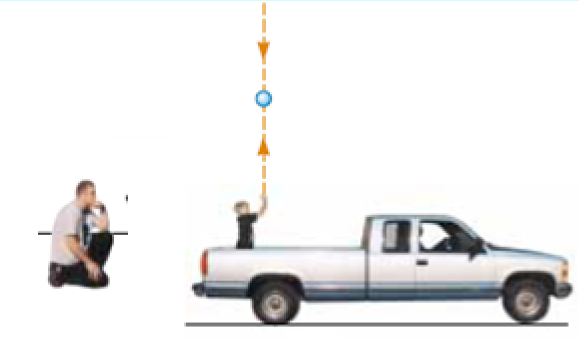
UNIT 9 RELATIVITY CONCEPTS AND POSTULATES OF SPECIAL RELATIVITY

Key unit competence: to *explain relativity Concepts and postulates of special relativity*

Introductory activity(Replace this photo)



Diana a student teacher in year two once was moving in a pick up as shown in the figure 9.1 above. She had a small ball that she projected upwards when the car was moving at a speed of 60km/h.

Basing on the statement above and figure 9.1, answer the following questions.

a) Do you think Diana was able to catch the ball 3 seconds later after projection assuming the car continued at a steady speed of 60 km/h?

b) What do you think was the shape of the path described by the ball as observed by Diana while in the car?

c) Yves a stationary observer at the banks of the road observes the projected ball right at a time when Diana projected it.Do you think the path of the ball as observed by Yves was similar to that of Diana? If not, can you describe what you think would be the observed path by him.

d) While still in the moving car, Diana moves at 5 km/h with respect to the car. Do you think as observed by Yves, Diana was moving at 5 km/h? If not, what is the estimation of speed of Diana as observed by Yves?

9.1 Concept of Relativity

Activity 9.1

On the first day of traveling in a car, Shyaka observed trees, stones, mountains and all stationary saw them moving in the direction where the car was coming from.

a) Were the trees, stones and mountains actually moving?
b) If No, why did Shyaka see them moving?
c) As Shyaka and friends in the same car tried to take over another speeding vehicle that was travelling in the same direction with the same speed, Shyaka observed that the car they were trying to overtake seemed to be stationary. Explain the cause of this effect

9.1.1 Introduction to special relativity

Physics as it was known at the end of the nineteenth century is referred to as **classical physics:**

- **Newtonian mechanics** beautifully explained the motion of objects on Earth and in the heavens. Furthermore, it formed the basis for successful treatments of fluids, wave motion, and sound.
- **Kinetictheory** explained the behavior of gases and other materials.
- **Maxwell's theory of electromagnetism**developed in 1873 by James Clerk Maxwell, a Scottish physicist embodied all of electric and magnetic phenomena,

Soon, however, scientists began to look more closely at a few inconvenient phenomena that could not be explained by the theories available at the time. This led to birth of the new Physics that grew out of the great revolution at the turn of the twentieth century and is now called **Modern Physics** (the ***Theory of Relativity*** **and** ***Quantum Theory)***.

Most of our everyday experiences and observations have to do with objects that move at speeds much less than the speed of light. Newtonian mechanics was formulated to describe the motion of such objects, and this formalism is still very successful in describing a wide range of phenomena that occur at low speeds. It fails, however, when applied to particles whose speeds approach that of light.

Experimentally, the predictions of Newtonian theory can be tested at high speeds by accelerating electrons or other charged particles through a large electric potential difference. For example, it is possible to accelerate an electron to a speed of $0.99\,c$ (where c is the speed of light) by using a potential difference of several million volts.

According to Newtonian mechanics, if the potential difference is increased by a factor of 4, the electron's kinetic energy is four times greater and its speed should double to $1.98\,c$. However, experiments show that the speed of the electron—as well as the speed of any other particle in the Universe—always remains less than the speed of light, regardless of the size of the accelerating voltage. Because it places no upper limit on speed, Newtonian mechanics is contrary to modern experimental results and is clearly a limited theory.

In 1905, at the age of only 26, Einstein published three papers of extraordinary importance:

- One was an analysis of **Brownianmotion**;
- a second (for which he was awarded the Nobel Prize) was on the **photoelectriceffect**.

❖ In the third, Einstein introduced his **special theory of relativity.**

Although Einstein made many other important contributions to Science, the **special theory of relativity** alone represents one of the greatest intellectual achievements of all time. With this theory, experimental observations can be correctly predicted over the range of speeds from to speeds approaching the speed of light. At low speeds, Einstein's theory reduces to Newtonian mechanics as a limiting situation (**principle of correspondence**).

It is important to recognize that Einstein was working on Electromagnetism when he developed the special theory of relativity. He was convinced that Maxwell's equations were correct, and in order to reconcile them with one of his postulates, he was forced into the bizarre notion of assuming that **space** and **timeare not absolute**.

In addition to its well-known and essential role in theoretical Physics, the Special Theory of Relativity has practical applications, including the design of nuclear power plants and modern global positioning system (GPS) units. These devices do not work if designed in accordance with non-relativistic principles.

9.1.2 Galilean transformation equation

(a) Principle of Galilean relativity

You've no doubt observed how a car that is moving slowly forward appears to be moving backward when you pass it. In general, when two observers measure the velocity of a moving body, they get different results if one observer is moving relative to the other. The velocity seen by a particular observer is called the velocity ***relative***to that observer, or simply **relative velocity.**

To describe a physical event, it is necessary to establish a **frame of reference**. You should recall from Mechanics that Newton's laws are valid in all inertial frames of reference. Because an **inertialframe frame** is defined as one in which Newton's first law is valid, we can say that an inertial frame of reference is one in which an object is observed to have no acceleration when no forces act on it. Furthermore, any system moving with constant velocity with respect to an inertial system must also be an inertial system.

There is no preferred inertial reference frame. This means that the results of an experiment performed in a vehicle moving with uniform velocity will be identical to the results of the same experiment performed in a stationary vehicle. The formal statement of this result is called the **principle of Galilean relativity**: "*The laws of Physics must be the same in all inertial frames of reference.*"

Let us consider an observation that illustrates the equivalence of the laws of Mechanics in different inertial frames. A pickup truck moves with a constant velocity, as shown in Fig. 9.2a.

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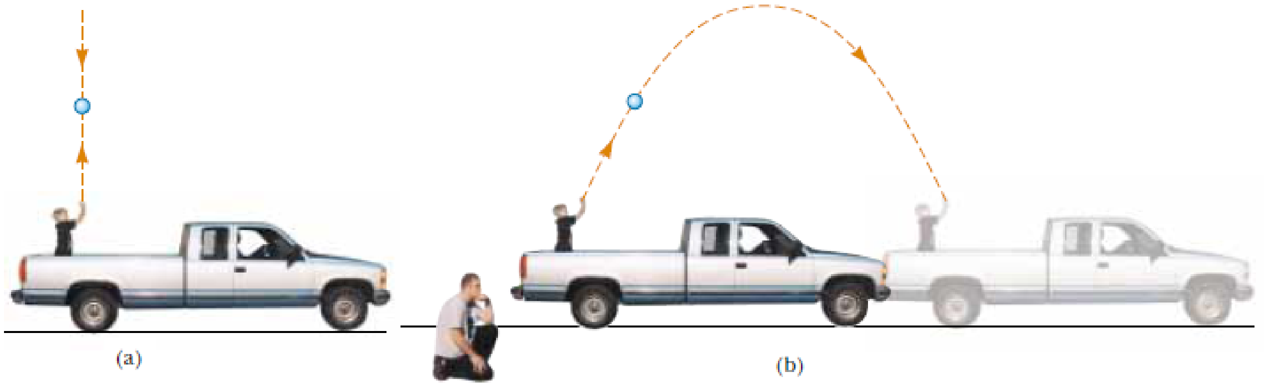

Fig.9. 2(a) The observer in the truck sees the ball move in a vertical path when thrown upward. (b) The Earth observer sees the path of the ball as a parabola.

If a passenger in the truck throws a ball straight up, and if air effects are neglected, the passenger observes that the ball moves in a vertical path. The motion of the ball appears to be precisely the same as if the ball were thrown by a person at rest on the Earth. The law of gravity and the equations of motion under constant acceleration are obeyed whether the truck is at rest or in uniform motion.

Now consider the same situation viewed by an observer at rest on the Earth. This stationary observer sees the path of the ball as a parabola, as illustrated in Fig. 9.2b. Furthermore, according to this observer, the ball has a horizontal component of velocity equal to the velocity of the truck.

Although the two observers disagree on certain aspects of the situation, they agree on the validity of Newton's laws and on such classical principles as conservation of energy and conservation of linear momentum. This agreement implies that no mechanical experiment can detect any difference between the two inertial frames. The only thing that can be detected is the relative motion of one frame with respect to the other. That is, the notion of absolute motion through space is meaningless, as is the notion of a preferred reference frame.

Example 9.1

1. A child sits upright in a wagon which is moving to the right at constant speedas shown in Fig.9.3. The child extends her hand and throws an apple straight upward (from her own point of view), while the wagon continues to travel forward at constant speed.

If air resistance is neglected will the apple land:

a) Behind the wagon
b) In the wagon
c) Or in front of the wagon?

Answer

The child throws the apple straight up from her own reference frame with initial velocity v_{yo} (Fig.9.3a). But when viewed by someone on the ground, the apple also has an initial horizontal component of velocity equal to the speed of the wagon, v_{xo} . Thus, to a person on the ground, the apple will follow the path of a projectile as shown in Fig.9.3b. The apple experiences no horizontal acceleration, so v_{xo} will stay constant and equal to the speed of the wagon. As the apple follows its arc, the wagon will be directly under the apple at all times because they have the same horizontal velocity. When the apple comes down, it will drop right into the outstretched hand of the child. The answer is (*b*).

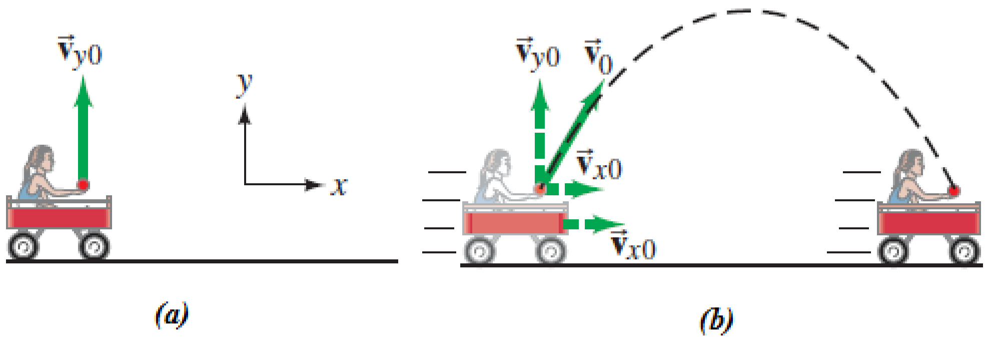

Fig.9. 3Wagon reference frame, (b) Ground reference frame

(b) Galilean space- time transformation equations

Suppose that some physical phenomenon, which we call an ***event,*** occurs in an inertial system. The event's location and time of occurrence can be specified by the four coordinates (x, y, z, t). We would like to be able to transform these coordinates from one inertial system to another one moving with uniform relative velocity.

Consider two inertial systems S and S' (Fig. 9.4). The system S' moves with a constant velocity $\boldsymbol{v}$ along the *xx*' axes, where v is measured relative to S.

We assume that an event occurs at the point P and that the origins of S and S' coincide at $t = 0$

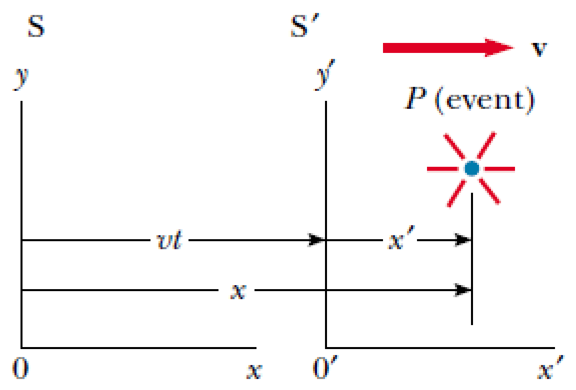

Fig.9. 4 An event occurs at a point *P*. The event is seen by two observers in inertial frames S and S', where S' moves with a velocity *v* relative to S.

An observer in S describes the event with space- time coordinates (x, y, z, t), whereas an observer in S' uses the coordinates (x', y', z', t') to describe the same event.

As we see from Fig. 9.4, the relationships between these various coordinates can be written

$$\begin{cases} x' = x - ut \\ y' = y \\ z' = z \\ t' = t \end{cases}$$

These equations are the **Galilean space- time transformation equations**.

Note that time is assumed to be the same in both inertial systems. That is, within the framework of classical mechanics, all clocks run at the same rate, regardless of their velocity, so that the time at which an event occurs for an observer in S is the same as the time for the same event in S'. Consequently, the time interval between two successive events should be the same for both observers.

Although this assumption may seem obvious, it turns out to be incorrect in situations where v is comparable to the speed of light.

Length and time intervals are absolute

Galilean- Newtonian relativity assumed that the lengths of objects are the same in one reference frame as in another, and that time passes at the same rate in different reference frames.

In classical mechanics, then, space and time intervals are considered to be **absolute**: their measurement does not change from one reference frame to another. The mass of an object, as well as all forces, are assumed to be unchanged by a change in inertial reference frame.

(c) Galilean-Newton Relative velocity

Now suppose that a particle moves a distance *dx* in a time interval *dt*as measured by an observer in S. It follows from Equations 12.**01** that the corresponding distance *dx*' measured by an observer in S' is

$$\begin{cases} dx' = dx - d(ut) \\ dy' = dy \\ dz' = dz \\ dt' = dt \end{cases} \Leftrightarrow v'_x = v_x - u$$

Where v_x and v'_x are the *x* components of the velocity relative to S and S', respectively. This is the **Galilean velocity transformation equation or relative velocity**. It is used in everyday observations and is consistent with our intuitive notion of time and space. As we shall soon see, however, it leads to serious contradictions when applied to electromagnetic waves.

Example 9.2

1. A girl on a 10-speed bicycle travels at 9 m/s relative to the ground as she passes a little boy on a tricycle going on opposite direction. If the boy is traveling at 1 m/s relative to the ground, how fast does the boy appear to be moving relative to the girl?

Answer

The velocity of the girl relative to the ground S: $u = 9\ m/s$

The velocity of the boy relative to the ground: $v = -1\ m/s$

The velocity of the boy relative to the girl: $v' = v - u \Leftrightarrow u = -1 - 9 = -10\ m/s$

Position and velocity are different in different reference frames, but length is the same

The position of an object is different when specified in different reference frames, and so is velocity.For example, a person may walk inside a bus toward the front with a speed of $v' = 2\ m/s$. But if the bus moves with $u = 10\ m/s$ respect to the Earth, the person is then moving with a speed of

$v = v' + u = 10 + 2 = 12\ m/s$ with respect to the Earth.

The acceleration of an object, however, is the same in any inertial reference frame according to classical mechanics. This is because the change in velocity, and the time interval, will be the same.

For example, the person in the bus may accelerate from 0 to $2\ m/s$ in 1.0 s,

So $a' = \dfrac{2\ m/s - 0\ m/s}{1.0\ s} = 2.0\ m/s^2$ in the reference frame of the bus

With respect to the Earth, the acceleration is $a = \dfrac{14\ m/s - 12\ m/s}{1.0\ s} = 2.0\ m/s^2$ which is the same.

Since neither *F*, *m*, nor *a* changes from one inertial frame to another, Newton's second law, $F = ma$ does not change. Thus Newton's second law satisfies the **relativity principle**. The other laws of mechanics also satisfy the relativity principle. That the laws of mechanics are the same in all inertial reference frames implies that no one inertial frame is special in any sense. We express this important conclusion by saying that **all inertial reference frames are equivalent** for the description of mechanical phenomena.

No one inertial reference frame is any better than another. A reference frame fixed to a car or an aircraft traveling at constant velocity is as good as one fixed on the Earth. When you travel smoothly at constant velocity in a car or airplane, it is just as valid to say you are at rest and the Earth is moving as it is to say the reverse. There is no experiment you can do to tell which frame is "really" at rest and which is moving. Thus, there is no way to single out one particular reference frame as being at **absolute rest**.

9.1.3 Einstein's principle of relativity

The special theory of relativity has made wide-ranging changes in our understanding of nature, but Einstein based his special theory of relativity on two**postulates**:

1. *The* ***principle of relativity:*** *The laws of Physics must be the same in all inertial reference frames.* The first postulate can also be stated as: *there is no experiment you can do in an inertial reference frame to determine if you are at rest or moving uniformly at constant velocity.*
2. *The* ***constancy of the speed of light****: The speed of light in vacuum has the same value* $c = 3.0\times10^8\ m/s$ *, in all inertial frames, regardless of the velocity of the observer or the velocity of the source emitting the light.*
3. ***Uniform motion is invariant:****A particle at rest or with constant velocity in one inertial reference frame will be at rest or have constant velocity in all inertial reference frames.*

The first postulate asserts that all the laws of Physics—those dealing with Mechanics, Electromagnetism, Optics, Thermodynamics, and so on—are the same in all reference frames moving with constant velocity relative to one another. This postulate is a sweeping generalization of the principle of Galilean relativity, which refers only to the laws of mechanics.

Einstein's second postulate immediately implies the following result***: It is impossible for an inertial observer to travel at c, the speed of light in vacuum.***

Note that postulate 2 is required by postulate 1: If the speed of light were not the same in all inertial frames, measurements of different speeds would make it possible to distinguish between inertial frames; as a result, a preferred, absolute frame could be identified, in contradiction to postulate 1.

These innocent-sounding propositions have far-reaching implications. Here are three:

1. **Events that are simultaneous for one observer may not be simultaneous for another**.

Two events occurring at different points in space which are simultaneous to one observer are not necessarily simultaneous to a second observer. The central point of relativity is this: Any inertial frame of reference can be used to describe events and do Physics. There is no preferred inertial frame of reference. However, observers in different inertial frames always measure different time intervals with their clocks and different distances with their meter sticks. A light flash goes off in the center of a moving train (Fig.9.5).

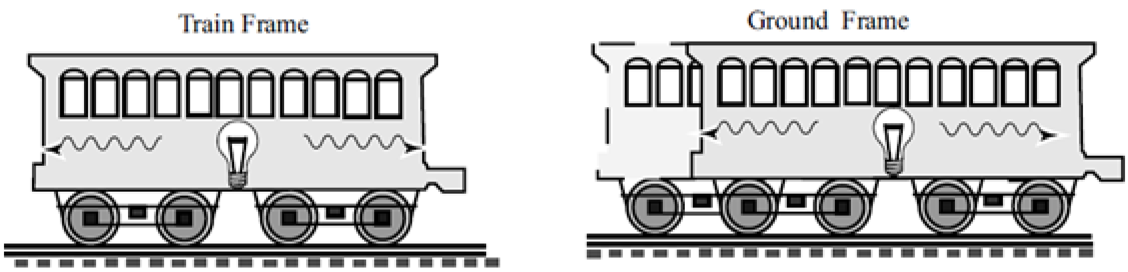

Fig.9. 5A light flash goes off in the center of a moving train

In the train's frame, the light hits the front and back of the car simultaneously. In the ground frame, the train is moving with velocity v, so the light strikes the rear of the car before reaching the front. Two events that are **simultaneous** in one frame are not simultaneous in another frame.

Nevertheless, all observers agree on the forms of the laws of Physics in their respective frames because these laws must be the same for all observers in uniform motion. For example, the relationship $F = ma$ in a frame S has the same form $F = ma'$ in a frame S' that is moving at constant velocity relative to frame S.

2. When two observers moving relative to each other measure a time interval or a length, they may not get the same results.
3. For the conservation principles for momentum and energy to be valid in all inertial systems, Newton's second law and the equations for momentum and kinetic energy have to be revised.

Application activity 9.1

1. A 2 000 kg car moving at 20.0 m/s collides and locks together with a 1 500 kg car at rest at a stop sign. Show that momentum is conserved in a reference frame moving at 10.0 m/s in the direction of the moving car.

2. A ball is thrown at 20.0 m/s inside a boxcar moving along the tracks at 40.0 m/s. What is the speed of the ball relative to the ground if the ball is thrown (a) forward (b) backward (c) out the side door?

3. In a laboratory frame of reference, an observer notes that Newton's second law is valid. Show that it is also valid for an observer moving at a constant speed, small compared with the speed of light, relative to the laboratory frame

4. You drive north on a straight two-lane road at a constant $88\ km/\text{h}$. A truck in the other lane approaches you at a constant $104\ km/\text{h}$. Find

(a) the truck's velocity relative to you

(b) Your velocity relative to the truck.

(c) How do the relative velocities change after you and the truck pass each other?

9.2 Relativistic Dynamics

Activity 9.7:

The expressions "Time flies" and "This has been the longest day of my life" or "a pleasant day may fly past", while "unpleasant hour may seem to last forever"suggest that time do not flow equally in all situations.

Can you describe any cases in which it is actually true that the flow of time is in some sense variable?

9.2.1 Time dilation: Moving clocks run slowly

We can illustrate the fact that observers in different inertial frames always measure different time intervals between a pair of events by considering a vehicle moving to the right with a speed *v*, as shown in Fig.9.6.

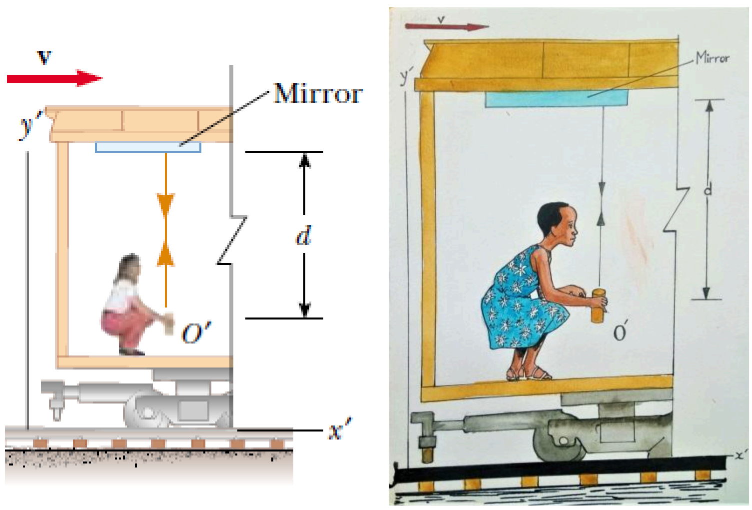

Fig.9. 6 A mirror is fixed to a moving vehicle, and a light pulse is sent out by observer *O*' at rest in the vehicle.

A mirror is fixed to the ceiling of the vehicle, and observer *O*' at rest in this system holds a laser a distance *d* below the mirror. At some instant, the laser emits a pulse of light directed toward the mirror (event 1), and at some later time after reflecting from the mirror, the pulse arrives back at the laser (event 2). Observer *O*' carries a clock *C*' and uses it to measure the time interval Δt_p between these two events. (The subscript *p* stands for *proper,* as we shall see in a moment.)

Because the light pulse has a speed *c*, the time it takes the pulse to travel from *O*' to the mirror and back to *O*' is

$$\Delta t_p = \frac{2d}{c} \qquad \textbf{(12.07)}$$

This time interval Δt_p measured by *O*' requires only a single clock *C*' located at the same place as the laser in this frame.

Now consider the same pair of events as viewed by observer *O* in a second frame, as shown in Fig.9.7a.

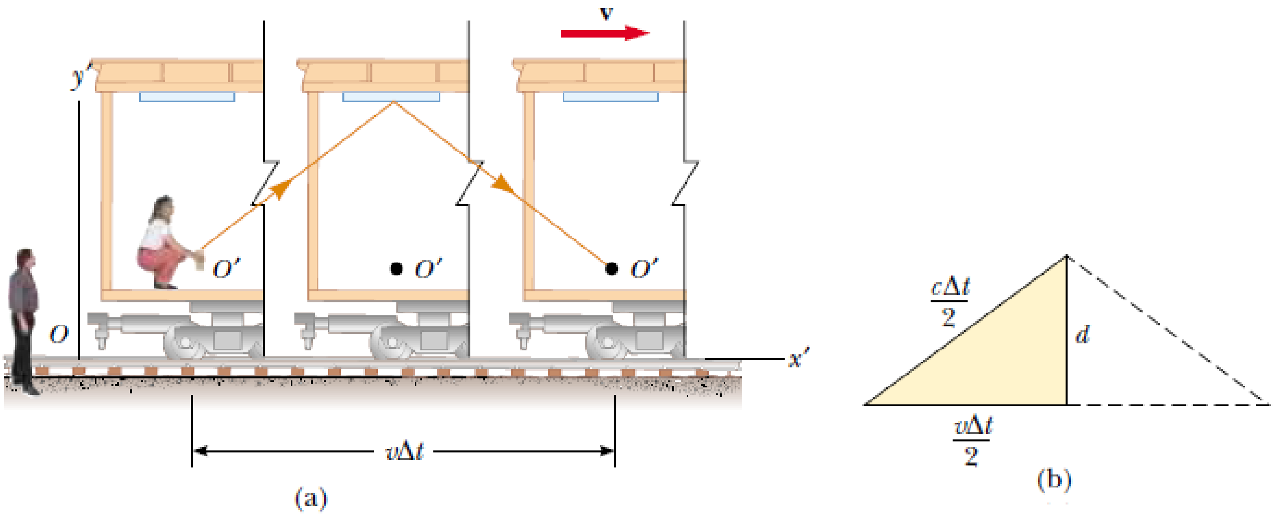

Fig.9. 7 (a) Relative to a stationary observer *O* standing alongside the vehicle, the mirror and *O*' move with a speed *v*. Note that what observer *O* measures for the distance the pulse travels is greater than 2*d*. (b) The right triangle for calculating the relationship between Δt and Δt_p.

According to this observer, the mirror and laser are moving to the right with a speed *v*, and as a result the sequence of events appears entirely different. By the time the light from the laser reaches the mirror, the mirror has moved to the right a distance

$$\Delta t_p = \frac{v\Delta t}{c} \quad , \qquad \textbf{(12.08)}$$

where Δt is the time it takes the light to travel from *O*' to the mirror and back to *O*' as measured by *O*.

In other words, *O* concludes that, because of the motion of the vehicle, if the light is to hit the mirror, it must leave the laser at an angle with respect to the vertical direction. Comparing Fig 9.7 and Fig.9.7a, we see that the light must travel farther in (Fig.9.7b) than in (Fig.9.7).

Note that neither observer "knows" that he or she is moving. Each is at rest in his or her own inertial frame.

According to the second postulate of the special theory of relativity, both observers must measure *c* for the speed of light. Because the light travels farther in the frame of *O*, it follows that the time interval Δ*t*measured by *O* is longer than the time interval Δt_p measured by *O*'. To obtain a relationship between these two time intervals, it is convenient to use the right triangle shown in Fig.9.7b. The Pythagorean Theorem gives

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

Solving for Δt gives $\Delta t = \frac{2d}{\sqrt{1-(\frac{v}{c})^2}}$

Because $\Delta t_p = \frac{2d}{c}$, we can express this result as $\Delta t = \frac{\Delta t_p}{\sqrt{1-(\frac{v}{c})^2}} = \gamma \Delta t_p$

Where

- Δt represents the time interval according to the stationary system. Time interval measured by an observer who is in motion with respect to the events and who views the events as occurring at different places.
- Δt_p represents the time interval according to the moving system (proper time). Time measured by an observer who is at rest with respect to the events and who views the events as occurring at the same place.
- v represents the relative speed between the two systems
- c speed of light in vacuum

A clock in motion relative to an observer would seem to be slowed down, by the beta factor

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

Fig.9.7 shows a graph of γ as a function of the relative speed u of two frames of reference. When u is very small compared to $\frac{u^2}{c^2}$ is much smaller than 1 and γ is very nearly *equal* to 1.

Because γ is always greater than unity, this result says that the time interval Δt measured by an observer moving with respect to a clock is longer than the time interval Δt_p measured by an observer at rest with respect to the clock. That is, $\Delta t > \Delta t_p$ this effect is known as **time dilation.**

In general, ***proper time*** is the time interval between two events measured by an observer who sees the events occur at the same point in space. Proper time is always the time measured with a single clock (clock *C*' in our case) at rest in the frame in which the events take place.

Example 9.3: Life time of Muon

1. A stationary muon decays in $2.2\times10^{-6}\ s$. What is its lifetime if it is moving at 0.97 c relative to laboratory clocks? How far does it travel before it decays?

Answer:

The proper time $\Delta t_p = 2.2\times10^{-6}\ s$ then

$$\Delta t = \frac{\Delta t_p}{\sqrt{1-(\frac{v}{c})^2}} = \frac{2.2\times10^{-6}\ s}{\sqrt{1-(\frac{0.97\ c}{c})^2}} = 9\ \mu s$$

During this time it travels a distance $d = vt_p = (0.97\times3\times10^8\ m/s)(9\times10^{-6}\ s) = 2.6\ km$

Thus, the dilated, or expended, lifetime provides sufficient time for the muon to reach the surface of the Earth.

If its lifetime were only $2.2\times10^{-6}\ s$, muon would travel only a distance *S* before disintegrating and could never reach the Earth:

$S = vt = (0.97\times3\times10^8\ m/s)(2.2\times10^{-6}\ s) = 640\ m$.

9.2.2 Length contraction

The measured distance between two points also depends on the frame of reference according to the special theory of relativity, and we illustrate this with a thought experiment. Observers on Earth watch a spacecraft traveling at speed v from Earth to, say, Neptune, Fig. 9.8a.The distance between the planets, as measured by the Earth observers, is L_p. The time required for the trip, measured from Earth, is

$$t = \frac{L_p}{v} \qquad \textbf{(12.11)}$$

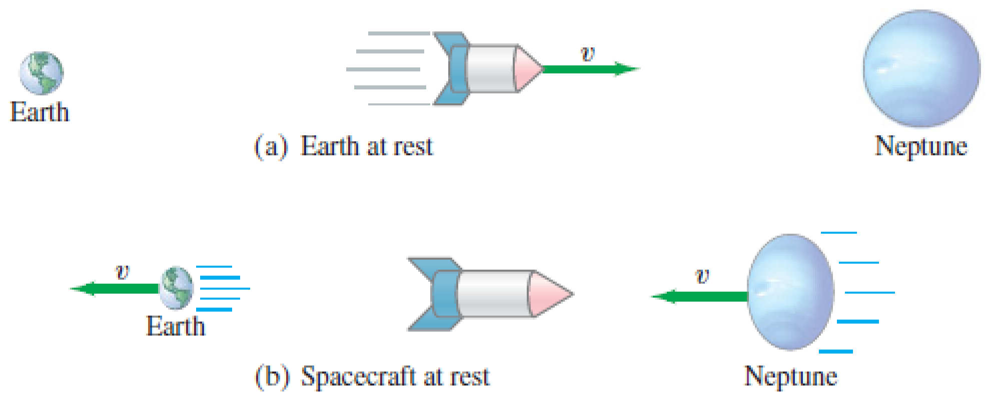

Fig.9. 8 (a) A spaceship traveling at very high speed from Earth to the planet Neptune, as seen from Earth's frame of reference. (b) According to an observer on the spaceship, Earth and Neptune are moving at the very high speed v: Earth leaves the spaceship, and a time later t_0 Neptune arrives at the spaceship. (Douglass & Giancoli, 1980)

In Fig. 9.8b we see the point of view of observers on the spacecraft. In this frame of reference, the spaceship is at rest; Earth and Neptune move with speed v. The time between departure of Earth and arrival of Neptune, as observed from the spacecraft, is the "**proper time** t_p "because these two events occur at the same point in space (i.e., at the spacecraft).That is, because of time dilation, the time for the trip as viewed by the spacecraft is

$$t_p = \frac{t}{\gamma}$$

Therefore the time interval is less for the spacecraft observers than for the Earth observers. Because the spacecraft observers measure the same speed but less time between these two events, they also measure the distance as less. If we let L be the distance between the planets as viewed by the spacecraft observers, then

$$L = vt_p = v\frac{t}{\gamma} = \frac{L_p}{\gamma}$$

The length of an object moving relative to an observer is measured to be shorter along its direction of motion than when it is at rest.

It is important to note that length contraction occurs *only along the direction of motion*

Example12.4: Length contraction

1.A spaceship flies past earth at a speed of 0.990 c. A crew member on board the spaceship measures its length, obtaining the value 400 m. What length do observers measure on earth?

Answer

The spaceship's 400 m length is the *proper* length because it is measured in the frame in which the spaceship is at rest. Our target variable is the length *l* measured in the earth frame, relative to which the spaceship is moving at 0.990 *c*.

$$L = L_p\sqrt{1-(\frac{u}{c})^2} = 400\sqrt{1-(\frac{0.990\,c}{c})^2} = 56.4\ m$$

2. A rectangle painting measures 1.00 m tall and 1.50 m wide see Fig.12.15. It is hung on the side wall of a spaceship which is moving past the Earth at a speed of 0.90 C.

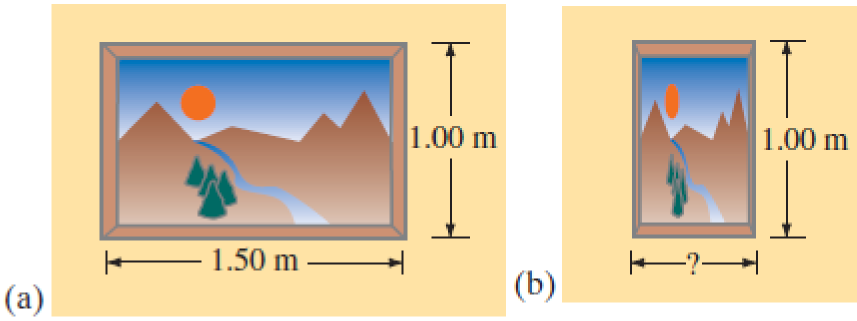

Fig.9. 9 Painting's contraction

a) What are the dimensions of the picture according to the captain of the spaceship?
b) What are the dimensions as seen by an observer on the Earth?

Answer

a) The painting (as well as everything else in the spaceship) looks perfectly normal to everyone on the spaceship, so the captain sees a 1.00 m by 1.50 m painting.

b) Only the dimension in the direction of motion is shortened, so the height is unchanged at 1.00 m.

The length, however, is contracted to

$$L = L_p\sqrt{1-(\frac{u}{c})^2} \Leftrightarrow L = 1.50\sqrt{1-(\frac{0.90\,c}{c})^2} = 0.65\ m$$

so the picture has dimensions 1.00 m × 0.65 m.

Application activity 9.2 relativistic dynamics

1. A passenger on a fictional high-speed spaceship traveling between Earth and Jupiter at a steady speed of 0.75*c* reads a magazine which takes 10.0 min according to her watch.

a. How long does this take as measured by Earth-based clocks?

b. How much farther is the spaceship from Earth at the end of reading the article than it was at the beginning?

2. An astronaut on a spaceship traveling at 0.75*c* relative to Earth measures his ship to be 23 m long. On the ship, he eats his lunch in 28 min. (*a*) What length is the spaceship according to observers on Earth? (*b*) How long does the astronaut's lunch take to eat according to observers on Earth?

Skills Lab 9

One day you happen to see aeroplane moving in space about 2 km from point of view. It is moving past your point of view.

Using relativistic knowledge explain why

a) i) The aeroplane appears too small as if even one man cannot fit.

ii) Imagine at that instant the aeroplane started landing (coming down to the observer).Describe all changes in the size of the aeroplane as seen by you.

b) Mutoni and Kalisa are all in a taxi from Remera heading to Nyabugogo.As they are seated and observe one another to be at rest. Explain why someone observing them from outside sees them moving at the same speed of the car.

End Unit Assessment 9

Multiple choices 1-6

1. The principle of relativity can be best stated as

a) The laws of physics differ only by a constant in all reference frames differing by a constant acceleration.
b) The laws of physics change from one inertial reference frames to another.
c) The laws of physics are the same in all inertial reference frames.

2. An inertial reference frame is best described by

a. one that moves with constant acceleration
b. a frame that is subject to constant forces
c. a frame that moves with constant velocity
d. a frame that is subject to Galilean transformations

3. The most significant revolution in Physics in the 20th century has been

A. Bohr's theory of hydrogen atom
B. Nuclear fusion
C. Plank's quantum theory and Einstein's theory of relativity
D. Quantum mechanics

4. Relativistic formulas for time dilation, length contraction, and mass are valid

A. only for speeds less than 0.10 *c*.
B. only for speeds greater than 0.10 *c*.
C. only for speeds very close to *c*.
D. for all speeds.

5. Which of the following will two observers in inertial reference frames always agree on? (Choose all that apply.)

A. The time an event occurred.
B. The distance between two events.
C. The time interval between the occurrence of two events.
D. The speed of light.
E. The validity of the laws of Physics.
F. The simultaneity of two events.

6. Two observers in different inertial reference frames moving relative to each other at nearly the speed of light see the same two events but, using precise equipment, record different time intervals between the two events. Which of the following is true of their measurements?

A. One observer is incorrect, but it is impossible to tell which one.
B. One observer is incorrect, and it is possible to tell which one.

C. Both observers are incorrect.
D. Both observers are correct.

7. (a) What will be the mean lifetime of a muon as measured in the laboratory if it is travelling at $v = 0.60\ c$ with respect to the laboratory? Its mean life at rest is 2.2×10^{-6} s.

(b) How far does a muon travel in the laboratory on average, before decaying?

8. The period of a pendulum is measured to be 3.0 s in the reference frame of the pendulum. What is the period when measured by an observer moving at a speed of 0.95 *c* relative to the pendulum?