$B = \frac{\mu_0 N I}{2R}$ $B = \mu_0 n I$ $\mu_0 = 4\pi \times 10^{-7}$ $B = \frac{\mu_0 I}{2\pi r}$ $\Phi = BA\cos\theta$

$I = \frac{\mathcal{E}}{R}$ $\mathcal{E} = -N\frac{\Delta\Phi}{\Delta t}$

Group Quiz ①

① A solenoid has a cross-sectional area of $6.0 \times 10^{-4}\ m^2$, consists of 400 turns per meter, and carries a current of 0.4A flowing clockwise when viewed from the end of the solenoid. A 10 turn coil is wrapped tightly around the circumference of the solenoid. The ends of the coil are connected to a 1.5Ω resistor. Suddenly, a switch is opened, and the current in the solenoid dies to zero in a time of 0.05s. Find the average current induced in the coil and state whether this induced current is clockwise or counterclockwise viewed from the same location mentioned before. Explain your choice of direction. Also, find the magnitude and direction of the magnetic field at the center of the coil as a result of the induced current. (Direction away from or towards the viewer as mentioned previously)

$d = v_i t + \frac{1}{2} a t^2$ $v_f = v_i + at$

Physics Quiz ②

$v_f^2 = v_i^2 + 2ad$ $d = \frac{1}{2}(v_i + v_f) t$ $d = \bar{v} t$

A flatbed railroad car moves at a velocity of 20 m/s relative to the ground on a flat straight horizontal track. A cannon on the railroad car fires a shell forward at an initial velocity of 300 m/s relative to the railroad car at an angle of 40°. Neglect air resistance.

ⓐ What will be the maximum height of the shell relative to its original height?

ⓑ What will be the shell's time in the air when it returns to its original height?

ⓒ How far will the shell have gone horizontally (relative to the ground) when it returns to its original height?

ⓓ What constant acceleration would the train require so that the shell hits the cannon when it returns to its original height? (The railroad car begins accelerating the instant the shell is fired.)

$\Sigma F = ma$ $\quad v_f = v_i + at$ $\quad f_{s,max} = \mu_s F_N$

$w = mg$ $\quad d = v_i t + \frac{1}{2} a t^2$

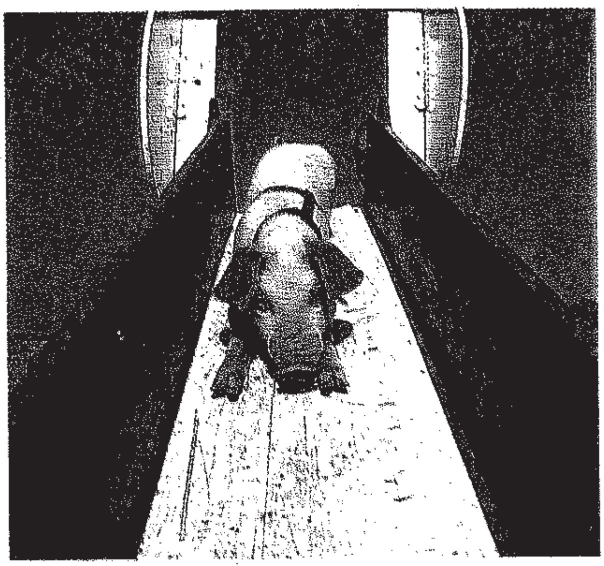
$f_k = \mu_k F_N$ $\quad v_f^2 = v_i^2 + 2ad$

(3)

Quiz

1. A 68 kg crate sits on a horizontal floor. A rope inclined at 15° above the horizontal pulls on it. (a) If the coefficient of static friction is 0.50, what minimum tension in the rope is required to start the crate moving? (b) If $\mu_k = 0.35$, what is the magnitude of the initial acceleration of the crate?

2. A pig slides down a 35° incline in twice the time it would take it to slide down a frictionless 35° incline. What is the coefficient of kinetic friction between the pig and the incline?

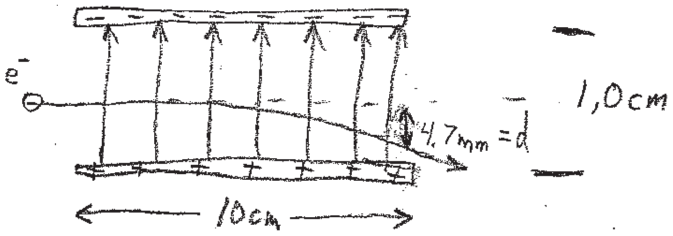


$F = qE$ $\quad v_f^2 = v_i^2 + 2ad$ $\quad$ Quiz ④ $\quad \Sigma F = ma$ $\quad \Delta V = Ed$

$1\,m = 10^3\,mm$ $\quad v_f = v_i + at$

$1\,m = 10^2\,cm$ $\quad d = v_i t + \frac{1}{2}at^2$

$q_{electron} = -1.6 \times 10^{-19}\,C$ $\quad m_{electron} = 9.11 \times 10^{-31}\,kg$



An electron in a computer monitor enters midway between oppositely charged parallel plates as shown. The initial speed of the electron is $6.15 \times 10^7\,m/s$ and its vertical deflection d is 4.7 mm.

ⓐ What is the magnitude of the electric field between the plates? Neglect air resistance and gravity. ⓑ What is the potential difference between the plates?

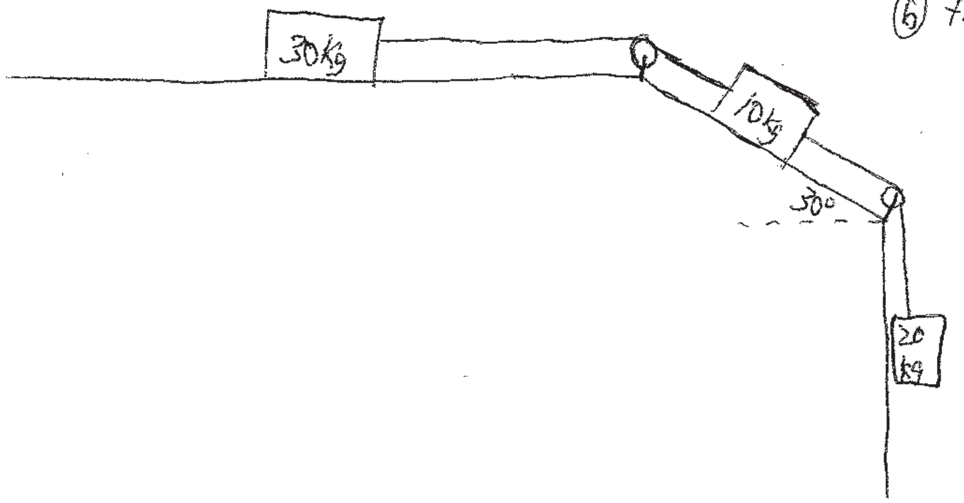
⑤ Quiz Show all work.

$W = mg$

$f_k = \mu_k F_N$

$\sum F = ma$

$\mu_k = 0.1$ for all surfaces.
It moves.
Find ⑤ the acceleration
⑥ the tension in each cable.



6

As a high speed passenger train traveling at 45 m/s rounds a bend and enters a section of straight track, the engineer is shocked to see that a runaway locomotive has improperly entered the track from a siding 670m ahead. The locomotive is heading toward the passenger train at a constant speed of 8.1 m/s relative to the ground. What must be the magnitude of the constant acceleration of the passenger train if a collision is just barely to be avoided?

20 – Images Formed by Concave Mirrors

Using the optical bench materials, find the focal length of one of the concave mirrors (WL-3520-04). Do this two times, once by producing an image smaller than the object and once with an image larger than the object, and find the percent difference between the two answers. Put the mirror back in its box. Repeat with the other mirror (WL-3520-08). Put it back in its box. Clean up. Get the wax off the table. In your formal lab write-up, be sure to include a procedure, materials, sketches, ray diagrams, data, calculations, a qualitative description of the images, and a conclusion.

1 Liquid Pressure

The *Vernier Gas Pressure Sensor or Biology Pressure Sensor* can measure pressure in the air or in a liquid. The sensor has a membrane with a vacuum on one side and the fluid on the other. It flexes with changes in pressure and produces a voltage. The sensor measures the pressure at the end of the plastic tube.

Purpose:

To determine the relationship between absolute pressure and depth in a liquid. In other words, what is the mathematical relationship that predicts absolute pressure (including air pressure and liquid pressure) at various depths in a liquid?

Apparatus:

Computer-controlled Pressure Sensor, Logger Pro, graduated cylinder, ruler, water.

What you will do:

In this lab you will follow the classic scientific method.

1. **First form at least one hypothesis. Write this in your lab book.**
2. Then design an experiment that will test the hypothesis. **Record the experimental procedure in language that would be clear to an uninformed reader.**
3. Perform the experiment. Make sure you use good experimental technique. **Record the data in a data table that is convenient and easy to interpret.**
4. **Analyze the data. Make a graph of the situation using graph paper (preferably directly in your lab book) and another using logger pro. Analyze the graphs. Use the curve fit capability with the logger pro graph.** Save this graph to your H drive for future use.
5. **Decide which mathematical model most nearly fits the data. Determine an equation(s) for the relationship.**
6. Make sure your model fits new situations. **In other words, use the model to predict at least two other pressures using depths that were not part of your previous data collection. One of the new depths should be between existing data points. The other should be outside existing data points. Then test to see if your predictions were accurate. How close were your test results to your predictions? If necessary, collect more data and change your mathematical model. Then test again.**
7. **Write a conclusion that summarizes your basic method of data collection and results, including the mathematical model indicated. Was your original hypothesis correct? If it was not correct, offer some reasons for the variation from your expected results. List at least three sources of error.**
8. Post lab: **After the mathematical formula for liquid pressure has been derived in class, return to your data and equation and logger pro graph and calculate the density of the fluid.**

3 Determining g on an Incline

revised

Purpose:

Use a Motion Detector to measure the speed and acceleration of a ball and a cart rolling down an incline. Determine the mathematical relationship between the angle of an incline and the acceleration of ball rolling down the ramp. Determine the value of free fall acceleration, *g*, by extrapolation. Compare the results for a ball with the results for a low-friction dynamics cart.

Apparatus : ramp, ball, cart, motion detector, books, meter stick

Discussion:

During the early part of the seventeenth century, Galileo experimentally examined the concept of acceleration. One of his goals was to learn more about freely falling objects. Unfortunately, his timing devices were not precise enough to allow him to study free fall directly. Therefore, he decided to limit the acceleration by using inclined planes. In this lab exercise, you will see how the acceleration of a rolling ball or cart depends on the ramp angle. Then, you will design an experiment and use the data you collect to extrapolate to the acceleration on a vertical "ramp;" that is, the acceleration of a ball in free fall. Rather than measuring time, as Galileo did, you will use the velocity graphs produced by a Motion Detector to determine the acceleration.

What to do:

1. **Make a hypothesis: which experimental object will lead to a more accurate experimental result for the acceleration of gravity, the raquet ball or the cart?**

2. **Draw an inclined ramp with a ball on it near the top of the ramp. Using vector components, find the acceleration of the cart down the ramp as a function of g and θ, the angle of elevation of the ramp. One of the components will be into the ramp, the other down the ramp. You will be solving for the component pointing down the ramp.**

3. Design an experiment that uses a motion detector and a ramp to measure the acceleration of gravity. Your method should include measurements of the acceleration as a function of θ. You should follow the basic methods of Galileo, using extrapolation and graphing. No vertical or near vertical drops are allowed. Use the velocity vs. time graphs to determine the acceleration. **Record the procedure.**

4. Perform the experiment twice, first with the raquet ball and then with the cart. Use logger pro to find the relevant data. **Record this data in two data tables, one for the raquet ball and one for the cart.**

5. **Analyze each of the two data sets by using Logger Pro graphing, curve fits, and extrapolation to determine the value of g. Record the values of g determined by using the raquet ball and by using the cart. Find the % error for each.**

6. **Write a conclusion that summarizes the procedure and results of your experiment. Was your hypothesis valid? Why do you think that one of the experimental objects gave much better results than the other? List three sources of error.**

3 Determining g on an Incline

Purpose:

Original

Use a Motion Detector to measure the speed and acceleration of a ball and a cart rolling down an incline. Determine the mathematical relationship between the angle of an incline and the acceleration of ball rolling down the ramp. Determine the value of free fall acceleration, *g*, by extrapolating the acceleration *vs.* sine of track angle graph. Compare the results for a ball with the results for a low-friction dynamics cart. Determine if an extrapolation of the acceleration *vs.* sine of track angle is valid.

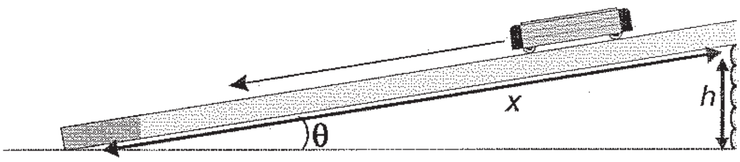
Apparatus : ramp, ball, cart, motion detector, books

Discussion:

During the early part of the seventeenth century, Galileo experimentally examined the concept of acceleration. One of his goals was to learn more about freely falling objects. Unfortunately, his timing devices were not precise enough to allow him to study free fall directly. Therefore, he decided to limit the acceleration by using fluids, inclined planes, and pendulums. In this lab exercise, you will see how the acceleration of a rolling ball or cart depends on the ramp angle. Then, you will use your data to extrapolate to the acceleration on a vertical "ramp;" that is, the acceleration of a ball in free fall. The acceleration is directly proportional to the sine of the incline angle, (θ). A graph of acceleration versus sin(θ) can be extrapolated to a point where the value of sin(θ) is 1. When sinθ is 1, the angle of the incline is 90°. This is equivalent to free fall. The acceleration during free fall can then be determined from the graph. We will see how valid this extrapolation can be. Rather than measuring time, as Galileo did, you will use a Motion Detector to determine the acceleration. You will make quantitative measurements of the motion of a ball rolling down inclines of various small angles. From these measurements, you should be able to decide for yourself whether an extrapolation to large angles is valid.

Procedure:

1. Connect the Motion Detector to the DIG/SONIC 1 channel of the interface.
2. Place a single book under one end of a 1 – 3 m long board or track so that it forms a small angle with the horizontal. Adjust the points of contact of the two ends of the incline, so that the distance, *x*, in Figure 1 is between 1 and 3 m.
3. Place the Motion Detector at the top of an incline.
4. Open the file "04 g On An Incline" from the *Physics with Computers* folder.
5. Hold the ball on the incline about 0.5 m from the Motion Detector.
6. Click [Collect] to begin collecting data; release the ball after the Motion Detector starts to click. Get your hand out of the Motion Detector path quickly. You may have to adjust the position and aim of the Motion Detector several times before you get it right. Adjust and repeat this step until you get a good run showing approximately constant slope on the velocity *vs.* time graph during the rolling of the ball.
7. Logger *Pro* can fit a straight line to a portion of your data. First indicate which portion is to be used by dragging across the graph to indicate the starting and ending times. Then click on the Linear Fit button, [icon], to perform a linear regression of the selected data. Use this tool to determine the slope of the velocity *vs.* time graph, using only the portion of the data for times when the ball was freely rolling. From the fitted line, find the acceleration of the ball. Record the value in your data table.
8. Repeat Steps 5 – 7 two more times.



9. Measure the length of the incline, *x*, which is the distance between the two contact points of the ramp. See Figure 1.
10. Measure the height, *h*, the height of the book(s). These last two measurements will be used to determine the angle of the incline.
11. Raise the incline by placing a second book under the end. Adjust the books so that the distance, *x*, is the same as the previous reading.
12. Repeat Steps 5 – 10 for the new incline.
13. Repeat Steps 5 – 11 for 3, 4, and 5 books.

14.Repeat Steps 5 – 13 using a low-friction dynamics cart instead of the ball.

Data Table

Data using ball							
Number of books	Height of books, h (m)	Length of incline, x (m)	$\sin(\theta)$	Acceleration trial 1 (m/s^2)	trial 2 (m/s^2)	trial 3 (m/s^2)	Average acceleration (m/s^2)
1							
2							
3							
4							
5							

Data using cart							
Number of books	Height of books, h (m)	Length of incline, x (m)	$\sin(\theta)$	Acceleration trial 1 (m/s^2)	trial 2 (m/s^2)	trial 3 (m/s^2)	Average acceleration (m/s^2)
1							
2							
3							
4							
5							

Analysis

1. Calculate the average acceleration for each height.

2. Using trigonometry and your values of x and h in the data table, calculate the sine of the incline angle for each height. Note that x is the hypotenuse of a right triangle.

3. Plot a graph of the average acceleration (y axis) *vs.* $\sin(\theta)$. Use page 3 of the experiment file. Carry the $\sin(\theta)$ axis out to 1 (one) to leave room for extrapolation.

4. Use the linear fit feature of Logger *Pro*, and determine the slope. The slope can be used to determine the acceleration of the ball on an incline of any angle.

5. On the graph, carry the fitted line out to $\sin(90^\circ) = 1$ on the horizontal axis by using the interpolate feature under analyze, and read the value of the acceleration at sin 90.[1]

6. How well does the extrapolated value agree with the accepted value of free-fall acceleration ($g = 9.8\ m/s^2$)?

7. Repeat the analysis, including the extrapolation, for the low-friction dynamics cart.

8. Why do you think the data for the dynamics cart resulted in an extrapolated value of g that was closer to the accepted value than the rolling ball data?

9. Discuss the validity of extrapolating the acceleration value to an angle of 90°.

[1] Notice that extrapolating to the y value at the $x = 1$ point is equivalent to using the slope of the fitted line.

5 -- Newton's 2nd Law

revised

Purpose: To determine the mathematical relationship between force and acceleration by using the apparatus listed below. In other words, how will acceleration change as force is changed?

Apparatus: Force Sensor, low friction dynamics carts, LabPro, track, low-g accelerometer

Discussion:

Newton's Laws form the basis for much of what we will study in the weeks ahead. Before we form a hypothesis, the class will discuss force sensors and accelerometers and how they are used and calibrated.

What to do:

1. **Form a hypothesis: what is the mathematical relationship between force and acceleration?**
2. Come up with a procedure that will allow you to test your hypothesis. This should include Logger Pro software setup and any calibrations needed. **Record the procedure.**
3. Do the experiment. **Record results in an appropriate data table. Make sure you record the mass of the cart and sensors.**
4. Analyze the data by graphing in Logger Pro and performing curve fits, etc. **Print your graph and regression equation.**
5. **Form a conclusion that summarizes the procedure and results. Was your hypothesis valid? Restate your regression equation and state what it means regarding the relationship between force and acceleration. What is (are) the meaning of the constant(s) in your regression equation?**

Newton's Second Law

original

How does a cart change its motion when you push and pull on it? You might think that the harder you push on a cart, the faster it goes. Is the cart's velocity related to the force you apply? Or does the force just *change* the velocity? Also, what does the mass of the cart have to do with how the motion changes? We know that it takes a much harder push to get a heavy cart moving than a lighter one.

A Force Sensor and an Accelerometer will let you measure the force on a cart simultaneously with the cart's acceleration. The total mass of the cart is easy to vary by adding masses. Using these tools, you can determine how the net force on the cart, its mass, and its acceleration are related. This relationship is Newton's second law of motion.

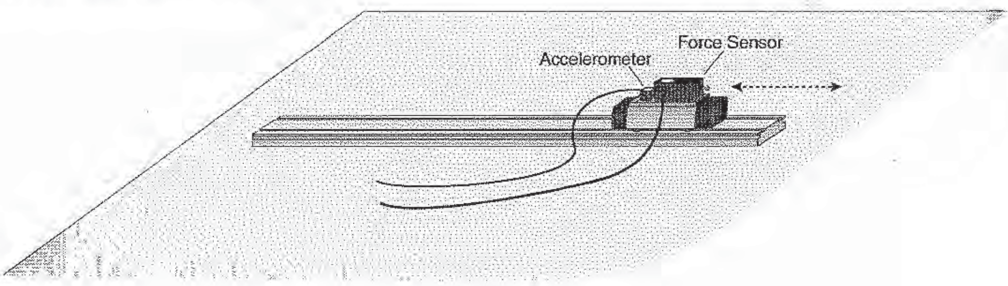


Figure 1

OBJECTIVES

- Collect force and acceleration data for a cart as it is moved back and forth.
- Compare force *vs.* time and acceleration *vs.* time graphs.
- Analyze a graph of force *vs.* acceleration.
- Determine the relationship between force, mass, and acceleration.

MATERIALS

computer
Vernier computer interface
Logger *Pro*
Vernier Low-g Accelerometer
Vernier Force Sensor
low-friction dynamics cart
0.500 kg mass

PRELIMINARY QUESTIONS

1. When you push on an object, how does the magnitude of the force affect its motion? If you push harder, is the change in motion smaller or larger? Do you think this is a direct or inverse relationship?
2. Assume that you have a bowling ball and a baseball, each suspended from a different rope. If you hit each of these balls with a full swing of a baseball bat, which ball will change its motion by the greater amount?
3. In the absence of friction and other forces, if you exert a force, F, on a mass, m, the mass will accelerate. If you exert the same force on a mass of $2m$, would you expect the resulting acceleration to be twice as large or half as large? Is this a direct or inverse relationship?

PROCEDURE

1. Connect a Dual-Range Force Sensor to Channel 1 on the Vernier computer interface. Connect the Low-g Accelerometer to Channel 2 on the interface.
2. Open the file "09 Newtons Second Law" from the *Physics with Computers* folder.
3. Attach the Force Sensor to a dynamics cart so you can apply a horizontal force to the hook, directed along the sensitive axis of your particular Force Sensor. Next, attach the Accelerometer so the arrow is horizontal and parallel to the direction that the cart will roll. Orient the arrow so that if you *pull* on the Force Sensor the cart will move in the direction of the arrow. Find the mass of the cart with the Force Sensor and Accelerometer attached. Record the mass in the data table.
4. Place the cart on a level surface. Make sure the cart is not moving and click [Zero]. Check to make sure both sensors are highlighted and click [OK].

Trial I

5. You are now ready to collect force and acceleration data. Grasp the Force Sensor hook. Click [Collect] and take several seconds to move the cart back and forth on the table. Vary the motion so that both small and large forces are applied. Make sure that your hand is only touching the hook on the Force Sensor and not the Force Sensor or cart body.
6. Note the shape of the force *vs.* time and acceleration *vs.* time graphs. Click the Examine button, , and move the mouse across the force *vs.* time graph. When the force is maximum, is the acceleration maximum or minimum? To turn off Examine mode, click on the Examine button, .
7. The graph of force *vs.* acceleration should appear to be a straight line. To fit a straight line to the data, click on the graph, then click the Linear Fit button, . Record the equation for the regression line in the data table.
8. Using the graphs, estimate the acceleration of the cart when a force of 1.0 N has acted upon it. Select Interpolate from the Analyze menu. Move the mouse across the graph and determine the acceleration (x) when the force (y) is nearly 1.0 N. Record the force and acceleration in the data table.
9. Repeat Step 8 using a force of –1.0 N.
10. Print copies of each graph.

Trial 2

11. Attach the 0.500 kg mass to the cart. Record the mass of the cart, sensors, and additional mass in the data table.
12. Repeat Steps 5 – 10.

DATA TABLE

Trial I

Mass of cart with sensors (kg)	

Regression line for force *vs.* acceleration data

	Force pulling cart (N)	Acceleration (m/s^2)
Force closest to 1.0 N		
Force closest to –1.0 N		

Trial 2

Mass of cart with sensors and additional mass (kg)	

Regression line for force *vs.* acceleration data

	Force pulling cart (N)	Acceleration (m/s^2)
Force closest to 1.0 N		
Force closest to –1.0 N		

ANALYSIS

1. Compare the graphs of force *vs.* time and acceleration *vs.* time for a particular trial. How are they different? How are they the same?
2. Are the net force on an object and the acceleration of the object directly proportional? Explain.
3. What are the units of the slope of the force *vs.* acceleration graph? Simplify the units of the slope to fundamental units (m, kg, s).
4. For each trial compare the slope of the regression line to the mass being accelerated. What does the slope represent?
5. Write a general equation that relates all three variables: force, mass, and acceleration.

EXTENSIONS

1. Use this apparatus as a way to measure mass. Place an unknown mass on the cart. Measure the acceleration for a known force and determine the mass of the unknown. Compare your answer with the actual mass of the cart, as measured using a balance.

9 Collisions: Momentum and Kinetic Energy

revised

Given: Collision and dynamic carts, track, computer, Logger Pro and LabPro, and motion detectors.

What to do:

1. You will investigate six types of collisions:
   a) a perfectly inelastic collision of two carts of approximately equal mass where one cart is moving initially and one is initially at rest
   b) a perfectly inelastic collision of two carts with unequal masses where one cart is moving initially and one is initially at rest
   c) a perfectly inelastic collision of two carts initially moving the same direction with equal masses and one of the carts is rear-ended
   d) a perfectly inelastic collision of two carts with unequal masses initially moving in opposite directions
   e) an elastic collision of two carts where one cart is moving and the other isn't (equal masses)
   f) an elastic collision of two carts of unequal mass initially moving the same direction and one of the carts is rear-ended
2. **Form two hypotheses: In which of the above collisions will momentum be conserved (within reasonable limits)? In which of the above collisions will kinetic energy be conserved?**
3. **Devise and record the procedure you will use to test your hypotheses.**
4. Perform the experiment and **record all relevant data in a clear and appropriate data table that will include masses, velocities, momentums, and kinetic energies both before and after the collisions. Make sure you show results for total momentum and total kinetic energy both before and after the collisions.**
5. **For each collision, find and record the % difference between total momentum before and after the collisions and the % difference between total kinetic energy before and after the collisions.**
6. **Write a conclusion that summarizes the purpose and procedure and that examines the validity of your hypotheses. Include three sources of error.**

Experiment

original

19

Momentum, Energy and Collisions

The collision of two carts on a track can be described in terms of momentum conservation and, in some cases, energy conservation. If there is no net external force experienced by the system of two carts, then we expect the total momentum of the system to be conserved. This is true regardless of the force acting between the carts. In contrast, energy is only conserved when certain types of forces are exerted between the carts.

Collisions are classified as *elastic* (kinetic energy is conserved), *inelastic* (kinetic energy is lost) or *completely inelastic* (the objects stick together after collision). Sometimes collisions are described as *super-elastic*, if kinetic energy is gained. In this experiment you can observe most of these types of collisions and test for the conservation of momentum and energy in each case.

OBJECTIVES

- Observe collisions between two carts, testing for the conservation of momentum.
- Measure energy changes during different types of collisions.
- Classify collisions as elastic, inelastic, or completely inelastic.

MATERIALS

computers
Vernier computer interface
Logger *Pro*
two Vernier Motion Detectors
dynamics cart track
two low-friction dynamics carts with magnetic and Velcro™ bumpers

PRELIMINARY QUESTIONS

1. Consider a head-on collision between two billiard balls. One is initially at rest and the other moves toward it. Sketch a position *vs.* time graph for each ball, starting with time before the collision and ending a short time afterward.
2. As you have drawn the graph, is momentum conserved in this collision? Is kinetic energy conserved?

PROCEDURE

1. Measure the masses of your carts and record them in your data table. Label the carts as cart 1 and cart 2.
2. Set up the track so that it is horizontal. Test this by releasing a cart on the track from rest. The cart should not move.
3. Practice creating gentle collisions by placing cart 2 at rest in the middle of the track, and release cart 1 so it rolls toward the first cart, magnetic bumper toward magnetic bumper. The carts should smoothly repel one another without physically touching.

4. Place a Motion Detector at each end of the track, allowing for the 0.4 m minimum distance between detector and cart. Connect the Motion Detectors to the DIG/SONIC 1 and DIG/SONIC 2 channels of the interface.

5. Open the file "19 Momentum Energy Coll" from the *Physics with Computers* folder.

6. Click Collect to begin taking data. Repeat the collision you practiced above and use the position graphs to verify that the Motion Detectors can track each cart properly throughout the entire range of motion. You may need to adjust the position of one or both of the Motion Detectors.

7. Place the two carts at rest in the middle of the track, with their Velcro bumpers toward one another and in contact. Keep your hands clear of the carts and click Zero. Select both sensors and click OK. This procedure will establish the same coordinate system for both Motion Detectors. Verify that the zeroing was successful by clicking Collect and allowing the still-linked carts to roll slowly across the track. The graphs for each Motion Detector should be nearly the same. If not, repeat the zeroing process.

Part I: Magnetic Bumpers

8. Reposition the carts so the magnetic bumpers are facing one another. Click Collect to begin taking data and repeat the collision you practiced in Step 3. Make sure you keep your hands out of the way of the Motion Detectors after you push the cart.

9. From the velocity graphs you can determine an average velocity before and after the collision for each cart. To measure the average velocity during a time interval, drag the cursor across the interval. Click the Statistics button to read the average value. Measure the average velocity for each cart, before and after collision, and enter the four values in the data table. Delete the statistics box.

10. Repeat Step 9 as a second run with the magnetic bumpers, recording the velocities in the data table.

Part II: Velcro Bumpers

11. Change the collision by turning the carts so the Velcro bumpers face one another. The carts should stick together after collision. Practice making the new collision, again starting with cart 2 at rest.

12. Click Collect to begin taking data and repeat the new collision. Using the procedure in Step 9, measure and record the cart velocities in your data table.

13. Repeat the previous step as a second run with the Velcro bumpers.

Part III: Velcro to Magnetic Bumpers

14. Face the Velcro bumper on one cart to the magnetic bumper on the other. The carts will not stick, but they will not smoothly bounce apart either. Practice this collision, again starting with cart 2 at rest.

15. Click Collect to begin data collection and repeat the new collision. Using the procedure in Step 9, measure and record the cart velocities in your data table.

16. Repeat the previous step as a second run with the Velcro to magnetic bumpers.

DATA TABLE

Mass of cart 1 (kg)		Mass of cart 2 (kg)	

Run number	Velocity of cart 1 before collision (m/s)	Velocity of cart 2 before collision (m/s)	Velocity of cart 1 after collision (m/s)	Velocity of cart 2 after collision (m/s)
1		0		
2		0		
3		0		
4		0		
5		0		
6		0		

Run number	Momentum of cart 1 before collision (kg•m/s)	Momentum of cart 2 before collision (kg•m/s)	Momentum of cart 1 after collision (kg•m/s)	Momentum of cart 2 after collision (kg•m/s)	Total momentum before collision (kg•m/s)	Total momentum after collision (kg•m/s)	Ratio of total momentum after/before
1		0					
2		0					
3		0					
4		0					
5		0					
6		0					

Run number	KE of cart 1 before collision (J)	KE of cart 2 before collision (J)	KE of cart 1 after collision (J)	KE of cart 2 after collision (J)	Total KE before collision (J)	Total KE after collision (J)	Ratio of total KE after/before
1		0					
2		0					
3		0					
4		0					
5		0					
6		0					

ANALYSIS

1. Determine the momentum (*mv*) of each cart before the collision, after the collision, and the total momentum before and after the collision. Calculate the ratio of the total momentum after the collision to the total momentum before the collision. Enter the values in your data table.

2. Determine the kinetic energy (½ mv^2) for each cart before and after the collision. Calculate the ratio of the total kinetic energy after the collision to the total kinetic energy before the collision. Enter the values in your data table.

3. If the total momentum for a system is the same before and after the collision, we say that momentum is *conserved*. If momentum were conserved, what would be the ratio of the total momentum after the collision to the total momentum before the collision?

4. If the total kinetic energy for a system is the same before and after the collision, we say that kinetic energy is *conserved*. If kinetic were conserved, what would be the ratio of the total kinetic energy after the collision to the total kinetic energy before the collision?

5. For your six runs, inspect the momentum ratios. Even if momentum is conserved for a given collision, the measured values may not be exactly the same before and after due to measurement uncertainty. The ratio should be close to one, however. Is momentum conserved in your collisions?

6. Repeat the preceding question for the case of kinetic energy. Is kinetic energy conserved in the magnetic bumper collisions? How about the Velcro collisions? Is kinetic energy consumed in the third type of collision studies? Classify the three collision types as elastic, inelastic, or completely inelastic.

EXTENSIONS

1. Using a collision cart with a spring plunger, create a super-elastic collision; that is, a collision where kinetic energy increases. The plunger spring should be compressed and locked before the collision, but then released during the collision. Measure momentum before and after the collision. Is momentum conserved in this case? Is energy conserved?

2. Using the magnetic bumpers, consider other combinations of cart mass by adding weight to one cart. Are momentum or energy conserved in these collisions?

3. Using the magnetic bumpers, consider other combinations of initial velocities. Begin with having both carts moving toward one another initially. Are momentum and energy conserved in these collisions?

4. Perform the momentum and energy calculations for the data tables using a spreadsheet.

revised

12—Magnetic Field in a Slinky

A solenoid is made by taking a tube and wrapping it with many turns of wire. A metal Slinky® is the same shape and will serve as our solenoid. When a current passes through the wire, a magnetic field is present inside the solenoid. Solenoids are used in electronic circuits or as electromagnets.

In this lab we will explore factors that affect the magnetic field inside the solenoid and study how the field varies in different parts of the solenoid. By inserting a Magnetic Field Sensor between the coils of the Slinky, you can measure the magnetic field inside the coil. You will also measure μ_0, the permeability constant. The permeability constant is a fundamental constant of physics.

OBJECTIVES

- Determine the relationship between magnetic field and the current in a solenoid.
- Determine the relationship between magnetic field and the number of turns per meter in a solenoid.
- Study how the field varies inside and outside a solenoid.
- Determine the value of μ_0, the permeability constant.

MATERIALS:

meter stick
DC power supply
Logger *Pro*
connecting wires
Vernier Magnetic Field Sensor
tape and cardboard
Slinky®
ammeter

WHAT TO DO:

1. First form hypotheses. **What is relationship between the magnetic field and the current in a solenoid? What is the relationship between magnetic field and the number of turns per meter in a solenoid?**

2. **Design and record a procedure that will test each of your hypotheses. Make a sketch of your experimental setup. Proper experimental procedure will hold one variable constant (for example the turns per meter in the first hypothesis) while the other variable is set for varying amounts. Then a graph is created (current vs. magnetic field for the first hypothesis) and curve fits are done to find the relationship.**

3. **Make appropriate data tables, one for each hypothesis.**

4. Setup and perform the experiment. Make sure you zero the magnetic field sensor when it is oriented in the proper direction with the current turned off. Do this each time you adjust the Slinky. **Record relevant data in the data tables.**

5. **Create graphs and do curve fits to find the relationship for each hypothesis. Print the graphs and record the regression equations.**

6. **Check the magnetic field intensity just outside the solenoid and comment on it.**

7. **Write a conclusion that summarizes the purpose and procedure and that answers the following questions. Was your hypothesis concerning the relationship between the magnetic field and the current in a solenoid valid? If not, what was the relationship? Was your hypothesis**

concerning the relationship between magnetic field and the number of turns per meter in a solenoid? If not what, what was the relationship?

Additional Analysis:

8. From Ampere's law, it can be shown that the magnetic field *B* inside a long solenoid is $B = \mu_0 nI$, where μ_0 is the permeability constant and n is the number of turns per meter. **Do your results agree with this equation? Explain. Assuming the equation in the previous question applies for your solenoid, calculate the value of μ_0 using your graph of *B vs. n.***

9. **Look up the value of μ_0, the permeability constant, in your notes or book and record it. Compare it to your experimental value and find the % error.**

The Magnetic Field in a Slinky

Original

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- Study how the field varies inside and outside a solenoid.
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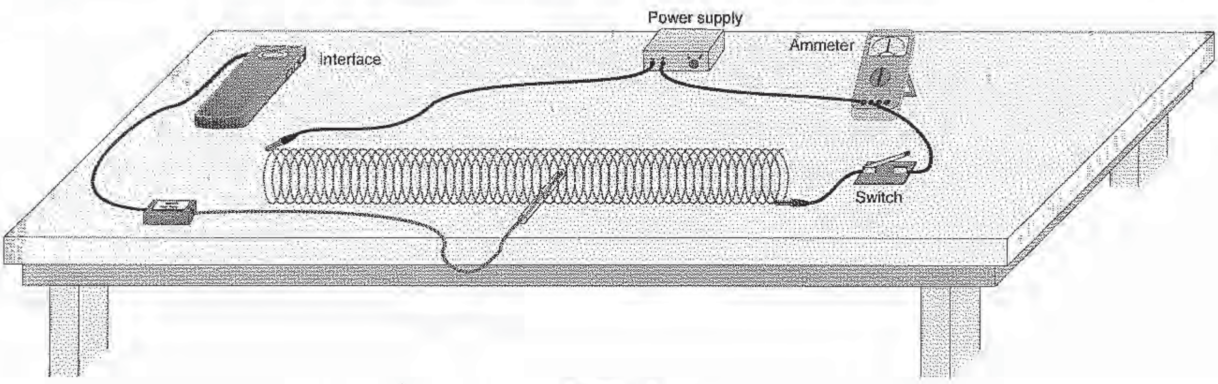

Figure 1

MATERIALS

computer
Vernier computer interface
Logger *Pro*
Vernier Magnetic Field Sensor
Slinky®
switch
meter stick
DC power supply
ammeter
cardboard spacers
connecting wires
tape and cardboard

INITIAL SETUP

1. Connect the Vernier Magnetic Field Sensor to Channel 1 of the interface. Set the switch on the sensor to *High*.
2. Stretch the Slinky until it is about 1 m in length. The distance between the coils should be about 1 cm. Use a non-conducting material (tape, cardboard, etc.) to hold the Slinky at this length.

3. Set up the circuit and equipment as shown in Figure 1. Wires with clips on the end should be used to connect to the Slinky. If your power supply has an accurate internal ammeter you do not need an additional external ammeter.

4. Turn on the power supply and adjust it so that the ammeter reads 2.0 A when the switch is held closed. **Note:** This lab requires fairly large currents to flow through the wires and Slinky. Only close the switch so the current flows when you are taking a measurement. The Slinky, wires, and possibly the power supply may get hot if left on continuously.

5. Open the file "29 Magnetic Field in Slinky" in the *Physics with Computers* folder. A graph will appear on the screen. The meter displays magnetic field in millitesla, mT. The meter is a live display of the magnetic field intensity.

PRELIMINARY QUESTIONS

1. Hold the switch closed. The current should be 2.0 A. Place the Magnetic Field Sensor between the turns of the Slinky near its center. Rotate the sensor and determine which direction gives the largest magnetic field reading. What direction is the white dot on the sensor pointing?

2. What happens if you rotate the white dot to point the opposite way? What happens if you rotate the white dot so it points perpendicular to the axis of the solenoid?

3. Stick the Magnetic Field Sensor through different locations along the Slinky to explore how the field varies along the length. Always orient the sensor to read the maximum magnetic field at that point along the Slinky. How does the magnetic field inside the solenoid seem to vary along its length?

4. Check the magnetic field intensity just outside the solenoid.

PROCEDURE

Part I How Is The Magnetic Field In A Solenoid Related To The Current?

For the first part of the experiment you will determine the relationship between the magnetic field at the center of a solenoid and the current flowing through the solenoid. As before, leave the current off except when making a measurement.

1. Place the Magnetic Field Sensor between the turns of the Slinky near its center.

2. Close the switch and rotate the sensor so that the white dot points directly down the long axis of the solenoid. This will be the position for all of the magnetic field measurements for the rest of this lab.

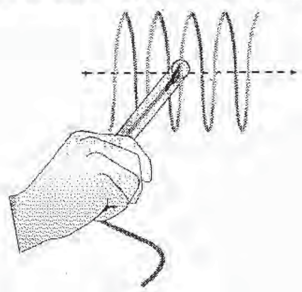

Figure 2

3. Click [▶ Collect] to begin data collection. Wait a few seconds and close the switch to turn on the current.

4. If the magnetic field increases when the switch is closed, you are ready to take data. If the field decreases when you close the switch, rotate the Magnetic Field Sensor so that it points the other direction down the solenoid.

5. With the Magnetic Field Sensor in position and the switch open, click on the Zero button, [Zero], to zero the sensor and remove readings due to the Earth's magnetic field, any magnetism in the metal of the Slinky, or the table.

6. Adjust the power supply so that 0.5 A will flow through the coil when the switch is closed.

7. Click [Collect] to begin data collection. Close the switch for at least 10 seconds during the data collection.

8. View the field *vs.* time graph and determine the region of the curve where the current was flowing in the wire. Select this region on the graph by dragging over it. Determine the average field strength while the current was on by clicking on the Statistics button, [STAT]. Record the average field in the data table.

9. Increase the current by 0.5 A and repeat Steps 7 and 8.

10. Repeat Step 9 up to a maximum of 2.0 A.

11. Count the number of turns of the Slinky and measure its length. If you have any unstretched part of the Slinky at the ends, do not count it for either the turns or the length. Calculate the number of turns per meter of the stretched portion. Record the length, turns, and the number of turns per meter in the data table.

Part II How is the Magnetic Field in a Solenoid Related to the Spacing of the Turns?

For the second part of the experiment, you will determine the relationship between the magnetic field in the center of a coil and the number of turns of wire per meter of the solenoid. You will keep the current constant. Leave the Slinky set up as shown in Figure 1. The sensor will be oriented as it was before, so that it measures the field down the middle of the solenoid. You will be changing the length of the Slinky from 0.5 to 2.0 m to change the number of turns per meter.

12. Adjust the power supply so that the current will be 1.5 A when the switch is closed.

13. With the Magnetic Field Sensor in position, but no current flowing, click [Zero] to zero the sensor and remove readings due to the Earth's magnetic field and any magnetism in the metal of the Slinky. Since the Slinky is made of an iron alloy, it can be magnetized itself. Moving the Slinky around can cause a change in the field, even if no current is flowing. This means you will need to zero the reading each time you move or adjust the Slinky.

14. Click [Collect] to begin data collection. Close and hold the switch for about 10 seconds during the data collection. As before, leave the switch closed only during actual data collection.

15. View the field *vs.* time graph and determine where the current was flowing in the wire. Select this region on the graph by dragging over it. Find the average field while the current was on by clicking on the Statistics button, [STAT]. Count the number of turns of the Slinky and measure its length. If you have any unstretched part of the Slinky at the ends, do not count it for either the turns or the length. Record the length of the Slinky and the average field in the data table.

16. Repeat Steps 13 – 15 after changing the length of the Slinky to 0.5 m, 1.5 m, and 2.0 m. Each time, zero the Magnetic Field Sensor with the current off. Make sure that the current remains at 1.5 A each time you turn it on.

DATA TABLE

Part I

Current in solenoid I (A)	Magnetic field B (mT)
0.5	
1.0	
1.5	
2.0	

Length of solenoid (m)	
Number of turns	
Turns/m (m^{-1})	

Part II

Length of solenoid (m)	Turns/meter n (m^{-1})	Magnetic field B (mT)

Number of turns in Slinky	

ANALYSIS

1. On Page 2 of the experiment file, plot a graph of magnetic field *B vs.* the current *I* through the solenoid.
2. How is magnetic field related to the current through the solenoid?
3. Determine the equation of the best-fit line, including the *y*-intercept. Note the constants and their units.
4. For each of the measurements of Part II, calculate the number of turns per meter. Enter these values in the data table.
5. On Page 3 of the experiment file, plot a graph of magnetic field *B vs.* the turns per meter of the solenoid (*n*).
6. How is magnetic field related to the turns/meter of the solenoid?
7. Determine the equation of the best-fit line to your graph. Note the constants and their units
8. From Ampere's law, it can be shown that the magnetic field *B* inside a long solenoid is

$$B = \mu_0 n I$$

   where μ_0 is the permeability constant. Do your results agree with this equation? Explain.

9. Assuming the equation in the previous question applies for your solenoid, calculate the value of $\square_0$ using your graph of *B vs. n*.
10. Look up the value of $\square_0$, the permeability constant. Compare it to your experimental value.
11. Was your Slinky positioned along an east-west, north-south, or on some other axis? Will this have any effect on your readings?

EXTENSIONS

1. Carefully measure the magnetic field at the end of the solenoid. How does it compare to the value at the center of the solenoid? Try to prove what the value at the end should be.
2. Study the magnetic field strength inside and around a toroid, a circular-shaped solenoid.
3. If you have studied calculus, refer to a calculus-based physics text to see how the equation for the field of a solenoid can be derived from Ampere's law.
4. If you look up the permeabilty constant in a reference, you may find it listed in units of henry/meter. Show that these units are the same as tesla-meter/ampere.
5. Take data on the magnetic field intensity *vs.* position along the length of the solenoid. Check the field intensity at several distances along the axis of the Slinky past the end. Note any patterns you see. Plot a graph of magnetic field (*B*) *vs.* distance from center. How does the value at the end of the solenoid compare to that at the center? How does the value change as you move away from the end of the solenoid
6. Insert a steel or iron rod inside the solenoid and see what effect that has on the field intensity. Be careful that the rod does not short out with the coils of the Slinky. You may need to change the range of the Magnetic Field Sensor.
7. Use the graph obtained in Part I to determine the value of μ_0.