FIRST:

Student Directions and Worksheet

Physics Interaction 3

Relative Velocity and Acceleration

Overview

Objective To learn how measurements of velocity and acceleration taken from different reference frames are related to each other.

Summary of Interaction First, you will be asked some questions to develop your intuition about these concepts. Then, you will observe “bandits” running atop “train cars” to record and analyze information about their relative velocity and acceleration.

Formulas Required

1. $v_{be} = v_{bt} + v_{te}$
   (vector velocity addition)

2. $a_{be} = a_{bt} + a_{te}$
   (vector acceleration addition)

3. $v_{be} = -v_{eb}$, $a_{bt} = -a_{tb}$ and so on
   (vector direction reversal)

4. $|v| = \sqrt{v_x^2 + v_y^2}$
   (magnitude of velocity)

Concepts Explored Relative velocity
Relative acceleration

Activity A: Hopping on a Bus

To get warmed up, answer the following questions. They are designed to focus you on the main concepts of this worksheet so that when you get to the experiments, your thoughts will be clearer.

Problem 1 — *Pretend that you are walking from the back to the front of a bus. The bus is moving forward at 10 m/s, and you are walking in the bus at 1 m/s. How fast are you walking relative to the ground?*

Problem 2 — *Now pretend that you are walking from the front to the back. The bus is still moving forward at 10 m/s, but you are walking 1 m/s toward the back. How fast are you now walking relative to the ground?*

Problem 3 — *Pretend that the bus driver and an observer on the sidewalk have accurate stopwatches. They both have agreed to time you as you walk from the back to the front of the bus, recording how much time it took. Will both of their measurements agree?*

Activity B: Observing a Bandit's Motion on a Train

Now imagine that you have disembarked from the bus and have hopped on a train. A bandit has also hopped on the train, but bandits being as they are, he has hopped onto the roof. What you are going to do is record some information about the bandit's velocity from different reference frames.

1. *Open the document* Bandit on a Train.

In this experiment, there is *one* bandit on the roof of *one* train car. However, you have been provided with two views of this scene. The first is from the point of view of an observer standing on the earth (observer E). The second is from the point of view of an observer moving along with the train (observer T). The view at the top is observer E's view; the view at the bottom is observer T's view.

2. *Run the experiment, stopping it when the bandit reaches the end of the train car (approximately).*

Problem 4 *Are the two views of the bandit consistent with each other? Specifically, would observer E and observer T agree that the bandit reached the end of the train car after the same amount of time?*

To analyze what you have observed, you will need to record information from the meters. Find the meter with the label "Velocity/Bandit to Train." This meter indicates the velocity of the bandit relative to the train. Be sure to read the velocity in the x-direction (V_x). In this worksheet, the velocity of the bandit relative to the train will be represented by the symbol v_{bt}. The velocity of the train relative to the earth will be represented by the symbol v_{te}.

Problem 5 *Record the value of the bandit's velocity relative to the train.*

Now record the velocity of the train relative to the earth.

Give some thought to what you have just observed. Think back to the story of hopping on the bus. You just recorded the velocity of the bandit relative to the train, and the velocity of the train relative to the earth.

Given the quantities v_{bt} and v_{te}, what prediction can you make about the velocity of the bandit relative to the earth? Explain how you arrived at your answer.

Problem 6 *Now look at the screen at the meter with the label "Velocity/Bandit to Earth." Record this value.*

Compare your prediction of the bandit's velocity to the recorded value.

3. *Close the document.*

Activity C: Observing the Bandit's Relative Velocity

This scenario is much like the one above; the difference is that the train has reversed direction. You will be focused on the relative velocity of the bandit as seen by observer E and observer T.

1. *Open the document* Bandit on a Train 2.

In this experiment, there is one bandit and one train, but you are provided with two views of the scene. The first view is from the reference frame of observer E (the observer on the earth) and the second view is from the reference frame of observer T (the observer moving along with the train).

2. *Run the experiment, stopping it when the bandit reaches the end of the train car (approximately).*

Problem 7 — *Are observer E's and observer T's views of this scene consistent with each other? (Specifically, would the two observers agree on the bandit's position on the train car at all points in time?)*

Problem 8 — *Record the velocity of the bandit with respect to the train. Remember to record the x-component of velocity (V_x) only.*

Record the velocity of the train with respect to the earth.

Using the values of v_{bt} and v_{te}, calculate the velocity of the bandit with respect to the earth.

Problem 9 — *Read the value of v_{be} from the meter.*

Compare the calculated value of v_{be} to the value on the third meter.

3. *Close the document.*

Activity D: Observing the Bandit's Relative Acceleration

This scenario is similar to the last, but the bandit will be accelerating relative to the train car, and the train car will be accelerating relative to the earth.

1. *Open the document* Bandit on a Train 3.

Again, there is one bandit and one train, but you are provided with two views of the scene. The first view is from the reference frame of observer E and the second view is from that of observer T.

Note that a net force is acting on the bandit, and another net force is acting on the train car. The bandit is increasing his speed as he runs forward; the friction from the soles of his shoes provide the force forward. The train car is accelerating; the force is provided from the pull of the car in front.

Note that there does not appear to be a net force acting on the train car from observer T's point of view. This is because observer T is being accelerated along with the train and therefore does not observe the train accelerating relative to him.

2. *Run the experiment, stopping it when the bandit reaches the end of the train car (approximately).*

Problem 10 — *Are observer E's and observer T's views of this scene consistent with each other?*

Problem 11 — *Record the acceleration of the bandit with respect to the train. Remember to record the x-component of acceleration (A_x) only.*

Record the acceleration of the train with respect to the earth.

Using the values of a_{bt} and a_{te}, calculate the acceleration of the bandit with respect to the earth.

Problem 12 — *Read the value of a_{be} from the meter.*

Compare the calculated value of a_{be} to the value on the third meter.

3. *Close the document.*

Activity E: Observing the Bandit's Relative Velocity **and** Acceleration

In activities C and D, you focused on only one aspect of the bandit's motion: his velocity or his acceleration. In this activity, you will be observing both of these measures simultaneously.

1. Open the document Bandit on a Train 4.

As before, there are two views of the same bandit.

Before running the experiment, be prepared to watch the two velocity meters and the two acceleration meters as the bandit moves toward the end of the train car. You will be asked to record your observations.

2. Run the experiment, mentally comparing the two velocity meters and the two acceleration meters.

3. Stop the experiment when the bandit reaches the end of the train car (approximately).

Problem 13 *Record the two values of the acceleration of the bandit.*

Record the two values of the velocity of the bandit.

Is the acceleration of the bandit as measured in one reference frame larger than the other? If so, which measurement is larger, and how much larger is it?

Using the recorded values of v_{bt} and v_{be}, you should be able to determine v_{te}.

Problem 14 *Explain how to compute v_{te} given v_{bt} and v_{be}. Then compute v_{te}. This will be referred to as your "first calculation" since you will recompute it later.*

Using the values of a_{bt} and a_{be}, you should be able to determine a_{te}.

Problem 15 *Explain how to compute a_{te} given a_{bt} and a_{be}. Then compute a_{te}.*

From this computation of the train's acceleration with respect to the earth, is it correct to say that the train and the earth are moving at a constant velocity with respect to each other?

4. *Reset and rerun the experiment. This time, stop it when the bandit is only halfway to the end of the train car (approximately).*

Problem 16 *Read the values of v_{bt} and v_{be} at this point in time and use them to compute the value of v_{te}.*

From your first and second calculations of v_{te}, is it correct to say that observer T and observer E are moving at a constant velocity relative to each other?

5. *Close the document.*

Additional Questions

1. *You are walking up an escalator at a rate of 1 step per second. The escalator is running at a speed of 0.5 steps per second.*

   What is your effective climb rate?

   Approximately how long will it take you to ascend the equivalent of 15 steps?

2. *The water of the Gulat River travels at a rate of 0.3 m/s. You paddle upstream at a rate of 0.7 m/s relative to the water. What is your velocity upstream relative to the earth?*

3. *An airplane is moving 600 mi/h northward with respect to the earth. The winds are blowing to the south at a rate of 20 mi/h with respect to the earth. What is the velocity of the plane with respect to the air?*

4. *A car is moving west along the highway at a rate of 2 km/h. A bug is crawling directly across the roof of the car from the driver's window to the passenger's window at a rate of 0.5 km/h. How fast is the bug moving with respect to the earth?*

5. *At a certain instant in time, a particle is accelerating upward at a rate of 3 m/s^2 with respect to the earth. At the same time, it is accelerating horizontally at a rate of 2.6 m/s^2 with respect to the earth. What is the magnitude of its total acceleration?*