Physics 101, Lab 1:
LINEAR KINEMATICS
PREDICTION SHEET

After reading through the Introduction, Purpose and Principles sections of the lab manual (and skimming through the procedures), answer the following questions, and **hand in this sheet prior to the beginning the lab**. Assume that the top of the track is the zero point for position and that down the track is the positive direction.

1. Predict the graphs (no scales are needed) of position vs time, velocity vs time, and acceleration vs time for run 1. (Constant velocity run.)

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2. Predict the graphs (no scales are needed) of position vs time, velocity vs time, and acceleration vs time for run 2. (Accelerated run.)

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3. Predict the graphs (no scales are needed) of position vs time, velocity vs time, and acceleration vs time for run 3. (Cart moving up then down the track.)

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Physics 101 Lab 1
LINEAR KINEMATICS

Equipment List:
- Laptop/Computer (with power supply if applicable)
- PASCO 750 Interface with Power Supply and USB cable
- Pasco Motion Sensor II
- Linear Track
- ME-9454 Dynamics Cart
- Spirit Level
- Wooden block or similar item to elevate one side of the track

Introduction: In this experiment you will use the Data Studio software program on the computer to record and analyze data from the motion of a cart moving in one dimension along a track. You will perform a total of 3 runs:

1) The cart will roll at “Constant Velocity” down the track,
2) The cart will “Accelerate” down the track,
3) The cart will roll up and then down the track.

Purpose: The purpose of this experiment is to learn the meaning of acceleration, its magnitude and direction, and to measure how an object accelerates. In addition you will gain an understanding of the relationships between “Position”, “Velocity” and “Acceleration” of an object, and the relationships between the graphs of these quantities.

Principles: Acceleration is the time rate of change of velocity. If the acceleration is constant $a = \Delta v/\Delta t$. In general, $a = dv/dt$. Any time the velocity changes there is an acceleration. In this experiment you will look at position, velocity and acceleration graphs of the motion of a cart rolling along a straight track.

Procedures:

1. Connect the PASCO 750 Interface to a USB port on the laptop/computer. Turn the computer on and log on using the “Student” account. Ensure that the green power light on the interface is on. If it is not check the power connection and the on/off switch at the rear of the unit.

2. Open Data Studio by double clicking on Data Studio icon. The welcome screen should appear and click on the “Create Experiment” icon

3. The interface inputs are of type types: Digital channels on the left and Analog channels on the right. First plug in the motion sensor leads into the digital channels, place the yellow plug in channel 1 and the black plug in channel 2. The motion sensor is a push fit on the end of the track. Attach it the end of the linear track where the length scale reads zero. Be careful to orient your apparatus so that the sound waves from the apparatus of adjacent groups will not interfere with your set up. Also ensure that there are no objects close to the track that could unintentionally reflect sound. The beam width switch should be set to “wide beam” and the tilt of the sensor should be adjusted using the side knob so that it is tilted slightly upwards.
4. Level the track using the spirit level. Ensure it is level both along and across the track. Adjust the level by screwing the feet in or out as required.

5. To configure the software to read data from the sensor, bring up the “Experimental Setup” window by clicking the setup button if it is not already shown. Click on the image of the interface over the area where the channel 1 digital input is.

6. Select the “Motion Sensor” from the sensor list by double clicking on it. The sensor control panel should appear under the image of the interface. Set the sample rate to 20Hz and ensure that the measurement checkboxes appear as they do in the image below:

7. Click on the “Motion Sensor” tab in the sensor control panel and the calibration screen will appear. The sensor will start to make a clicking sound if everything is connected correctly. Place a cart on the track so that the plunger faces away from the sensor and the smooth rear face is aligned with the 1.00m mark in the linear track. Adjust the tilt of the sensor so that the “Present Sensor Distance” reading agrees reasonably well with the scale on the track when the cart is moved between 50cm and 200cm. Below 50cm, the sensor is not fast enough to be accurate.
When you are satisfied that sensor is operating correctly, place the cart so that its rear is aligned with the 1.00m and press the “Set Standard Distance = Standard Distance” button, ensuring that the “Standard Distance” text box reads “1.00m”.

8. Create a graph by double clicking on ‘Graph’ in the “Display” list on the lower left portion of window. The “Please Choose a Data Source” window should appear, select “Position Ch 1 & 2” from the list by double clicking to result in a graph.

9. Click and drag the “Velocity, Ch 1&2(m/s)” label from the top left hand corner onto the graph until a dotted line appears around the entire graph and then release the mouse button to result in a velocity/time graph being added to existing graph. Repeat for “Acceleration, Ch 1&2 (m/s/s)” so that there are three graphs showing.

10. Click on “Align matching x scales” button (5th from the left on the toolbar.)

11. Maximize the graph window.
12. **Rename the Graph 1.** Click once on ‘Graph 1’ in the “Display” window to make it active. Double click on the label in the lower left hand panel to rename it by overwriting ‘Graph 1’. Use the initials of every member of your group together with the run number as the name. Example: DA, KO, MS, Run 1.

13. Perform a linearity check by going back to the motion sensor setup control by clicking on the “Setup” button and then clicking on the “motion sensor” tab to display the “Present Sensor Distance”. Move the cart along the track from 50cm to 180cm stopping at roughly 20cm intervals. The sensor measurement should agree with the tape measure on the track at all positions in this range. Adjust the apparatus until the sensor measurements are reliable.

14. **Prepare track and cart for Run 1 (constant Velocity run).** Adjust the friction screw on bottom of cart (if it is still installed) so there is no braking. Level the track with the spirit level. **When you do take data on the computer, be sure to release cart from 0.5 m or further away from motion sensor.** The sensor does not perform well when the cart is less than 0.5 m in front. Make sure that someone is responsible for catching the cart when it reaches that end of the track. The carts are quite expensive and the delicate bearings are easily damaged if the cart is dropped.

15. **Take Data for Run 1.** First click on the Start button (upper center), then gently push the cart from a position 0.5 m away from motion sensor. After cart reaches end of track click on the Stop button. (The ‘Start’ button turns into a ‘Stop’ button after it is clicked on once.) The graph should now show the data points for position vs. time, and in the data box (upper left) there should appear data for Position (x), Velocity (v) and Acceleration (a) vs. time runs. The three graphs should now display the data from Run 1. If you are unhappy with your result then you can delete the run by selecting the *Experiment > Delete Last Data Run* menu item.

16. Scale the graphs so that only datapoints collected during the period when the cart is traveling freely are shown by holding down the mouse button and drawing a box around the datapoints of interest. Datapoints within the region of interest will turn yellow. Then right click and select “scale” from the context menu. Repeat as necessary until you are satisfied with the time period shown.

17. **Adjust Graph Axes.** For each graph, place the cursor on a number on the vertical axis, wait until it turns into a spring, then click and drag to adjust the axis to show appropriate level of detail. Do this for each of the Position, Velocity and Acceleration graphs. By hovering the mouse pointer just to the right of the vertical axes, it will turn into a hand which will allow you to pan along the axis.

18. **Use program to calculate the average Velocity of the cart.** Click and drag a box around the data points in the Velocity vs. Time graph, and then *click on the Σ button* to display the Mean values for y and x. Be careful to ensure that the data points for which you wish to calculate statistics always remain selected.

19. **Use program to calculate the average Acceleration of the cart.** Click and drag a box around the data points in the Acceleration vs. Time graph. The numbers in the legend box should automatically update.

20. **Print ‘Landscape’ copies of the Graphs.** From the ‘File’ menu in the data studio program select ‘Print Setup’, and a print window should open. Select ‘Landscape View’ under the ‘Orientation’ option. Select “OK” when you have finished with the setup. Now go to the *File(Print menu, choose the number of copies so that each member of the group will have one, and then click OK. Your data will be sent to the wireless printer.*
21. **Prepare for Run 2** (Accelerated run). Change the angle of the track by raising the end where the sensor is by about 6 inches. To perform accelerated run simply release cart from same place along track as Run 1, (about 0.5 m from motion sensor) and let it roll. Try to catch cart just before it leaves the end of track.

22. Activate the Position graph by clicking anywhere inside it. Click on the ‘Data’ button and deselect the Run#1 data, by clicking on it. The Run 1 Position data is now hidden. If necessary, it can be restored. Do the same procedure for the Velocity and Acceleration Data.

23. **Take data for Run 2** (Accelerated motion). Ensure that the y=0 line is visible in the velocity plot.

24. Use program to calculate the average **Acceleration** of the cart. Click and drag a box around the data points in the Acceleration vs. Time graph.

25. **Linear Fit the velocity of the cart.** Click on the Velocity graph and select the data points of interest. Click on “Fit” and choose “Linear Fit” from the drop down menu. Click and drag the results box and place it in a free area on the graph. The slope of the best fit line should be close to the Mean Acceleration.

26. **Print the graphs for Run 2.** Change the graph name to “Run 2”. Repeat the instructions in step 17 to print the graph for this run. (You do not need to select the ‘Landscape’ option again.)

27. **Prepare for Run 3** (Motion up and down track). Practice giving the cart a push up the track so that it comes to within 0.5 m of the motion sensor before returning back down the track. **MAKE SURE TO KEEP THE CART FROM BUMPING INTO THE MOTION SENSOR AND FROM FALLING OFF THE TRACK.** When you feel confident that you can push the cart with the right initial speed then proceed to make a run with recorded data.

28. **Take the data for Run 3** (Motion up and down track).

29. Use program to calculate the average **Up Acceleration** of the cart. Click and drag a box around the data points in the Acceleration vs. Time graph during the time period when the cart was gaining height and traveling up the track. The average value indicated will be called \( a_{up} \).

30. **Perform a linear fit to the velocity of the cart during the time when the cart was gaining height.** Highlight the Velocity graph for approximately the same time period as that used in the last step. The slope of the velocity graph should be close to the the value of \( a_{up} \).

31. **Print the graphs for Run 3-up.** Change the graph name to “Run 3-up”.

32. Use program to calculate the average **Down Acceleration** of the cart. Click and drag a box around the data points in the Acceleration vs. Time graph during the period when the cart was losing height. The average acceleration during this period will be called \( a_{down} \).

33. **Perform a linear fit to the velocity of the cart during the time when the cart was losing height.** Highlight the Velocity graph for approximately the same time period as that used in the last step. The slope of the velocity graph should be close to the the value of \( a_{up} \).

34. **Print the graphs for Run 3-down.** Change the graph name to “Run 3-down”.


35. Measure the angle of incline of the track relative to the horizontal table top. Develop your own method to do this. Describe your method in your notes. Compare your answer with that obtained by placing a digital protractor on the inclined surface.

36. Save your data and note the LACCD serial number of your computer. Shut down the computer.
QUESTIONS AND ANALYSIS
LINEAR KINEMATICS

The analysis section of this lab consists of answering the following qualitative and quantitative questions.

1. Co-ordinate system
   a. How many dimensions does the motion take place in?
   b. Where along the track is the zero point (origin) of the position axis?
   c. What direction along the track is positive, and why is this direction positive?

2. Compare graphs. Carefully compare your predicted graphs with those of the observed data for Run 2. Explain in detail how your predicted graphs for this run differ from the actual graphs you obtained.

3. Velocity is the slope of position vs. time. Using the ‘landscaped’ position vs time graph that you printed out for run 2, pick 5 points along the graph that are roughly evenly spaced and construct tangent lines to the curve of x vs. t at each of these points. Draw a slope triangle for each tangent line, and measure the slopes to determine the velocities at these 5 times (Remember, instantaneous velocity is the slope of the x vs. t graph). Be sure to make the base of your slope triangles at least 0.20 s long. Compare these five slopes with the five corresponding values of the velocity from the v vs t graph, evaluated at the tangent points (aka times) you chose. Draw a table that summarizes your results and discuss your findings, including answering the following questions: Are the slopes positive or negative? What does this tell you? Are the slopes increasing, decreasing or staying constant? What does this tell you?

4. Displacement is the integral of velocity vs. time. Show for run 2 that the area under the velocity graph for a selected time interval is equal to the change in displacement during the same time interval. Choose a time interval of about 0.5s.

5. Calculating acceleration. We will calculate the value of acceleration in the following two ways. To begin, we will state without proof for the moment that the ideal acceleration of an object sliding with friction up an incline at an angle $\theta$ is $a_{\text{up}} = g \sin \theta + \mu \cos \theta$, while the ideal acceleration of an object sliding down an incline with friction is $a_{\text{down}} = g \sin \theta - \mu \cos \theta$, where $\mu$ is known as the coefficient of kinetic friction, and is taken to be a positive constant, and $g$ is the acceleration of gravity, which is approximately 9.8 m/s$^2$. We can see that the $g \sin \theta$ term is the ‘part’ of acceleration just due to the incline, and that the $\mu g \cos \theta$ term is due to the friction. We can eliminate $\mu$ between these two equations by adding and dividing by 2 to obtain: $a_{\text{exp}} = (a_{\text{up}} + a_{\text{down}}) / 2 = g \sin \theta$. Calculate the experimental value of acceleration, $a_{\text{exp}}$ using your experimental values of $a_{\text{up}}$ and $a_{\text{down}}$. Estimate the uncertainty in $a_{\text{exp}}$. Next determine the theoretical value of acceleration by, $a_{\text{theory}} = g \sin \theta$. Are $a_{\text{exp}}$ and $a_{\text{theory}}$ consistent with each other?