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Lab 2: One-Dimensional Kinematics

In this lab we will investigate the one dimensional linear motion of an object moving along a frictionless surface. We will study the three basic aspects of its motion: *position* (measured in meters m), *velocity* (measured in meters per second m/s), and *acceleration* (measured in meters per second squared m/s^2). The *position* of an object in one dimension, for example, along the x direction (or axis), is its distance from a defined origin on our coordinate system.

Velocity $\vec{v}$ is defined as the time rate of change of the position. Velocity has both a magnitude, which we call *speed* ($v = |\vec{v}|$), *and* a direction with respect to the origin of our chosen coordinate system. Mathematically, we can express the instantaneous velocity of an object moving in one dimension as the derivative of position with respect to time:

$$\vec{v} = \frac{d\vec{x}}{dt} \tag{1}$$

If the object is traveling in one dimension with a constant speed v, we can derive an expression for its position as a function of time via Eqn. 1 by separating variables and integrating with respect to time:

$$x(t) = x_0 + vt \tag{2}$$

If the velocity of an object is changing over time, then the object is *accelerating*. Acceleration is a vector and thus has both magnitude and a direction, indicating how the velocity is changing over time. If the directions of the velocity and acceleration are the same, the object is speeding up. If the directions of the velocity and acceleration are opposite, the object is slowing down (decelerating). Acceleration is defined by:

$$\vec{a} = \frac{d\vec{v}}{dt} = \frac{d^2\vec{x}}{dt^2} \tag{3}$$

In the special case of constant acceleration (in magnitude and direction!) we can use the equations above to derive the following kinematic equations for motion in 1D with constant acceleration:

$$v(t) = v_0 + at \tag{4}$$

$$x(t) = x_0 + v_0 t + \frac{1}{2}at^2 \tag{5}$$

$$v^2 = v_0^2 + 2a(x - x_0) \tag{6}$$

where v and v_0 are the final and initial speeds, respectively, occurring over the change of position $(x - x_0)$.

Part 1: Walking Motion on a Flat Surface

1.1 Now you will study 1D motion by analyzing the walking motion a person using the "Moving Man" applet found here. The applet will simulate the walking motion of a person at various positions, speeds, and accelerations. You can download the applet and directly run it off your computer (requires Java) *or* you can run the simulation remotely through your browser by clicking the "browser compatible version". The applet's user interface is shown in Figure 1. Make sure you click on the "Charts" tab in order to generate position, velocity, and acceleration graphs. To aid you, check the boxes to show the velocity and acceleration vectors.

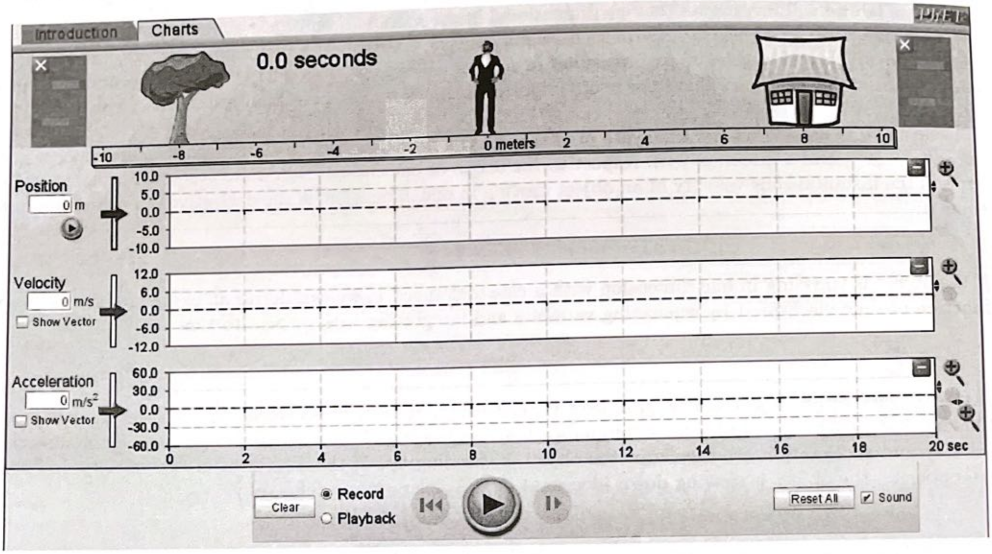


Figure 1: The Moving Man applet - simulates walking motion in 1 dimension.

1.2 Set the man +4 meters away from the origin. If he travels *towards* the origin at a constant speed of 1.5 m/s, *predict* (i.e. calculate) the amount time it will take him to travel a total distance of 8 meters.

$t =$ 5.5 s.

$x(t) = 4 + (-1.5)(t)$

$\frac{-1.5t}{-1.5} = \frac{-4}{-1.5}$

$\boxed{t = 5.5\ s}$

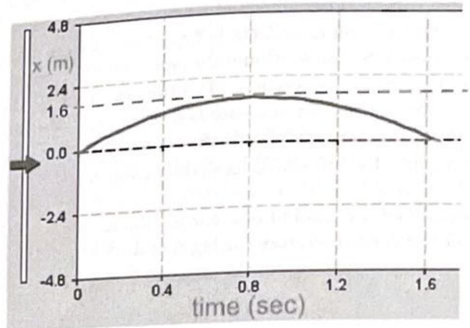
Run the simulation to check your above prediction and also observe the "position" and corresponding "velocity" graphs with respect to time. You can zoom in on the graphs for better resolution and sense of scale. Record the experimental value for the time it takes for the man to travel a distance of 8 m.

$t_{exp} =$ 5.45.

Compare this value with the predicted one.

Close, it is in the error margin of 0.5 s.

1.2 Now consider a new problem, where a person moves with constant acceleration along the x-axis such that her position is described by the x vs. t graph shown below:



- In one or two sentences, describe the person's motion:

The person starts moving and their velocity increases until they reach 1.6. Then, the velocity decreases as the person goes back to the initial position.

- At what time is the person's velocity zero?

At $t = 0.8$ s

- Using this graph, estimate the person's initial velocity and acceleration. *Hint*: Based on symmetry arguments, the person's initial and final speeds should be equal in magnitude but in opposite directions. Next, think about the person's total displacement for the full duration of their motion. Use Eqns 4 - 6.

$v_0 =$ 4 m/s, $a =$ -5 m/s^2

$a = \frac{v - v_0}{t}$ $1.6 = v_0 (0.8) + \frac{1}{2}\left(\frac{v - v_0}{t}\right) t^2$ $-4 = .8t$

$1.6 = v_0 (0.8) + \frac{1}{2} - \frac{v_0}{t} t^2$, $v_0 = 4$ m/s $0 = 4 + a(-.8)$

- The best fit curve for this position graph is given by $x(t) = C + 4t - 2.45t^2$, where C is some constant. Determine the acceleration of the person by differentiating this curve equation twice (see Eqn. 3). Does it agree with your above results?

$x'(t) = 4 - 4.9t$, $x''(t) = -4.9$

It agrees because it's only 0.1 m/s^2 off of the estimate, meaning they agree.

Part 2: Linear Motion Along an Inclined, Frictionless Plane

In this part of the lab you will use the Physics Aviary app found here to investigate the one dimensional linear motion of an object gliding along a frictionless, inclined track.

In an actual mechanics lab, the motion of objects is typically studied using two different sensor types: motion detectors and photogates. A motion detector continuously monitors the position of an object relative to the detector itself. Using a data acquisition and analyzing system, "Position vs. Time", "Velocity vs. Time", and "Acceleration vs. Time" graphs are generated. In essence, a photogate is a timer that can provide the "instantaneous" speed of an object as it passes through it. An internal clock records the time it takes for the object to pass through the photogate and the average "instantaneous" speed is evaluated by dividing the length of the object by the time it takes to pass through.

The Physics Aviary app simulates the motion of a car gliding along a frictionless, inclined track, providing two distinct scenarios: (i) motion of the car is monitored using a motion sensor placed close to the top of the incline and (ii) the speed of the car at a particular position on the inclined plane is determined using a photogate.

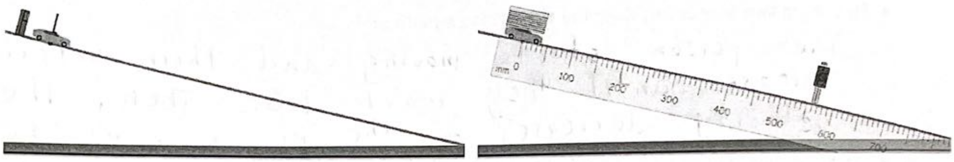


Figure 2: Car gliding down a frictionless ramp. The motion is investigated first by using a motion sensor place at the top of the ramp (left) and then using a photogate placed close to the bottom of the ramp (right).

2.1 Start the simulation app. Your simulation page should look similar to Figure 2 (left). Near the bottom of the simulation window you will see empty "Position vs. Time" and "Velocity vs. Time" graphs. These graphs will get populated once the simulation is started. Click on the car to release it from *rest* and start data collection. Note that the maximum working range of the motion sensor is 40 cm. Data collected at larger distances are not accurate. Sketch the two graphs on graph paper and be sure to label the axes, indicate units, and evenly label the graduation tick-marks.

2.2 Use your velocity graph to determine the (constant) acceleration of the car as it moves down the ramp. Mark on the graph the data points used in your calculation and clearly show your work.

$a =$ ≈ 0.97

$v(t) = v_0 + at$ $\quad V = \frac{x_2 - x_1}{t_2 - t_1}$ $\quad \frac{0.4 - 0}{0.64 - 0} = \frac{0.4}{0.64} = 0.625$

$0.625 = 0 + 0.64a$ $\quad a = \frac{0.625}{0.64}$ $\quad a = 0.9765625$

2.3 Click on the motion sensor to clear the page and start the second part of the simulation, where data is collected using a photogate (see Fig. 2 (right)). Please note that the angle of the ramp remains the same.

Record the initial distance between the car and the photogate.

$d =$ 490 mm ± 5mm

2.4 Use your experimental value for the car's acceleration from before and the kinematics equations on page 1 to predict the speed of the car as it passes through the photogate. Assume the car starts from rest. Show your work.

$v_{theoretical} =$ 30.936 m/s

$v^2 = v_0^2 + 2a(x - x_0)$ $\quad v^2 = 2(0.977)(490 - 0)$

$v^2 = 1.953125(490)$ $\quad \sqrt{v^2} = \sqrt{957.03125} = \boxed{30.936 \text{ m/s}}$

2.5 You will now experimentally determine the speed of the car as it passes through the photogate. Click on the car to release it from *rest* and start collecting data. Note how the photogate records the times when the index card (of width 7.5 cm) attached to the car enters and leaves the photogate. Using the width of the card and the time it takes to pass through the photogate, calculate the speed of the car at the photogate position. Show your work.

$v_{experimental}$ = 29.88 m/s

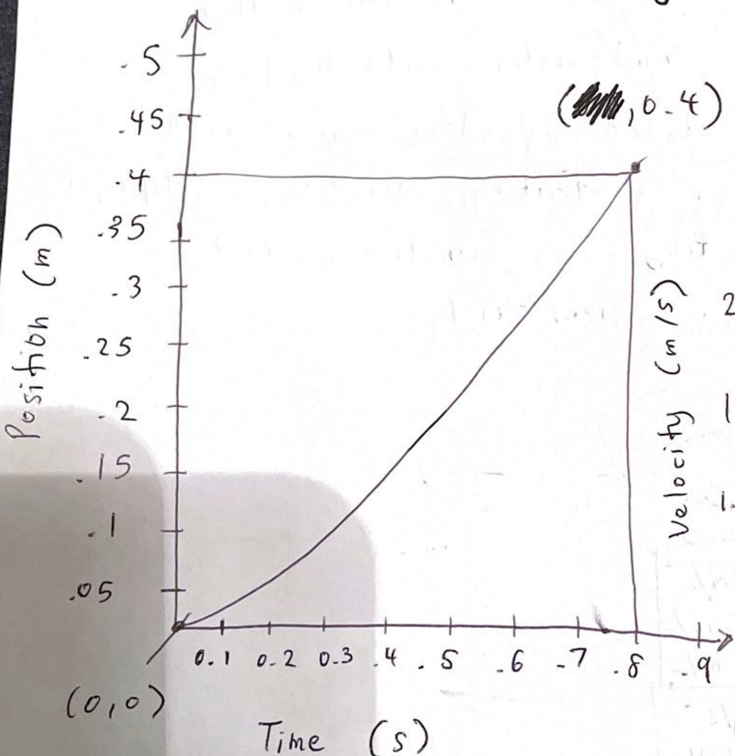
$$V = \frac{X_2 - X_1}{t_2 - t_1} = \frac{7.5 - 0}{0.783 - 0.532} = \frac{7.5}{0.251} = 29.88 \text{ m/s}$$

2.6 Compare the theoretical and experimental values of the speed. Discuss at least two sources of errors that could lead to discrepancies between the two values.

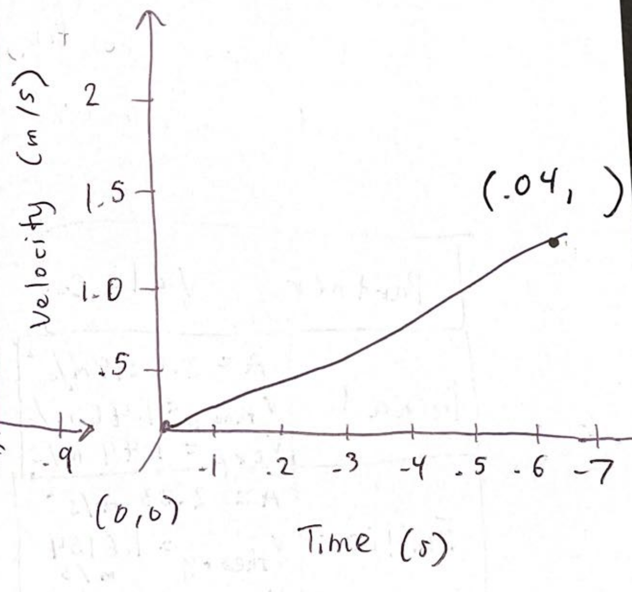
They are different values of about 1.1 m/s, being relatively large. There could be an instrumenta error with the simulations as the motion sensor, photogate, and reuler could lead to some error. The second equation error would be not adding, subtracting, dividing, multiplying and square rooting the function, which heavily increases uncertainty.

Partner	Values
Donal	A = 2.0218 m/s^2 V_{theory} = 1.46 m/s V_{exp} = 1.44 m/s
Emilio	A = 2.33 m/s^2 V_{theory} = 1.6154 m/s V_{exp} = 2.0776 m/s

2.1 graphs



Position (m)
.5
.45
.4
.35
.3
.25
.2
.15
.1
.05
0.4)
0.1 0.2 0.3 .4 .5 .6 .7 .8 .9
(0,0)
Time (s)



Velocity (m/s)
2
1.5
1.0
.5
(.04,)
.1 .2 .3 .4 .5 .6 .7
(0,0)
Time (s)