities of the source of the light or of any detector (observer) of the light (**The Speed of Light Postulate**).

Let's see where these two simple postulates take us.



$$\Delta t_p = \frac{2d}{c}$$



By Pythagorean Theorem

$$\left(\frac{c\Delta t}{2}\right)^2 = \left(\frac{v\Delta t}{2}\right)^2 = d^2$$

$$\Delta t = \frac{2d}{c\sqrt{1-\frac{v^2}{c^2}}} = \frac{\Delta t_p}{\sqrt{1-\frac{v^2}{c^2}}}$$

It is common to define

$$\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$$

"Proper" time is measured by an observer in an inertial frame for events that occur at the <u>same</u> position in that frame.

Experimental tests of time dilation

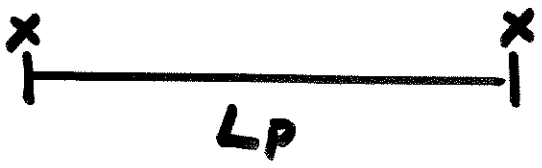
Hafele and Keating (1971): Two sets of extremely accurate atomic clocks. Leave one set in the lab, fly the other set around the world on commercial aircraft.

Muon lifetime and range: Muon lifetime is 2.2 microseconds (proper time). Typical speed is 0.998c. But for time dilation, range would be about 700 m. With time dilation, earth observer sees a lifetime of 35 microseconds and a range of about 10 km.

LENGTH?

Define "proper" length as length of object as measured by observer at rest relative to object (i.e. in same inertial frame)

O_p :



$$\Delta t = L_p / v$$

O: $\Delta t_0 = \Delta t / \gamma \Rightarrow L = v \Delta t_0$

$$= v \frac{\Delta t}{\gamma}$$

$$L = \frac{L_p}{\gamma} = L_p \sqrt{1 - \frac{v^2}{c^2}} = \frac{L_p}{\gamma}$$

MOMENTUM & ENERGY?

$$p = \frac{mv}{\sqrt{1 - \frac{v^2}{c^2}}} = \gamma m v$$

$$KE = (\gamma - 1) mc^2$$

$$= \gamma mc^2 - E_R$$

$$E_R = mc^2$$