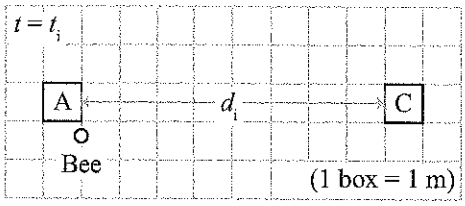
I. Position and displacement relative to different observers

Two cars, A and C, move directly toward one another. At time t_i, the cars are $d_i = 8$ m apart as shown, and at time t_f, they are $d_f = 4$ m apart.

A bee moving with constant velocity is at the front of car A at time t_i, and at the front of car C at time t_f.



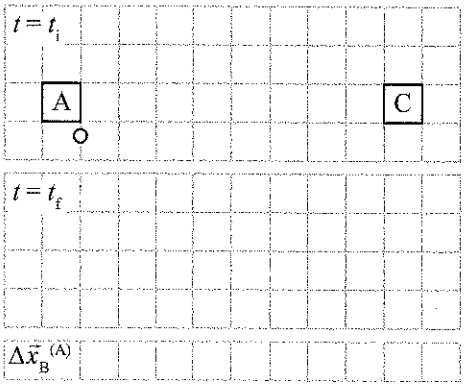
A. Consider the motion of the cars and the bee in the reference frame of car A. Let $\Delta\vec{x}_B^{(A)}$ represent the displacement of the bee as measured in the frame of car A.

1. Rank $|\Delta\vec{x}_B^{(A)}|$, d_i, and d_f from largest to smallest. If any two are equal, state so explicitly. Explain.

2. The diagram at right shows the locations of the cars and the bee at time t_i in the reference frame of car A.

   On the diagram, show the locations of the cars and the bee at time t_f in the reference frame of car A. Explain how you determined the location of each object. (*Hint:* Start with car A.)

In the reference frame of car A



3. In the space provided above right, draw $\Delta\vec{x}_B^{(A)}$.

   Is your ranking in part A.1 consistent with the vector that you drew? If not, resolve the inconsistency.

4. Is the quantity $\Delta\vec{x}_B^{(A)}$ associated with:

   - *a single instant in time* or *an interval of time?* Explain.

   - *the distance between two objects* or *the distance traveled by a single object?* Explain.

   Describe how you could use $\Delta\vec{x}_B^{(A)}$ to determine $\vec{v}_B^{(A)}$, the velocity of the bee as measured in the reference frame of car A.

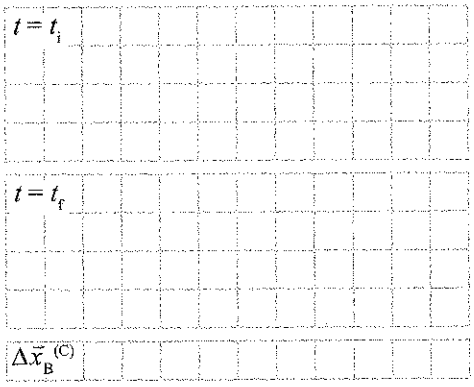
B. Consider the motion of the cars and the bee in the reference frame of car C. Let $\Delta\vec{x}_B^{(C)}$ represent the displacement of the bee as measured in the frame of car C.

1. Rank $|\Delta\vec{x}_B^{(C)}|$, d_i, and d_f from largest to smallest. If any two are equal, state so explicitly. Explain.

2. On the diagram at right, show the locations of the cars and the bee at times t_i and t_f in the reference frame of car C.

   Compare your completed diagram with those of your partners. Resolve any inconsistencies.

In the reference frame of car C



3. In the space provided, draw $\Delta\vec{x}_B^{(C)}$, the displacement of the bee as measured in the reference frame of car C.

   Is your ranking in part B.1 consistent with the vector that you drew? If not, resolve the inconsistency.

C. Does the distance between two objects depend on the frame in which it is measured? Cite a specific example from your work above that supports your answer.

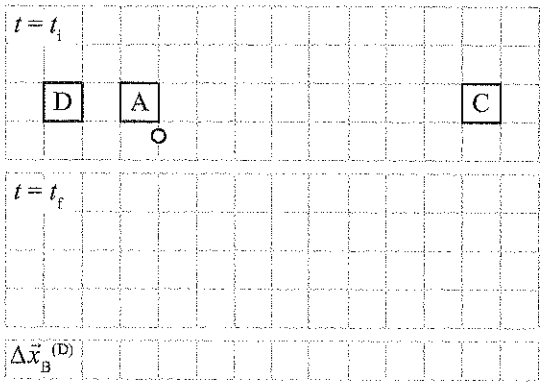
Does the distance traveled by a single object depend on the frame in which it is measured? Cite a specific example from your work above that supports your answer.

Is the speed of the bee measured in the reference frame of car A *greater than, less than,* or *equal to* that measured in the reference frame of car C? Explain.

D. Suppose that car D moves so as to remain a fixed distance behind car A at all times.

The diagram at right shows the locations of the three cars and the bee at time t_i in the reference frame of car D.

In the reference frame of car D



1. On the diagram, show the locations of the cars and the bee at time t_f in the reference frame of car D.
2. In the space provided, draw the vector $\Delta\vec{x}_B^{(D)}$, the displacement of the bee as measured in the reference frame of car D.
3. Is $|\Delta\vec{x}_B^{(D)}|$ *greater than, less than,* or *equal to* $|\Delta\vec{x}_B^{(A)}|$? Explain.

If all displacements of an object (such as the bee) are measured to have the same value by two different observers, those observers are said to *be in (or have) the same frame of reference.*

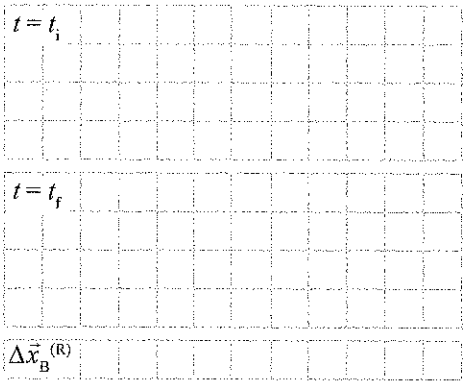
E. Which of the cars, if any, are in the same frame of reference? Explain.

Generalize your answer to describe the conditions under which two observers are in the same frame of reference.

F. Now consider the motion of cars A and C and the bee from the reference frame of the road. Suppose that the cars move with the same speed as each other in this frame.

1. On the diagram, show the locations of cars A and C and the bee at times t_i and t_f in the reference frame of the road. Explain how you determined the location of each object.

In the reference frame of the road

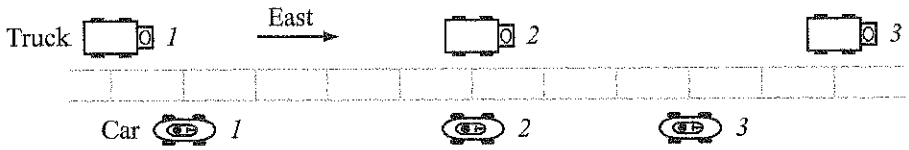


2. In the space provided, draw a vector to represent $\Delta\vec{x}_B^{(R)}$, the displacement of the bee as measured in the reference frame of the road.

G. Rank the magnitudes of the displacement of the bee as measured in the reference frames of car A, car C, and the road. If any two are equal, state so explicitly.

II. Relative velocity

A car and a truck move on a straight road. Their positions are shown at instants *1–3*, separated by equal time intervals.

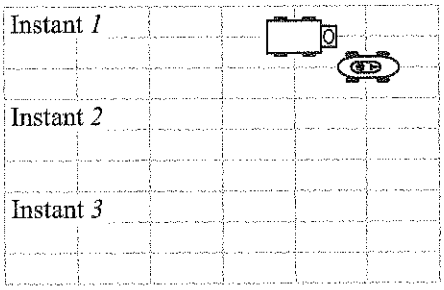


A. Describe the motion of the car and the truck in the reference frame of the ground (*i.e.*, specify the direction of motion of each object and whether each object is *speeding up, slowing down,* or *moving with constant speed* in the reference frame of the ground).

B. Complete the diagram at right by showing the locations of the car and the truck at instants *2* and *3 as measured in the reference frame of the truck.*

Explain how your completed diagram is consistent with the fact that the truck is at rest in its own frame of reference.

In the reference frame of the truck



C. Use your completed diagram to draw average velocity vectors for the car *in the reference frame of the truck* for the intervals indicated.

- In the reference frame of the truck, is the car *moving to the east, moving to the west,* or *at rest?* Explain.

Average velocity of car in frame of truck

from *1* to *2* ☐

from *2* to *3* ☐

- In the reference frame of the truck, is the car *speeding up, slowing down,* or *moving with constant speed?* Explain.

D. How does the description of motion of the car in the reference frame of the truck compare to that in the reference frame of the road?

E. During a small time interval Δt from just before to just after instant *2*, does the car *move to the east, move to the west,* or *remain at rest* in the reference frame of the truck? Explain.

In the space provided, draw an arrow to indicate the direction of the *instantaneous* velocity vector of the car in the reference frame of the truck at instant *2*. If the velocity is zero, state that explicitly.

Direction of instantaneous velocity of car in frame of truck at instant *2*

Consider the following statements:

Statement 1: "At instant 2 the car and the truck are side by side, so the velocity of the car in the truck's frame is zero at that instant."

Statement 2: "Before instant 2, the truck is catching up to the car, so the truck sees the car as slowing down."

Do you agree or disagree with each of the statements? Explain.

➪ Discuss your reasoning with an instructor.