# Physics 123 Lab 1: Kinematics in One Dimension

## Physics 123: Electricity and Magnetism

Instructor: Professor Andrew Boudreaux, Andrew.Boudreaux@wwu.edu

**Introduction**

Classical mechanics, perhaps the oldest branch of physics, seeks to describe and explain how things move. The focus is on objects that are not too small and not too fast, such as specks of dust, soccer balls, and satellites. (Quantum mechanics is needed for the very small, and relativistic mechanics for the very fast.) *Kinematics*, the subject of this lab, refers to the description of motion, without concern for its causes. *Dynamics*, the subject of future labs, is the effort to explain *why* things move the way they do.

In kinematics, the concepts of *velocity* and *acceleration* are the main players. They are both ratio quantities, so proportional reasoning has a big role. Graphs, equations, and verbal descriptions are used to represent specific motions. In this lab you will use an ultra-sonic motion sensor coupled to a computer to generate motion graphs in real time, so that you can focus your attention on understanding what's going on, rather than making large numbers of measurements with rulers and stopwatches.

**Overview of the labs**

As discussed in the lab syllabus, each week's lab begins with a guided inquiry portion, continues with a reflection activity in which you revisit your initial prelab answers, and culminates with the open-ended "synthesis challenge." The synthesis challenge is previewed at the beginning of the lab each week so that you know where you are headed and can connect what you learn in the guided inquiry to what you need to do later. In addition, specific learning targets are found at the beginning of the lab so that you know what you are expected to learn. Grading criteria are made public, so that you know how you will be assessed on that learning. (See the Lab Syllabus.)

Your partners and your instructor will support your work in these labs. We expect that you will actively engage and learn through collaboration and consensus. Ask questions and offer your ideas. This period of time is set aside for you to practice and learn physics. We hope the labs spark your interest and that you enjoy the intellectual challenge!

**Learning targets**

Listed below are the main learning goals for this lab. These show up again at the beginning of each activity, so that you know what each activity is intended to help you learn.

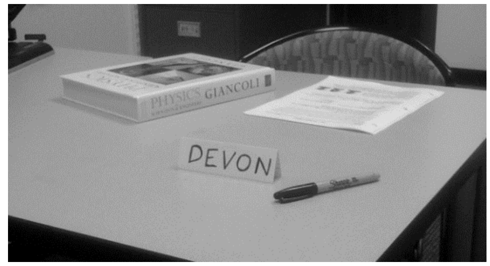
After this lab, you should be able to:

1. Draw and interpret *position* and *velocity* graphs for specific motions.
2. Apply proportional reasoning to relate velocity, change in position, and change in time, and to relate acceleration, change in velocity, and change in time.
3. Translate back and forth between graphs, equations, and verbal descriptions of motion.
4. Analyze the turnaround point of a one-dimensional accelerated motion.
5. Apply the equations for motion with constant acceleration to make quantitative predictions.

**Equipment:**

- computer and interface box,
- motion sensor
- low friction cart and 2-meter track
- colored pencils (blue, green, red, orange)
- motorized toy car
- fan unit with batteries
- meter stick
- 5" x 8" notecards and felt markers

## Activity I: Meet your partners




Physics is not a spectator sport! Throughout the term you will be working actively with your partners to learn through collaboration and consensus. Using an index card and a felt marker, make a nametag. Make sure it is easy to read, and bring it with you to lab every week. Introduce yourself to your partners and spend a few minutes getting to know one another.

Now that you have met your own lab partners, we would like to introduce you to a "fictitious" lab group: Victor, Kate, and Devon. They have lots of good ideas, but sometimes get stuck or confused (as most people do when first learning physics).

At times during this course, you will be asked to critique the explanations that Victor, Kate, and Devon have for the experiments in the lab. The idea here is that being able to reflect on and evaluate what is accurate and what is problematic in someone else's argument is a valuable tool for learning.

**Preview of Synthesis Challenge**

At the end of this lab, you will be asked to tackle the following challenge:

> *Meeting in the middle*. A battery operated fan cart and a motorized toy car are placed two meters apart and started toward each other at the same time. Where will they meet? To make your prediction, you can experiment with the cart and the car individually, but do not run them both at the same time! If you succeed on the first try, you can earn extra credit!

As you work through the lab, keep this scenario in mind. The guided experiments and questions should help you in thinking about the challenge task and planning a solution.

## Activity II: Using the motion sensor

*The goal of this activity is to familiarize you with the motion sensor.*

The motion sensor used in these experiments bounces ultrasound off of a target. The time between emitting a signal and receiving the reflection enables the system to compute the distance from the sensor to the target. When you start the sensor it will let you know it is running by emitting regular clicks.

A. Make sure the motion sensor is plugged into the interface box with the yellow plug in channel 1 and the black plug in channel 2. You will start by collecting data while a lab partner walks back and forth in front of the sensor. For this application, set the motion sensor beam to **wide**. Later, when recording the motion of a cart on a track, you should use the **narrow** setting.

   Different software packages are available to convert the motion sensor data into graphs on the computer. Commonly used programs include *Capstone, Data Studio* and *Logger Pro*.

   Once you have opened the software successfully, you should see axes for plotting *x vs. t*. Generate a graph by clicking ***Start*** and having one lab partner walk away from and back towards the motion sensor. Take turns walking in front of the sensor to see how the system works.

   Based on your results:

   - Where does the origin seem to be located?
   - What direction is positive?

## Activity III: Position and velocity graphs

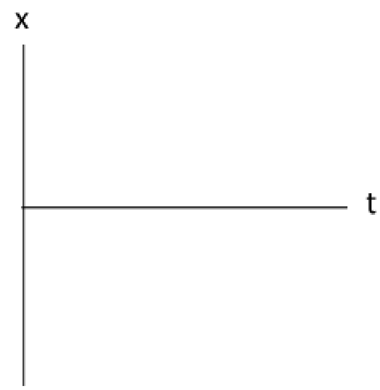
*In this activity, you will analyze a motion using position and velocity graphs. The focus is on Learning Targets 1, 2, and 3*

Obtain a metal track and low friction cart. Attach the motion sensor to one end of the track. Switch the beam to ***Narrow***. Raise the opposite end of the track using a physics book or other object.

A. Consider the following motion:

> The cart is placed at the midpoint of the track and is given a quick, gentle shove *away* from the motion sensor. The cart moves almost to the top the incline (away from the sensor) with decreasing speed, turns around, and moves back toward the sensor with increasing speed. The cart is "caught" about 30 cm from the sensor.

Sketch a *prediction* for the *x vs. t* graph that would be generated. When making your sketch, ignore the quick shove that starts the motion as well as the "catch " that ends the motion.

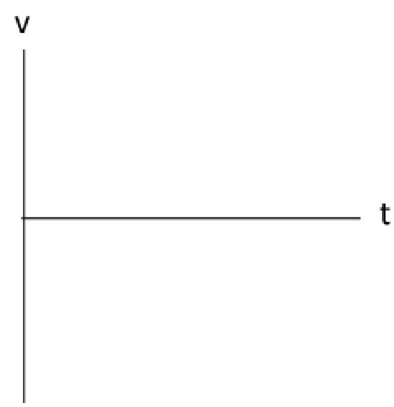



B. Clear out your previous data, then conduct the experiment and check your prediction.

If your results are *consistent* with what you predicted, use a colored pencil to place a "√" on your graph. If your prediction was incorrect, then use the colored pencil to sketch in the correct graph.

Discuss your results with your partners. Once you are satisfied that you understand this situation:

- Use your graph to determine a time at which the fan car had a speed of 0.25 m/s, and
- Sketch a prediction for the $v$ vs $t$ graph that corresponds to your position graph.




C. Check your result by generating a velocity graph. The software programs are (somewhat) user friendly. If you have trouble figuring out how to use the existing position graph to generate a velocity graph, ask your instructor.

Does the velocity graph read 0.25 m/s at the time you predicted? Does the shape of the velocity graph match your prediction? If your findings are not what you expected, then resolve the inconsistency by discussing your ideas with your partners until it makes sense. As before, use a colored pencil to either check off your prediction or sketch in a new graph.

D. You should have found that the velocity graph is a straight line. This suggests that *something* is constant about the motion of the cart.

   1. Describe what is constant about this motion. (*Note:* Avoid using "physics-y" terms such as *acceleration* in your answer. Try to use everyday language instead.)

   2. Compute the numerical value of the slope of the velocity graph: _______________

      Now provide an *interpretation* of this number. "Interpret" means to describe the specific information that the slope number conveys about the motion. Avoid using the term "per"; instead, explain its meaning using more informal, everyday language. Also note that "acceleration" is a name, not an interpretation.

The slope you have computed is referred to as the *acceleration* of the cart. Your interpretation of this number involves *proportional reasoning,* a type of quantitative reasoning commonly used in physics. Proportional reasoning is not the same thing as the manipulation of equations. However, proportional reasoning can and should help guide you in your use of equations in physics.

E. Use a different color pencil to mark and label the portion(s) of the position and velocity graphs for which the cart was speeding up, as well as the portion(s) for which it was slowing down. Check your answers with your partners.

   Is it possible for an object to be speeding up and have a negative acceleration? Explain by referring to your results above.

F. *Summarizing questions:*

   1. How can the *direction* of an object's motion be determined from an *x vs t* graph?

      How can the *speed* of an object's motion be determined from an *x vs. t* graph?

   2. How can you tell from an ***x vs t* graph** whether an object is *speeding up, slowing down,* or *moving with constant speed?*

      How can you tell from a ***v vs t* graph** whether an object is *speeding up, slowing down,* or *moving with constant speed?*

G. The goal of this activity was to work on Learning Targets 1-3. Review these learning targets. If you are not feeling confident about them, take this opportunity to discuss your thinking with an instructor.

## Activity IV:

*This activity focuses on Learning Target 4, analysis of a "turn around."*

A. Consider again the motion and motion graphs from the previous activity.

   1. As the cart moved up the incline, what was the direction of its acceleration vector? Explain.

   2. As the cart moved back down the incline, what was the direction of its acceleration vector? Explain.

   3. At the turnaround point, what was the direction does of the cart's acceleration vector? Was it zero? Explain.

B. When Victor, Kate and Devon were going through this activity together they had different ideas about the cart's acceleration at the turnaround point.

> Victor: "*The acceleration should be zero at the turnaround. That's when the cart switches from moving up to moving down.*"
>
> Kate: "*From just before the turnaround to just after, there is a change in velocity. That means there should be an acceleration.*"
>
> Victor: "*But nothing changes in an instant. The instantaneous acceleration should be zero right at the top.*"
>
> Devon: "*Wait a minute. We know that the velocity is zero at the turnaround point. If the acceleration were also zero, then the cart would get "stuck" at the top and never start moving down!*"

Discuss the dialogue with your partners and annotate it with colored pencil. Use blue or green to mark the parts that make sense and are good building blocks for understanding, and red or orange to mark the parts that are problematic and need modification. Add brief comments to show how the productive parts could be built on and/or the problematic parts improved.

The idea that *something* must be zero at the turnaround is compelling and in some way makes sense. What might Victor be thinking about, and how could you help him refine his ideas?

## Activity V: Equations for motion with constant acceleration

*This activity concerns Learning Target 3, translating back and forth between equations and graphs, and Learning Target 5, applying equations to make quantitative predictions.*

Imagine that you overhear two students talking about what happened in lecture:

> Devon: "*I liked it when the professor derived the formula with $\frac{1}{2}at^2$ in it. I've always wondered where that came from.*"
> Kate: "*Do you remember how she did it? I was trying to explain it to my friend and realized I didn't understand the derivation.*"
> Devon: "*Well, I know she said that while it can be done with calculus, you don't <u>need</u> calculus. She started by drawing the v vs t graph for an object with an initial velocity and constant acceleration.*"

Help Devon and Kate recreate what the professor did by deriving an expression for the displacement of an object in an amount of time $t$. The object moves with constant acceleration $a$ and has initial velocity $v_o$ at time t = 0. *(Do not assume that $v_o = 0$!)* Try to do this, as Devon said, *without* using calculus.

Use the space below to explain your ideas and lay out your derivation in detail.

## Activity VI: Reflection

Each week, the lab will ask you to reflect on your learning by comparing your initial ideas to your current understanding.

*Obtain your prelab*. Together with your partners, go over the questions and come to agreement on how to explain them. As you go, use colored pencils to annotate your own prelab:

- Use green or blue to underline the parts of your reasoning that were productive, and

- Use red or orange to underline parts that you now feel are problematic and need revising.

Add brief comments to identify where and how your initial ideas were problematic, and how they could be improved. Focus not just on whether you had the correct answers, but also on the quality of your explanations. Discuss your reflections with your partners.

When you are ready, check your annotated pre-lab with your instructor. The "checkout discussion" is an opportunity to make sure that you are confident in explaining the physics underlying the prelab questions, and also that you have reviewed your initial ideas and resolved any difficulties that you had with the concepts or reasoning. Your lab HW will involve applying these ideas to new situations. This will be easier if you make sure you have a thorough understanding of the prelab. So, now is a great opportunity to discuss your ideas in detail with your lab partners and with your instructor.

***After participating in the checkout discussion, have your instructor initial your prelab.***

## Activity VII: Synthesis Challenge

Use the ideas you have developed in this lab to tackle the following challenge task:

*Meeting in the middle.* A battery operated fan cart and a motorized toy car are placed 2 meters apart and started toward each other at the same time. (At the start, the fan is turned on and the cart is released from rest, while the toy car is turned on and placed on the track.)

*Where will they meet?!*

To make your prediction, experiment with the cart and the car individually, but do not run them together. You can use any of the equipment, ideas, or techniques from the lab. When you have a prediction, call your instructor over before testing it.

Below record sketches, data, graphs, calculations, *etc.* that were important in your thinking. (You may use the back of this page or a blank sheet.) Summarize your group's thinking in enough detail so that another group (and your instructor) could follow and repeat your experiment. Stating the answer is less important than describing the steps that led to that answer. As part of your lab HW, you will write a mini-report describing your solution in enough detail so that another group (and your instructor) could follow and repeat your experiment. To write this report, you will need to refer back to your notes.