AP Physics

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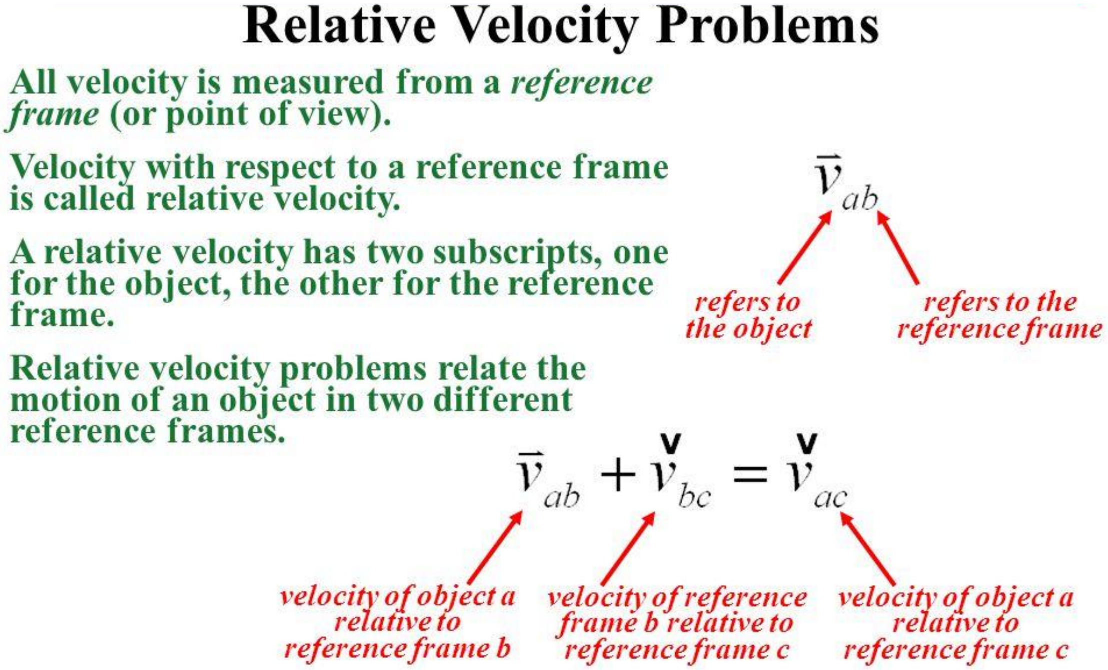
Relative Motion



Relative Velocity Problems

All velocity is measured from a *reference frame* (or point of view).

Velocity with respect to a reference frame is called relative velocity.

A relative velocity has two subscripts, one for the object, the other for the reference frame.

Relative velocity problems relate the motion of an object in two different reference frames.

$$\vec{v}_{ab}$$

refers to the object

refers to the reference frame

$$\vec{v}_{ab} + \overset{\vee}{v}_{bc} = \overset{\vee}{v}_{ac}$$

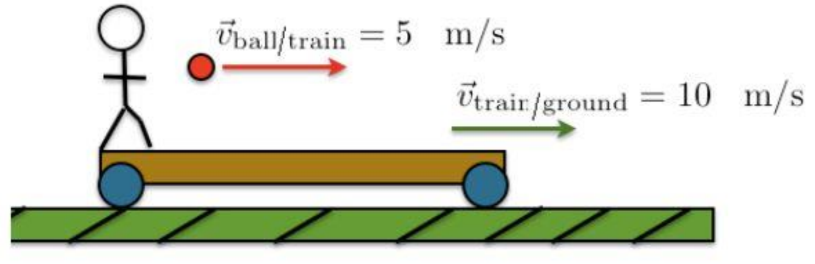
velocity of object a relative to reference frame b

velocity of reference frame b relative to reference frame c

velocity of object a relative to reference frame c

Finding the Relative Velocity Relative to a Stationary Reference Point – in 1-D: Example #1

- When finding the relative velocity of an object that is on another moving object the velocities are added together (the final velocity is relative to the Earth)
- The general formula that is used is:
  $\vec{v}A/B$= $\vec{v}$A/C + $\vec{v}$C/B
- The formula is read as Velocity of A relative to the Velocity of B is equal to the Velocity of A relative to the Velocity of C plus the Velocity of C relative to the Velocity of B
- The C's cancel each other out & we are left with the values at each end (A & B)
- This process is known as Galilean Velocity Addition



$$\vec{v}_{\text{ball/ground}} = \vec{v}_{\text{ball/train}} + \vec{v}_{\text{train/ground}}$$

V(ball relative to the ground) = 5 m/s + 10 m/s = 15 m/s

Figure 3.16 illustrates the concept of relative velocity by showing a passenger walking toward the front of a moving train. The people sitting on the train see the passenger walking with a velocity of +2.0 m/s, where the plus sign denotes a direction to the right. Suppose the train is moving with a velocity of +9.0 m/s relative to an observer standing on the ground. Then the ground-based observer would see the passenger moving with a velocity of +11 m/s, due in part to the walking motion and in part to the train's motion. As an aid in describing relative velocity, let us define the following symbols:

$$\mathbf{v}_{\boxed{\mathbf{PT}}} = \text{velocity of the } \boxed{\text{Passenger}} \text{ relative to the } \boxed{\text{Train}} = +2.0\,\text{m/s}$$

$$\mathbf{v}_{\boxed{\mathbf{TG}}} = \text{velocity of the } \boxed{\text{Train}} \text{ relative to the } \boxed{\text{Ground}} = +9.0\,\text{m/s}$$

$$\mathbf{v}_{\boxed{\mathbf{PG}}} = \text{velocity of the } \boxed{\text{Passenger}} \text{ relative to the } \boxed{\text{Ground}} = +11\,\text{m/s}$$

In terms of these symbols, the situation in Figure 3.16 can be summarized as follows:

$$\mathbf{v}_{\mathbf{PG}} = \mathbf{v}_{\mathbf{PT}} + \mathbf{v}_{\mathbf{TG}} \tag{3.7}$$

or

$$\mathbf{v}_{\mathbf{PG}} = (2.0\,\text{m/s}) + (9.0\,\text{m/s}) = +11\,\text{m/s}$$

According to Equation 3.7, $\mathbf{v}_{\mathbf{PG}}$ is the vector sum of $\mathbf{v}_{\mathbf{PT}}$ and $\mathbf{v}_{\mathbf{TG}}$, and this sum is shown in the drawing. Had the passenger been walking toward the rear of the train, rather than the front, the velocity relative to the ground-based observer would have been $\mathbf{v}_{\mathbf{PG}} = (-2.0\,\text{m/s}) + (9.0\,\text{m/s}) = +7.0\,\text{m/s}$.

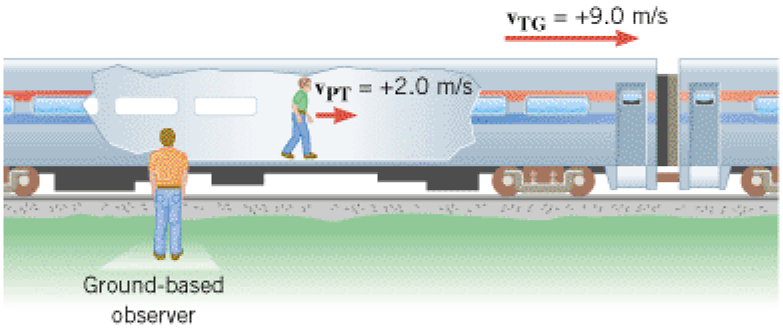


Figure 3.16 The velocity of the passenger relative to the ground-based observer is $\mathbf{v}_{\mathbf{PG}}$. It is the vector sum of the velocity $\mathbf{v}_{\mathbf{PT}}$ of the passenger relative to the train and the velocity $\mathbf{v}_{\mathbf{TG}}$ of the train relative to the ground: $\mathbf{v}_{\mathbf{PG}} = \mathbf{v}_{\mathbf{PT}} + \mathbf{v}_{\mathbf{TG}}$.

Each velocity symbol in Equation 3.7 contains a two-letter subscript. The first letter in the subscript refers to the body that is moving, while the second letter indicates the object relative to which the velocity is measured. For example, $\mathbf{v}_{\mathbf{TG}}$ and $\mathbf{v}_{\mathbf{PG}}$ are the velocities of the **T**rain and **P**assenger measured relative to the **G**round. Similarly, $\mathbf{v}_{\mathbf{PT}}$ is the velocity of the **P**assenger measured by an observer sitting on the **T**rain.

The ordering of the subscript symbols in Equation 3.7 follows a definite pattern. The first subscript (P) on the left side of the equation is also the first subscript on the right side of the equation. Likewise, the last subscript (G) on the left side is also the last subscript on the right side. The third subscript (T) appears only on the right side of the equation as the two "inner" subscripts. The colored boxes below emphasize the pattern of the symbols in the subscripts:

$$\mathbf{v}_{\boxed{\mathbf{PG}}} = \mathbf{v}_{\boxed{\mathbf{P}}\mathbf{T}} + \mathbf{v}_{\mathbf{T}\boxed{\mathbf{G}}}$$

In other situations, the subscripts will not necessarily be P, G, and T, but will be compatible with the names of the objects involved in the motion.