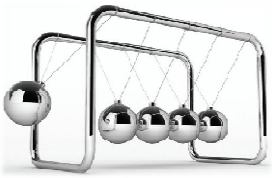
SPH4U UNIVERSITY PHYSICS

REVOLUTIONS IN MODERN PHYSICS: ...

- The Special Theory of Relativity (P.574-579)

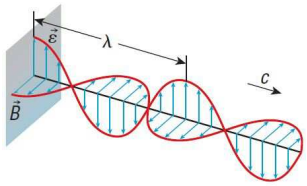
Trouble in Paradise?

At the turn of the 20th century, many scientists felt that they were close to a complete understanding of the physical world. Newtonian or classical mechanics, based on Newton's laws of motion, provided the principles by which all matter behaved and established the idea of the conservation of energy.



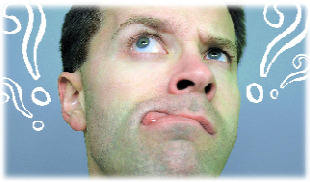
Trouble in Paradise?

Building on Maxwell's mathematical description of electric and magnetic fields, physicists successfully unified the subjects of electricity, magnetism, and optics which led to the concept that light is a combination of oscillating electric and magnetic fields.



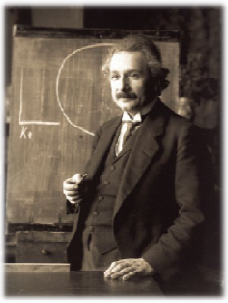
Trouble in Paradise?

At the time, only a few questions remained. The nature of the atom was still unclear. Physicists had observed that light emitted from perfect radiators (called "blackbodies"), did not behave as predicted. The phenomenon by which metals give up electrons under certain kinds of light also had physicists mystified. Moreover, contrary to Maxwell's assumptions that all electromagnetic waves, like all waves, needed a medium, there was no evidence to support this.



Trouble in Paradise?

Physicists expected to solve these problems within the framework of familiar physical models and principles. However, new models and principles needed to be developed in order to explain these problems, and these new ideas radically changed the way physicists understood their once-familiar universe. One of the main contributors to these new models was Albert Einstein.



NOTE!

Einstein's ideas in physics changed our perception of space and time.

Frames of Reference

Recall from earlier chapters that a ***frame of reference*** *is a coordinate system that you can use to observe and describe motion. Any frame of reference that is at rest or moves with a constant velocity is an* ***inertial frame of reference****. And within an inertial frame of reference, Newton's laws apply whether there is movement or not.*

FRAME OF REFERENCE (FOR)

- coordinate system that can be used to observe/describe motion

INERTIAL FRAME OF REFERENCE

- FOR that is at rest or moves with a constant velocity (i.e. a = 0)
- FOR in which Newton's laws of motion apply

Frames of Reference

PRACTICE

1. Suppose you are inside a windowless railway car. A billiard table is at the centre of the car.
   (a) While rolling a cue ball forward, you notice that the ball slows down suddenly, even though you have not applied a backward force on the ball. Explain the motion of the ball in terms of inertial or non-inertial frames of reference.

   (a) non-inertial FOR – accelerating forward

Frames of Reference

PRACTICE

1. Suppose you are inside a windowless railway car. A billiard table is at the centre of the car.
   (b) While rolling a cue ball forward, you notice that the ball rolls to the right, even though you have not applied a sideways force on the ball. Explain the motion of the ball in terms of inertial or non-inertial frames of reference.

   (b) non-inertial FOR – accelerating to the left

The Principle of Relativity

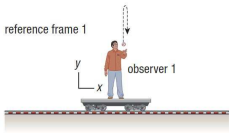
PRACTICE

2. Do Newton's laws remain unchanged for an observer in a different inertial frame?

   yes – it only changes the way in which the motion of the object appears to the first observer

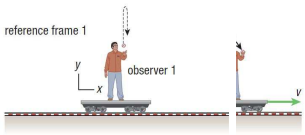
The Principle of Relativity

For example, when observer 1 throws a ball upward, regardless of whether he is moving or not, he observes that the ball's motion is purely along the vertical (y) direction.



The Principle of Relativity

But when the railway car has a speed v relative to observer 2, the ball appears to undergo projectile motion with displacements along both the x and y direction.



The Principle of Relativity

Once corrected, then, by considering the velocities of the two reference frames, the physical results become the same for both reference frames. This situation provides the basis for the principle of relativity: for all inertial frames of reference, the laws of Newtonian mechanics are the same. The main idea of the ***principle of relativity*** *has a long history, going back at least to the work of Galileo in the 1600s. This is sometimes referred to as* ***classical relativity****.*

PRINCIPLE OF RELATIVITY

- Newton's laws of motion are the same in all inertial FOR

The Speed of Light Principle

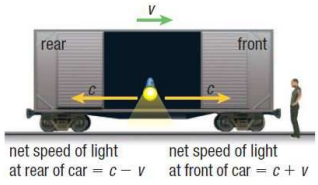
For 200 years, physicists knew that Newton's laws of motion remained the same in all inertial frames. However, electromagnetic waves seemed to be different. As it was then understood, Maxwell's theory stated that the speed of light with respect to the ether was always c = 3.0 x 10^8 m/s. This meant that if you were at rest and observed a light source move relative to the ether, you would measure the speed of light to be different from c, depending on where you were standing.

RECALL!

Ether was the proposed medium through which electromagnetic waves were once believed to propagate.

The Speed of Light Principle

For example, when the railway car below is at rest, the speed of light from the flashlight in both directions is c. And when the railway car moves at speed v relative to the ether, we would expect a stationary observer in front of the car to measure c + v for the speed of light. By similar reasoning, we would expect a stationary observer behind the car to measure c – v.

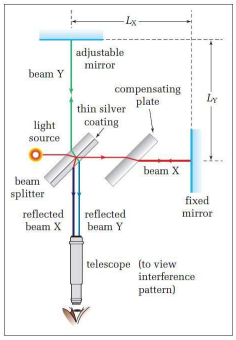


The Speed of Light Principle

However, experimental evidence did not support the idea that the speed of light varied with the speed of the inertial frame. Experiments performed by Michelson and Morley with the aid of interferometer in 1887 to try to detect the ether showed no change in the speed of light with the motion of Earth.

NOTE!

In an interferometer, if the two beams (X and Y) are not in phase, they will interfere with each other, producing an interference pattern that can be seen in the telescope.



The Speed of Light Principle

Ultimately, the results of these and similar experiments suggested that electromagnetic waves do not require a medium in which to propagate, and that the existence of ether could not be proven experimentally. This implied that the speed of light (and, in fact, all members of the electromagnetic spectrum) through a vacuum should be seen as being the same in any inertial frame of reference. This was known as the ***speed of light principle****.*

SPEED OF LIGHT PRINCIPLE

- the speed of light through a vacuum should be seen as being the same in any inertial frame of reference

Einstein's Special Theory of Relativity

NOTE!

Given the unsatisfactory consequence of classical electromagnetism, as well as the lack of evidence for the ether, Einstein proposed two postulates that were based on (a) the principle of relativity and (b) the speed of light principle.

Postulate 1: The Principle of Relativity

The laws of physics are the same in all inertial frames of reference. No physics experiments can ever determine whether you are at rest or moving at a constant velocity

Einstein's Special Theory of Relativity

NOTE!

Given the unsatisfactory consequence of classical electromagnetism, as well as the lack of evidence for the ether, Einstein proposed two postulates that were based on (a) the principle of relativity and (b) the speed of light principle.

Postulate 2: The Speed of Light Principle

There is at least one inertial frame of reference, in which, for an observer at rest in this frame of reference, the speed of light, c, in a vacuum is independent of the motion of the source of the light.

Einstein's Special Theory of Relativity

Separately, the two postulates were not extraordinary. When considered together, however, the postulates led to an entirely new understanding about our universe. That is, the speed of light must be constant and the same in all inertial frames of reference because the laws of physics do not prefer one frame of reference over another. This explanation was the basis for the ***special theory of relativity****.*

Special Theory of Relativity

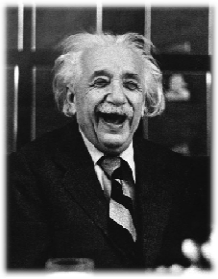
All physical laws are the same in all inertial frames of reference, and the speed of light is independent of the motion of the light source or its observer in all inertial frames of reference.

Einstein's Special Theory of Relativity

THE SPECIAL THEORY OF RELATIVITY

In any inertial frames of reference:

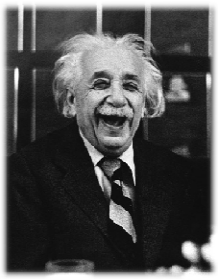
1. the laws of physics are the same, and
2. the speed of light is independent of the motion of the light source or its observer (i.e. all observers who measure the speed of light will find it has the same value ☞ c)



Einstein's Special Theory of Relativity

NOTE!

The first statement had been accepted since the time of Galileo and Newton. The second statement was a radical departure from the common understanding of the basics of physics, so it took scientists a long time to accept it. Eventually it was accepted, and the special theory of relativity is now considered to be one of the principal scientific triumphs of the 20th century.



Einstein's Special Theory of Relativity

PRACTICE

3. Suppose an astronaut in a rocket moving at 0.5c along Earth's surface shines a light forward from the rocket.
   (a) Calculate the speed of the light compared to that of the astronaut.
   (b) Calculate the speed of the light compared to that of Earth's surface.

   (a) c
   (b) c

Einstein's Special Theory of Relativity

PRACTICE

4. You are travelling in a spacecraft without windows. You are also far from any planets or stars. Describe an experiment that you could perform to determine:
   (a) whether you are at rest or moving at a constant velocity.
   (b) whether you are in an inertial or a non-inertial frame of reference.

   (a) no experiment can be performed to determine whether you are at rest or moving at a constant velocity
   (b) answers will vary

✔ Check Your Learning

TEXTBOOK

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