Lesson 1 Frames of Reference

MEASUREMENT OF MOTION

THE BIG IDEA

- The measurement of motion depends on the frame of reference.

As you begin this unit, some questions you might want to consider…

- When are measurements considered to be relative?
- How is a vector addition/subtraction different from scalar addition/subtraction?
- What are the implications of the theory of special relativity?
- What might be the age of a sibling who travels to Mars at half the speed of light and returns a few years later?
- How can you determine the angle that you need to travel at to land a motorized boat on the opposite bank across a body of moving water?
- How can you represent an effect of special relativity?

When you are finished this unit, you are expected know the following…

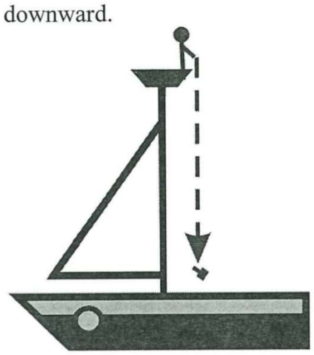
- frames of reference
- relative motion within a stationary reference frame
- postulates of special relativity
- relativistic effects (for example, changes in time, length, and mass) within a moving reference frame

Lesson 1 FRAMES OF REFERENCE

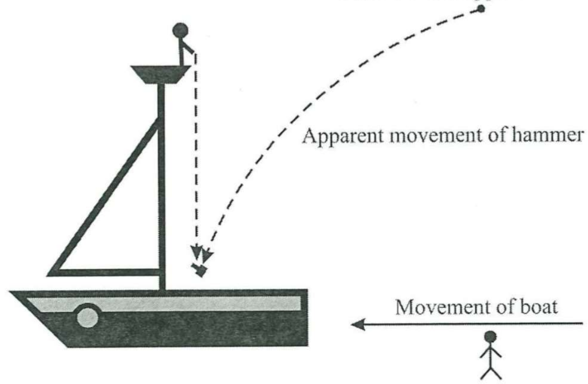
NOTES

Relativity is a concept originally developed by Galileo. He found that the apparent motion of an object depended on the **frame of reference** of the observer. For example, consider an observer on a sea shore watching a ship quickly sail past at a constant velocity. As the observer watches, a sailor working at the top of the mast drops a hammer.

From the frame of reference of the sailor, the hammer falls straight downward.



From the frame of reference of the observer, the hammer falls downward, but it also moves forward along with the ship.



In both cases, the laws of motion hold true. Any time an object is in motion, its motion appears differently relative to a particular frame of reference. It is equally true that there is no absolute or "preferred" point from which to measure motion.

INERTIAL FRAMES OF REFERENCE

In the given example, both the sailor and the observer are in **inertial frames of reference**. *Inertial* refers to the fact that the frame is neither accelerating nor decelerating. The *frame of reference* is the area in which the laws of physics work the same for all observers within it.

The most commonly used inertial frame of reference is Earth. For example, when car A travels at a velocity of 25 m/s south, this is in reference to the fixed environment around it—Earth's surface. If this car approaches car B travelling south at 20 m/s, car A has a velocity of 5 m/s south relative to car B. Because both cars are travelling with constant velocity, they are each travelling in their own inertial frame of reference.

Inertial frames of reference are at rest or move at a constant velocity.

If the frame of reference were to change, this may change the numerical quantities with which the motion is described, but Newton's laws still apply equally in all such frames. For example, the passengers travelling in a windowless railcar along an ultra-smooth, level track with all sounds and vibrations damped would not perceive that the railcar was moving. Newton's laws would hold for any investigation conducted in the railcar, but all results would be identical to those obtained if the car were stationary. That is the defining feature of an inertial frame of reference.

Example

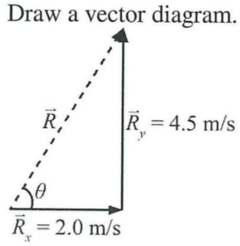
A boat travels at a velocity of 4.5 m/s north across a river. The river current is 2.0 m/s east. What is the velocity of the boat relative to the shore?

Solution

The velocity of the boat with respect to the shore is the sum of the velocity of the boat relative to water (4.5 m/s north) and the velocity of the river relative to the shore (2.0 m/s east).

These vectors are added in the same way in which displacement vectors are added. Since the velocity of the boat is measured relative to the water, and the water's velocity is measured with respect to the shore, the relative velocity of an object moving on the water with respect to the stationary shore will be the sum of the two velocities.

Draw a vector diagram.



Find the magnitude of $\vec{R}$ using the Pythagorean theorem.

$$\begin{aligned} R &= \sqrt{R_x^{\,2} + R_y^{\,2}} \\ &= \sqrt{(2.0\text{ m/s})^2 + (4.5\text{ m/s})^2} \\ &= 4.9\text{ m/s} \end{aligned}$$

Find the direction using $\tan\theta = \dfrac{\text{opposite}}{\text{adjacent}} = \dfrac{R_y}{R_x}$.

NOTES

$$\tan\theta = \frac{4.5 \text{ m/s}}{2.0 \text{ m/s}}$$
$$\theta = 66°$$
$$\therefore \vec{R} = 4.9 \text{ m/s } 66° \text{ N of E}$$

NON-INERTIAL FRAMES OF REFERENCE

Frames of Reference:
inertial: non-accelerating
non-inertial: accelerating

If railcar moved in a sharp curve to the left, the passengers would perceive a "force" pushing everything in the railcar to the right. However, this "force" does not exist. Even though this "force" may have a name, it is imaginary. It is called a psuedo-force.

The railcar accelerates as it goes around the curve (centripetal acceleration) and the frame of reference attached to the railcar is called a **non-inertial frame of reference**. The defining feature of non-inertial frames of reference is that they introduce apparent forces within the frame of reference. The apparent force in this case is often called the centrifugal force. The observing passengers feel their inertia moving them in the same direction as before the curve, but when the railcar enters into the curve it actually moves left into the passengers' inertial path. The passengers perceive this inertia as a push to the right inside the railcar. However, the real force is a push to the left on the entire frame of reference.

PRACTICE EXERCISES

1. A boat with a speed of 2.5 m/s on still water is now in a river with a velocity of 1.0 m/s south. What is the velocity of the boat relative to the shore when the boat is headed south?

2. What is the velocity of the boat relative to the shore when the boat is headed north?

3. What is the velocity of the boat relative to the shore when the boat is headed west?

4. An object floats at rest relative to the dining area of a large spacecraft initially moving with a constant velocity relative to the stars. An astronaut strapped to his seat in the back of the spacecraft looks at the object. The spacecraft suddenly begins to accelerate forward in the direction of the astronaut's gaze. From the astronaut's perspective, how will the object appear to move when the spacecraft accelerates?

5. Sharks have very highly developed senses that enable them to "see" in very dim light and pick up vibrations in the water. They are also very fast—the blue shark has been measured at speeds of 64 km/h. If a blue shark, swimming at its maximum speed heading east, is chasing a fish swimming at 15 km/h east, what does the motion of the fish appear to be relative to the shark?