Relative Motion

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P2.3a: Describe and compare the motion of an object using different reference frames. Relative Motion:
P1.2f: Critique solutions to problems, given criteria and scientific constraints.

Vector, Scalar

A scalar quantity is one that can be described by a single number:

temperature, speed, mass

A vector quantity deals inherently with both magnitude and direction:

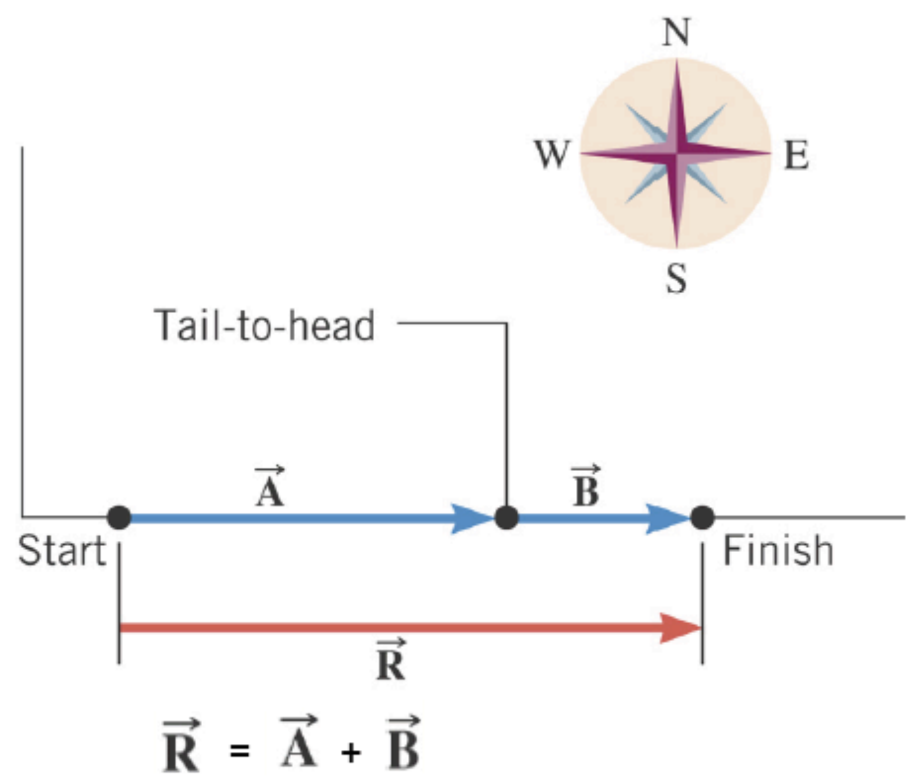
velocity, force, displacement

Arrows are used to represent vectors. The direction of the arrow gives the direction of the vector.

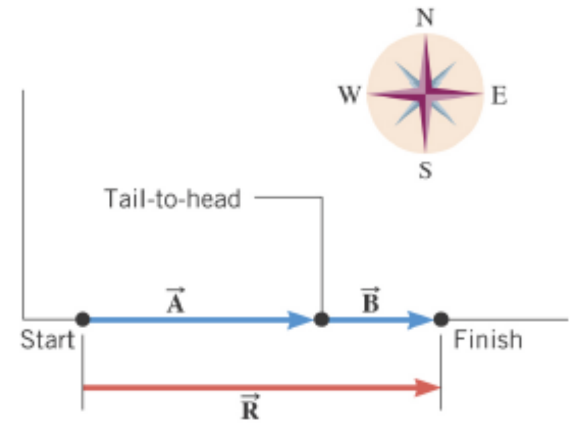
By convention, the length of a vector arrow is proportional to the magnitude of the vector. 8 is the double of 4. The length of vector 8 lb is twice that of 4 lb.

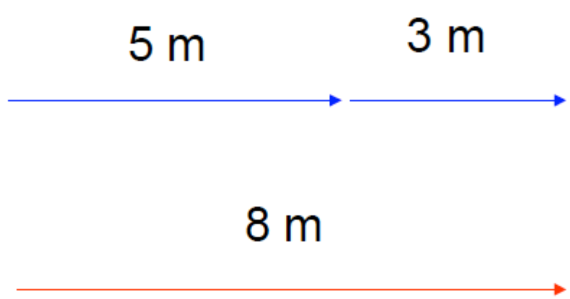
Adding Vectors

Often it is necessary to add one vector to another. A. Vectors are added by joining them head to tail. The vector sum is represented by an arrow drawn from the tail of the first vector to the head of the last vector.



To add two vectors on the same direction, combine them by adding their magnitudes together. Below is an example.

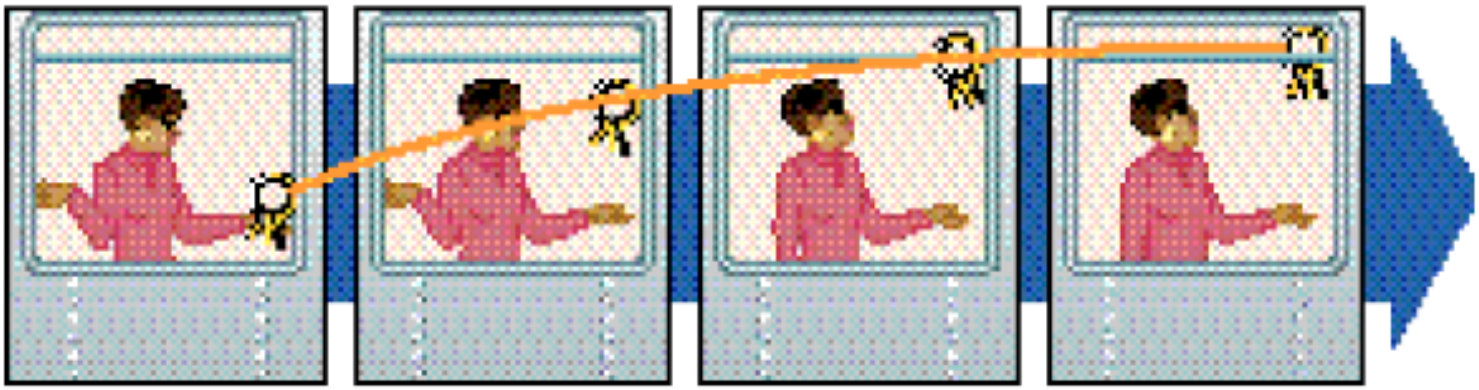




To add two vectors that are in opposite directions, change the sign of one vector so that they have the same direction, and add their magnitude.

Application: Relative Motion

The figure below shows an experiment performed inside a uniformly moving train.



When the keys are tossed straight up. As seen from inside, the tossed keys go straight up. As seen from the outside, the keys appear to move along an ascending parabola (shown as the orange line path).

A **reference frame** describe the orientation of an object’s motion with regard to its position, distance, speed, and direction.

When an object is in motion in a reference frame, that is also in motion, the motion of the object will generally appear different to an observer at rest outside the reference frame versus an observer at rest in the reference frame.

Relative Velocity, or Speed with Direction
${}_1\vec{V}_3 = {}_1\vec{V}_2 + {}_2\vec{V}_3$

${}_1\vec{V}_3$, ${}_1\vec{V}_2$, ${}_2\vec{V}_3$ are vector quantities representing velocities.

Suppose a train is moving at 20 km/h [E]. Seated passengers are not moving relative to the train and for someone who is sitting in the train. For someone who is standing outside, passengers are moving at 20 km/h [E] relative to the ground.

A passenger walking inside a moving train has different velocities relative to the train and the ground.

Practice Problem:

A train is moving at 20 km/h [E]. A passenger walking inside a moving train.

i) If a passenger on this train walks ***towards the front*** of the train at speed of 3 km/h. What is the passenger's velocity (speed) relative to the ground (or for someone standing outside)?

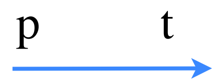
The velocity of a passenger relative to the ground (${}_{p}V_{g}$) = passenger velocity relative to the train (${}_{p}V_{t}$) + the train's velocity relative to the ground (${}_{t}V_{g}$).

$$\boxed{{}_{p}\vec{V}_{g} = {}_{p}\vec{V}_{t} + {}_{t}\vec{V}_{g}}$$

V: velocity, p: passenger, g: ground, t: train

${}_{t}\vec{V}_{g} = 20\ \text{km/h[E]}$

${}_{p}\vec{V}_{t} = 3$ km/h[E]



The passenger and the train are going in the same direction (east, or positive), then the vectors are added.

${}_{p}\vec{V}_{g} = {}_{p}\vec{V}_{t} + {}_{t}\vec{V}_{g} = 3 + 20 \;\; = \;\; 23$ km/h [E].

So the passenger velocity relative to the ground is 23 km/h [E].

ii) If the passenger walks ***towards the back*** of the train with a velocity of 3 km/h [W]. What is the relative velocity of the passenger relative to the ground?

Remember: To add two vectors that are in opposite directions, change the sign of one vector so that they have the same direction, and add their magnitude.

${}_{t}\vec{V}_{g} = 20$ km/h[East] $\qquad t \longrightarrow g$

${}_{p}\vec{V}_{t} = 3$ km/h[West] $\qquad t \longleftarrow p$

Change the sign

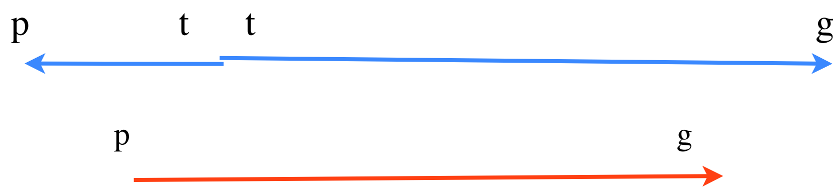
${}_{p}\vec{V}_{t} = -\,3$ km/h[East] $\qquad p \longrightarrow t$

$${}_{p}\vec{V}_{g} = {}_{p}\vec{V}_{t} + {}_{t}\vec{V}_{g}$$

$$= 3 \text{ km/h[W]} + 20 \text{ km/h[E]}$$

$= 20$ km/h[E] - 3 km/h[E]

$= 17$ km/h [E]



Practice Problems: Answer the following questions.

1. A baseball pitcher is warming up as he travels to a game by airplane. The velocity of the airplane relative to the ground is: $_a\vec{V}_g$ = 400 km/h [West]. The pitcher throws a ball with a velocity of $_bV_a$ 150 km/h relative to the airplane. What is the ball's velocity relative to the ground, if the pitcher throws the ball towards

    a) the front of the plane? Both the ball and the plane are in West direction.

    b) the rear of the plane? The plane is going West and the ball is going East.

Use the relative motion formula:

$$_b\vec{V}_g = {_b\vec{V}_a} + {_a\vec{V}_g}$$

V; velocity, p; plane, g; ground a; air

2. Search and find one other application for relative motion. Discuss.