

Lab 2.1 – Constant Velocity in a Straight Line

Purpose

There are a number of ways of representing (modeling) motion that we'll find useful. In this lab we'll look at a variety of useful models including

- Ink jet dots - an ink jet printer produces dots on a page at equal time intervals. When attached to a moving cart the dots provide a record of where the cart was after each time interval.
- Signed numbers representing the position and time of the cart at various instants can be used to calculate values for the cart's speed and velocity.
- Photogates – a light beam interrupted by a passing cart will start and stop a timer to give us a record of when the cart was at a series of given positions.
- Graphs – a graph of the cart's position at each instant of its travel describes the cart's motion over time including its speed and the direction of its motion.
- The magnitude and direction of the cart's velocity can be represented by arrows whose size and direction indicate the speed and direction of motion of the cart.

Our purpose is to learn to understand motion as well as models for describing it. These models will be useful in describing other phenomena that lie ahead.

Equipment

Virtual Dynamics Track

A computer mouse, trackball or stylus. The touchpads built into laptops don't work so well with this apparatus, but they'll do in a pinch.

Logger Pro (LP) software

PENCIL

Explore the Apparatus/Theory

Open the Virtual Dynamics Track Lab on the website. This is the most versatile apparatus that we'll use in the lab program. Only a few of its features are visible when you start it up. We'll discover them as we go.

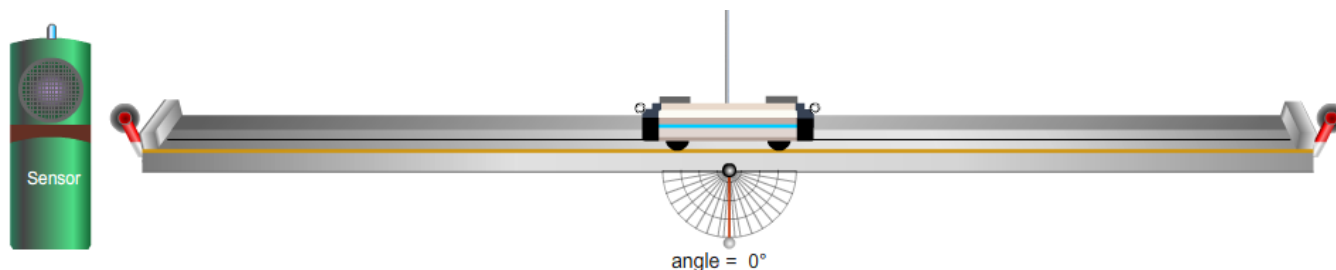


Figure 1

Familiarize yourself with the apparatus

When you first load the virtual lab you should see a message in the box at the bottom of the screen.

Drag over objects for more information.
Right-click (Mac: Ctrl-click) for context menus related to the graph or apparatus.

Try it. Without clicking, move your pointer over each item on the screen.

When you roll over the cart the message indicates that you can click on the cart to drag it along the track. Try it.

Try letting it go when it's moving. Practice throwing it at slow and fast speeds left and right. Notice how it behaves when it hits either end of the track. How do you stop it? Try the stop sign.

Try clicking on the ruler icon. Note that you can drag the ruler up and down. You'll use the ruler to measure the location of the cart, actually its mast. Click the ruler icon again to hide it. Like many icons, this one toggles on/off.

Some features are accessed by clicking on icons but more often you'll see labeled buttons. Try [Pick Vo & Go!] Sounds like a lottery game. Vo means original velocity. It's 100 cm/s by default. This helps you launch the cart cleanly with a reproducible launch speed. Try to launch the cart to the left.

See if you can figure out how to make the track tilt at a 5° angle and then return it to 0° . (We'll assume that a positive angle means uphill to the right.)

Feel free to mess around. You can't hurt it. You'll often find that clicking on a button makes new ones and appear and others hide.

Introduction – Constant velocity in a straight line

Suppose you were given a pair of rabbits, one male and one female. Every few months you look in on them in the spacious outdoor pen you've provided. Every time you look there are more rabbits. One of your recorded observations might be "boy, there sure are a lot of rabbits out there." Later, "Wow, I think there are even more than last year."

To better understand this phenomenon you'd need to count them at regular intervals. And you might make a table, or better yet a graph. And you might find an equation that matches the graph. With your graph or equation you could predict the future population. And when it leveled off you'd know that something was different. And you'd look for a new influence, like a fox.

None of those numbers and equations and graphs and theories are rabbits. They are abstract representations of rabbits and how they interact and the effect of outside forces like predators or the size of their enclosure. Together they make up a **model** of rabbit population growth. That is, your graph is not a group of rabbits, but to some extent it behaves like one.

In physics we develop models for understanding the nature and behavior of physical things much simpler than rabbits. We'll begin by studying the different ways that objects move.

In this lab we're interested in looking at a very simple type of motion – motion at a constant velocity in a straight line. Just as with the rabbits we need to abstract from "there it goes" to some more information-rich ways of representing motion. The actual, well virtual, cart moving along the track is a real, well virtual, event. We need a way of describing its motion in words diagrams, equations, etc. By doing this we can intellectually make predictions and compare this motion to other motions.

I. Ink Jet Dots

The first way we'll do this is by letting the cart leave behind a trail of colored dots as it moves. To do this we'll use the Ink Jet Dots tool. Click the tool's radio button (Ink Jet Dots) to load it. The first thing you'll notice is a paper feeder above the track. There's also a red dot on the mast of the cart. That's the ink jet. Give the cart a good toss and click on [Start Ink Dots]. Get the idea? Now click [Stop Ink Dots] and [Clear Last Dots].

In figure2 you see the new controls that have appeared. Since the paper has feed upward Click [Feed Dn] a few times until "Title:" appears. [Feed Dn] feeds half a line. [X8] feeds four lines. Try [Show All] and [Show Top]. Roll you mouse over [Print] to see just how it works. The print outs are perfect on a nice printer. Ink jets are a bit sketchier.

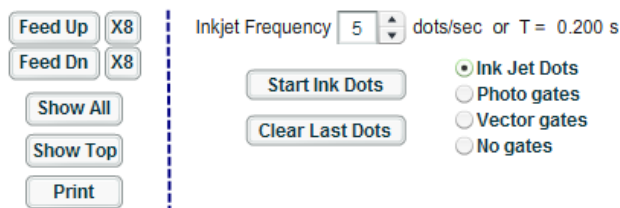


Figure 2


Finally, we can set the time interval between dots by using the inkjet frequency numeric stepper. We want to print two dots per second or a dot every .5 seconds. Use the up and down arrows to set this. The time, T, between dots will be .500 s. Now we're ready.

[Set $\theta = 0^\circ$]

Click the [Go] (Pick Vo & Go!) button. Watch the motion down the track and after it bounces off the bumper. These two motions are similar in some ways and different in others. Now tilt the track up and down. This looks different but it may not

be exactly clear how. We're looking for ways of talking about these motions that will allow us to compare them – which is faster, how long would it take a cart to go 30.0 cm, etc.

Follow these steps. Note the comments in parentheses.

1. [Set $\theta = 0^\circ$]
2. After "Title:" type "Constant Velocity Lab, Ink Dots." (Just click where you want to type. Never type <Enter>.)
Result:  Title: Constant Velocity Lab, Ink Dots.
3. Below the title type "f = 2 dot/sec, and Vo = 20.0 cm/s." (Do the same sort of labeling in future.)
4. Set f = 2 Hz, Vo = 20.0 cm/s, and Recoil = 0. (Look for it.)
 - a. Drag the cart to the left end of the track.
 - b. [Start Ink Dots] (That is, click "Start Ink Dots")
 - c. [Go]
 - d. [Stop Ink Dots] when the cart stops. (That's what Recoil = 0 was for.)

Q1. What do these dots represent? OK I'll do this one.

Each dot represents the location of the cart at a certain time. The sequence of dots represents its changing position over time.

Q2. How much time passes as the cart passes from one dot location to the next. _____s

Q3. Since the time and distance between adjacent dots are both approximately constant, what does this say about the motion of the cart?

Note: You may have noticed that the first and last dots are not reliable. Just ignore them.

5. [Feed Up] a line. Two clicks. (Remember to type in a label as before.)
6. Set Vo = 40 cm/s

Q4. Prediction: How will the pattern differ this time? How will the new dot spacing indicate that the speed has doubled?

7. Try it and see.

Q5. Any discrepancies? Remember to ignore the first and lost dots.

Q6. How will the dot spacing for Vo = 80 cm/s compare to Vo = 20 cm/s?

8. Give it a try. Hopefully your predictions were correct.

Q7. How is the constancy of speed indicated with the ink dots? I.e., how can you tell that the speed is constant?

Q8. How is the relative magnitude (size) of different speeds indicated with the ink dots?

Q9. Let's see if our system is well calibrated. Use the space below for your responses.

- How can you compute the cart's speed using the time between dots (.500 s), and the ruler?
- Try it for the 80 cm/s trial. Show your data and your calculations. It's better to use as many dots as possible in your measurements, but be sure to ignore the first and last dots.
- Calculate the percentage error assuming that 80.0 cm/s is the accepted value.

$$\% \text{ error} = \frac{|\text{measured value} - \text{accepted value}|}{\text{accepted value}} \times 100\%$$

Q10. On a new line reproduce your 2 dot/sec, 40 cm/s trial. How will spacing be affected if $f = 1$ ($T = 1$ s)? Try with green ink and 40 cm/s. Explain why you get this different spacing.

Q11. With $T = 1$ sec the distance between dots is _____ what it was with $T = .5$ s. Since both _____ and _____ have doubled, the speed is _____. (Choose from: same, speed, time, distance, twice, half)

9. Set $f = 2$ Hz, $V_o = 40$ cm/s to the left, and Recoil = 0, blue dots. [Go]

Q12. How do you make the cart go to the left, still using the Go button? _____

Q13. Can you tell the direction of the cart's motion from looking at dots? _____

If you're connected to a printer you can print out your collection of dots now. But it's not required. (Feed all the way down.)

So far ...

- Speed is the rate at which distance is traveled
- Speed is given by distance traveled in a given interval of time
- Speed = distance/time
- Constant spacing in a given time indicates constant speed
- We can't determine the direction of travel with the ink dots

II. Photogates

OK, let's try a new gadget that looks at motion in a different way.

1. Click the Photo gates radio button. You'll see:

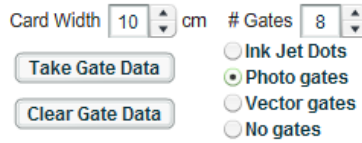


Figure 3

- a. Set the card width to 10 cm, # gates to 8, and $V_0 = 20$ cm/s, and Recoil = 0.
- b. Drag the cart to the left end of the track.
- c. [Take Gate Data] (Click it.)
- d. [Go]
- e. [Stop Gate Data] when the cart stops.

You should get something like this. (I've added the ruler.)

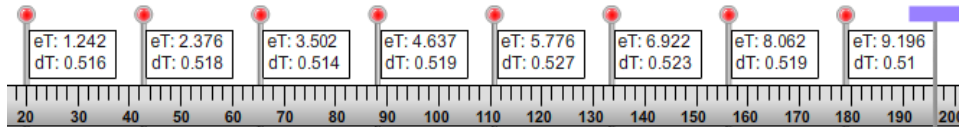


Figure 4

What does all this mean? Each “flag” displays a pair of numbers. The top ones, labeled “eT:” seem to be increasing steadily. The bottom ones, labeled “dT:” seem to be pretty constant. Here's how it works.

a)		<p>The red light atop the mast shines toward you. A detector (not shown) closer to you receives the light. <u>These two together are the photogate.</u> (Like an elevator door sensor.)</p> <ol style="list-style-type: none"> a. When the center of the red beam is interrupted by the purple card, a signal is sent to the computer telling it that the leading end of the card has entered “the gate.” b. In figure b) half of the card has passed through the gate. This also means that the mast of the cart is at the center of the gate. c. The trailing end of the card has just exited the gate. It again signals this to the computer and heads for the next gate. So the computer has an arrival time and a departure time for each card. <p>The computer calculates dT, the time during which the gate was blocked. (Fig a to c.) It then calculates the elapsed time from when you hit [Take Gate Data] to when the center of the card is in the gate. (Fig b.) That's eT, the time when the cart (mast) reaches the detector.</p>
b)		
c)		

2. For $V_0 = 20$ cm/s, record the **average** measured dT, \overline{dT} , for all eight gates, in the table. (Moving right.)

		20 cm/s	40 cm/s	80 cm/s
Moving Right →	Predicted dT	X		
	Avg. Measured \overline{dT}			
← Moving left	Predicted dT			
	Avg. Measured \overline{dT}			

3. Let's take some new data. We'll use the same V_0 s as before: 20, 40, and 80 cm/s.
4. Based on your measured \overline{dT} , for 20 cm/s, predict dT for 40 cm/s and 80 cm/s and enter these values in the table.

Q1. What is your logic in determining your answer?

5. Take readings for these two speeds and enter them into the table as your measured dT s.

Q2. With the ink dots in part I, dT was constant and the distance between dots varied for different speeds, but for a given speed, the distances between dots was _____.

Q3. In this part, for a given speed, the distance traveled between gates and the time between gates, are both _____.

Q4. With increasing speed, the time, dT , is _____.

6. Make dT predictions for all three speeds with the cart moving to the left and then measure them with the photogates.

*****NOTE: The right three gates give bad dT readings at slow speeds. Please ignore them, with my apologies*****

Q5. How is constant speed indicated when using the photogates? _____

Q6. How is the magnitude of the speed indicated by photogates? _____

7. Does the data in Table 1 indicate direction? _____

With the ink dots and the photogates we haven't been accounting for the direction of motion. But the direction is surely an important aspect of any motion. It's time we dealt with that. **Speed with a direction specified is called velocity.** For given velocity, speed is the magnitude of the velocity. Let's formalize our measurements a bit.

8. [Clear Gate Data]

9. Turn on the ruler and drag it just above the cart.

The ruler will represent an **x-axis**, where $x = 0$ at left end and positive values increase to the right. We could just as well put $x = 0$ at the center but our apparatus isn't set up that way.

Position is also a quantity that has a direction in that an object could be to the left or the right of $x = 0$. If it is to the right we would say that its position is positive. To the left it's negative.

10. Reduce the number of gates to two. Place one at 40.0 cm and the other one at 80.0 cm.

On our x-axis we would say that the two **positions** are $x_1 = + 40.0$ cm, $x_2 = +$ _____ cm.

The **distance** between the gates is just 100 cm regardless of which way the cart moves. But we can take direction into account if we define a new quantity called the **displacement**.

When an object moves from position x_1 to position x_2 , the object's **displacement** is defined as its **change in position**, where change is the final value minus the initial value.

On our track, we would say:

Displacement, $\Delta x = x_{\text{final}} - x_{\text{original}}$ where **delta**, Δ means the **change in x** which is the final value minus the initial value.

11. Shoot cart to right at 20 cm/s.

The displacement, $\Delta x = x_2 - x_1 = 140 \text{ cm} - 40 \text{ cm} = +100 \text{ cm}$

12. Shoot cart to left at -20 cm/s.

Q7. Now the displacement, $\Delta x = \underline{\hspace{1cm}} - \underline{\hspace{1cm}} = \underline{\hspace{1cm}} \text{ cm} - \underline{\hspace{1cm}} \text{ cm} = \underline{\hspace{1cm}} \text{ cm}$

Q8. For a displacement of -100 cm, the **magnitude** of the displacement $\underline{\hspace{1cm}}$ cm, and the – sign indicates the $\underline{\hspace{1cm}}$.

We defined speed as distance traveled/time taken. We can use this new quantity, the displacement, to define the **velocity** which includes direction of motion which it inherits from the displacement.

Velocity, v , is the displacement/time taken. Or,

$$\mathbf{Velocity} = \frac{\Delta x}{\Delta t} = \frac{x_f - x_o}{t_f - t_o}$$

13. Let's find the velocity of our cart using that idea. Fire the cart in each direction to find V_{right} and V_{left} . Show your answers along with your calculations. You'll use the elapsed time to calculate Δt .

Q9. $V_{\text{right}} = \underline{\hspace{2cm}}$

$V_{\text{left}} = \underline{\hspace{2cm}}$

And furthermore ...

- We see that distance and speed are descriptions of how far and how fast an object is going that include no reference to the direction of motion.
- Displacement and velocity are similar concepts but include an indication of direction. In physics we are much more interested in the latter.
- Quantities which include direction are referred to as **vectors**. Quantities which have no direction are referred to as **scalars**.

III. Graphing position vs. time

You probably noticed that in the previous section, graphs were being drawn below the track. Graphs are a very powerful tool for describing motion. They innately record the magnitude and direction in a very visual way so that they pop right out.

You'll need the motion sensor this time. Give it a try. Just click on the sensor. It will turn to face the track and the graph will begin to be plotted. Throw or "Vo" the cart and you'll see a straight, rising or falling line. Click the sensor again to stop data taking. The sensor is its own on/off switch.

1. Turn on the ruler and position it just above the cart.
2. Recoil = 0.
3. Set Match Graphs to 1. You'll see a big orange dot, the position indicator, on the vertical position axis. Drag the cart to the 100-cm-point on the ruler. Drag the cart back and forth. You'll see the position indicator rise and fall to match the cart's motion.
4. Your goal is to create three lines on the graph. Use
 - Red for +20 cm/s
 - Green for +40 cm/s
 - Blue for -80 cm/s
5. **Before doing this with the apparatus**, try your hand at drawing each of the graphs that you expect to see. There's more than one way to proceed, but here are some questions that you may struggle with.
 - a. "Where (x, t) do I start my line?" It might help to start each graph at a different point, but it's up to you.
 - b. "Then what?" There's more than one way to proceed. Do your best. It's really instructive to try to develop a plan using concepts that we've already worked with. Just remember that the velocity for each trial is constant. That's the key.
 - c. "Can't I just peek?" No. There are some insights to pick up while doing this. You'll have more ownership if your do it unassisted.

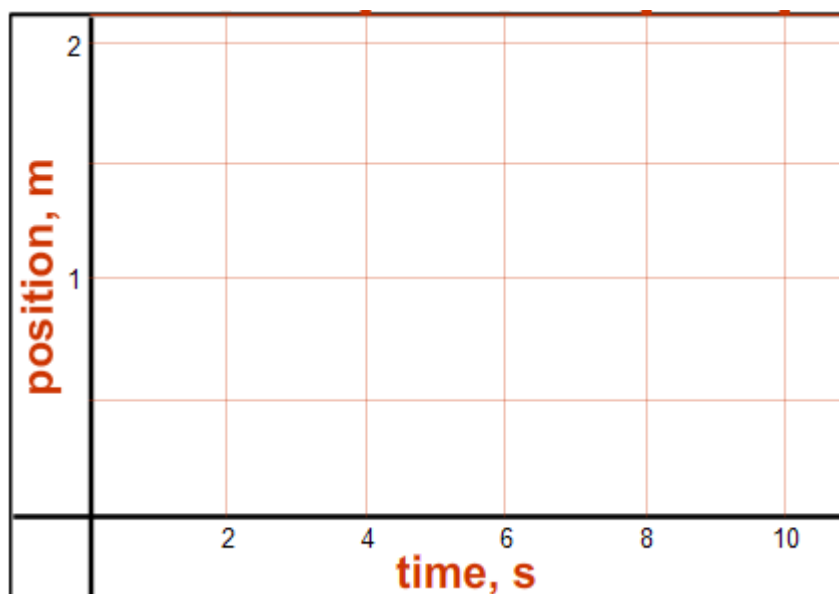


Figure 5

6. So how did that go? Hopefully you figured out a few things to work with. Don't panic if you didn't. You at least have your mind ready to do something with the explanation below. Here are some possible observations and givens.
 - a. For positive velocities the cart goes from left to right on the track so it starts at a low value for x . So those graphs start down near the origin and rise to higher points later in time. Likewise the -80 cm/s cart is going to the left so it starts at a high x value and goes toward lower values of x . So it starts high on the graph and drops.
 - b. **Velocity** = $\frac{\Delta x}{\Delta t} = \frac{x_f - x_o}{t_f - t_o}$
 - c. Since the velocity is constant the cart will go equal distances in equal time intervals. So if it starts at (x_1, t_1) , at a time Δt later it will be at x_2 which will be $\Delta x = v\Delta t$ further along and thus higher on the graph. So x_2 will be at $x_1 + v\Delta t$.
 - d. The velocity equation also tells us that the velocity is just the slope of the line (rise over run) and since the velocity is constant, the slope must be constant. So once you have two points, you can connect the two with a straight line and extrapolate to larger times.
 - e. The slope will be positive value for a positive velocity and negative for negative velocities.

Ex. Do this on the Figure 5 graph.

Suppose you chose your first point to be (40 cm, 2.5 s). Plot this point on the graph.

The velocity is $+20$ cm/s. So 5.0 seconds later it will have traveled

$$\Delta x = v\Delta t = 20 \text{ cm/s} \times 5.0 \text{ s} = 100 \text{ cm}$$

So it will now be at

$$x_2 = x_1 + v\Delta t = 40 \text{ cm} + 100 \text{ cm} = 140 \text{ cm}$$

This is a second point that will be on the graph. Plot this second point.

Since the velocity is constant you can connect these two points with a straight line. Got it?

7. Let's try it with the apparatus for +20 cm/s. Set $V_0 = 20$ cm/s, and recoil = 0. Put the cart at the left.
 - a. Match Graphs = 1
 - b. [Photo gates], use 2 gates: 40 and 140 cm. These are just for reference points not for data.
 - c. [Sensor] (click it.) and then [Go].
 - d. [Sensor] when the cart hits the right end to stop the sensor.

You should have something like this:

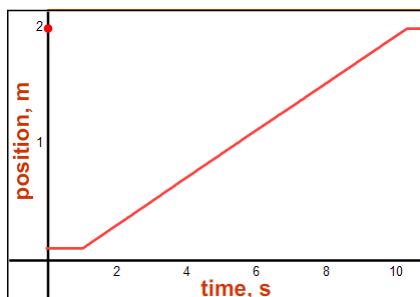


Figure 6

8. Let's analyze what we have.

<ol style="list-style-type: none"> a. Move the cart to 40 cm, where the first gate is located. The position indicator should move to match. b. At the top-right of the graph grab the horizontal handle and drag it down until its horizontal grid line passes through the position indicator as shown. c. Move a vertical handle horizontally until its grid line intersects with the horizontal grid line and the graph line as shown. d. This intersection point locates (x_1, t_1), where we're using the 40-cm point for the sake of clarity. 	
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<ol style="list-style-type: none"> e. Repeat for the 140-cm point. Let it be point (x_2, t_2). f. With our two points (x_1, t_1), and (x_2, t_2), we see that Δx is just the height of a triangle and Δt is the base. g. The slope of the line is just $\Delta x / \Delta t$. h. The slope of the line is the velocity. In this case the slope is positive so the velocity is positive. That makes sense because a positive line will result in $x_2 > x_1$ which means the cart's going to the right. 	
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9. Now try it with the other 2 graphs. Remember

- Red for +20 cm/s (Done)
- Green for +40 cm/s
- Blue for -80 cm/s

For the second and third cases repeat the procedures describe above to first draw it by hand on Figure 5 and then use the lab apparatus to check your work.

10. Here are all the graphs for ± 20 cm/s, ± 40 cm/s, ± 80 cm/s. Make sure that you understand how each graph describes each different motion.

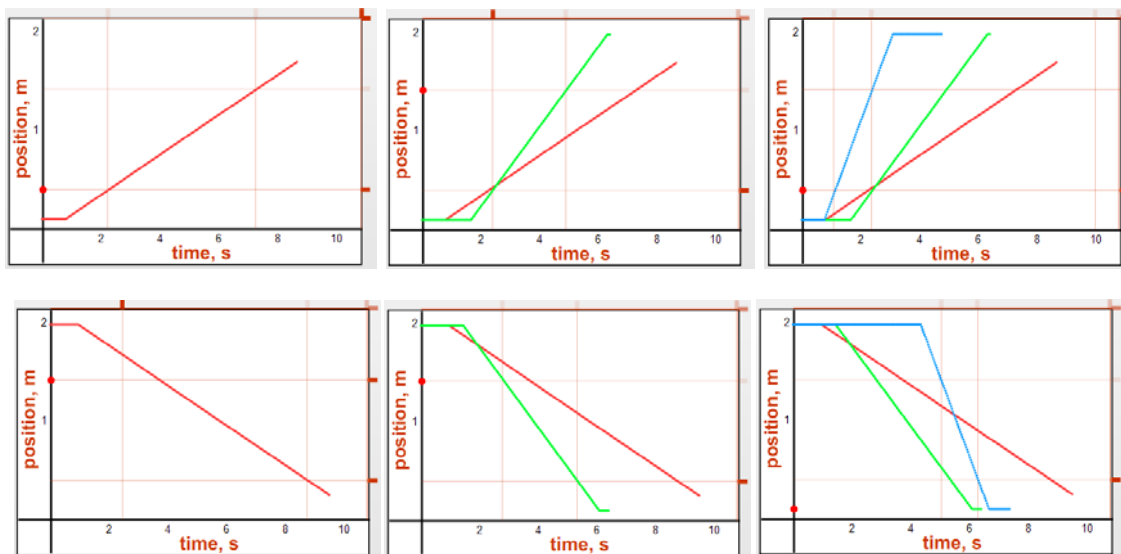


Figure 7

And furthermore ...

- A linear graph indicates a constant velocity.
- The **magnitude** of the velocity is given by the slope (steepness) of the graph of position vs. time.
- The **direction** of the velocity is given by the sign of the slope. A positive slope (rising line) indicates a velocity in the positive direction. Likewise for a negative slope.
- **Velocity** = $\frac{\Delta x}{\Delta t} = \frac{x_f - x_o}{t_f - t_o}$
- $\Delta x = v\Delta t$ and hence $x_2 = x_1 + v\Delta t$

11. Let's try this with a couple of unknown velocities. To the right of the V_0 numeric stepper is another one labeled $V_0?$. Entering a number in this box and clicking [Go] will give the cart a repeatable, unknown velocity. Your task is to find two unknown velocities. $V_0? = 1$, and $V_0? = 4$. For each velocity.
- Find the direction of the velocity by launching the cart from the middle of the track.
 - Create a graph of each motion using the apparatus. (Set $T_{max}(s)$ to 5 for better scaling.)
 - Copy each of the two lines to the graph below.
 - From the lines determine each of the two constant velocities. Record your answers in the space provided. Be sure to include a sign to indicate the direction of the velocity. Show your work in the space below the graph.
 - From your graph determine the approximate position of each cart half-way through its motion. This means the constant velocity portion of its motion. Ignore any zero-velocity portions of the graphs.

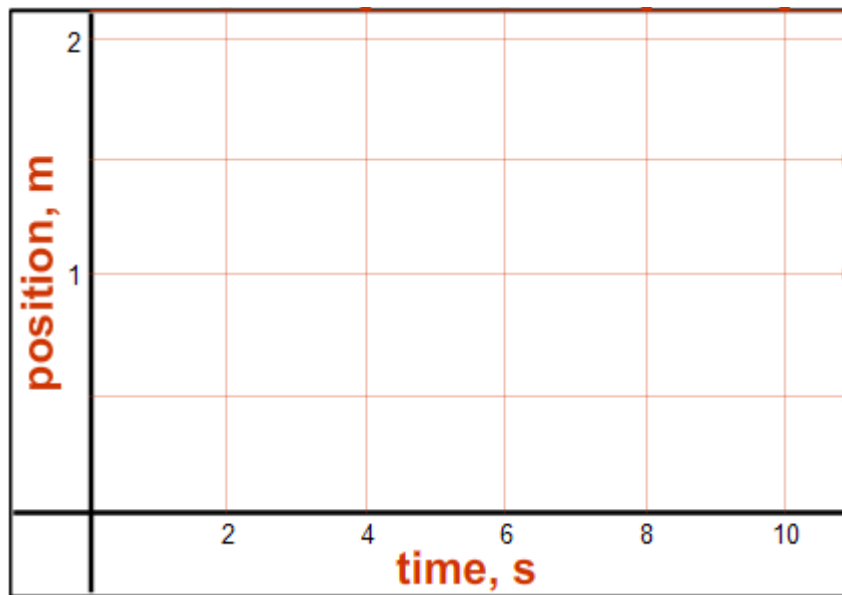


Figure 8

$V_1 =$ _____ cm/s

$V_4 =$ _____ cm/s

IV. Vectors

1. In the previous section we used plus and minus signs to indicate direction along an axis. Here's another way.

If you're standing on the street and someone asks how to get to a building on that street you might say "4 block that-a-way." When working with vector quantities we have a similar method of stating a magnitude and pointing in the correct direction. We draw vector arrows (often just referred to as vectors). The length of a vector arrow is proportional to the magnitude of the vector quantity it describes. The direction of the arrow indicates the direction of the vector.

So a vector representing a velocity of 35 cm/s, east might be an arrow 7 cm long pointing to the right. The scale would be $(35 \text{ cm/s}) / (7 \text{ cm}) = 5 \text{ cm/s} / \text{cm}$ of length of the arrow. Using that scale, (shown below the two arrows),

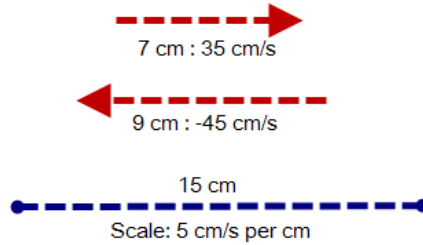


Figure 9

2. Our cart has eight different vectors associated with it! Seven represent forces. We just want to look at one for now, the velocity vector.

a. [No gates]

b. Turn on dynamic vectors using this button:
(Like the ruler it's a toggle switch.)



c. You'll see a bunch of vectors (vector arrows) overlapping the cart. You'll also see a bunch of check boxes below the sensor. Uncheck all but Velocity.

d. Recoil = 1

3. Fire the cart with various \pm velocities. Try throwing it at different velocities.

Q1. Draw the velocity vectors for +80cm/s and -80 cm/s and describe how they are similar and how they're different.

Q2. How does it a vector arrow indicate the magnitude of the velocity? The direction?

Q3. How can you tell by watching the velocity vector that the magnitude of the velocity is constant?

Q4. Put the cart at the left end of the track. Set $V_0 = 200 \text{ cm/s}$. Turn on the friction pad. Go!

Describe what you observe and your interpretation of what in represents.
