One Dimensional Collisions[1]

Fall 20xx

Name: Solution

Partners:

Introduction

The purpose of this experiment is to perform experiments to learn about momentum, impulse and collisions in one dimension. *Write all of your answers in the space provided within these instructions. Write in complete sentences, and be sure to show your work.* *You won't be penalized for incorrect predications; however, you will lose points if your results don't match your prediction, and you say that it does!*

Investigation 1: Which packs the bigger wallop – a clay blob or a superball?

Newton's first two laws can be expressed as follows:

- Law 1: An object in motion remains in motion and an object at rest remains at rest unless acted on by an external force.
- Law 2: The rate of change of motion is directly proportional to the force and is in the same direction as the force. OR The net force on an object is equal to the product of its mass and acceleration where the acceleration and net force are in the same direction.

Scenario: You are sleeping in your sister's room while she is away at college. Your house is on fire and smoke is pouring into the partially open bedroom door. To keep the smoke from coming in, you must close the door. The quickest way to close the door is to throw something at it. You have only one chance! You must choose between a blob of clay or a superball. There isn't time to throw both.

1. *Prediction 1*: Assuming the clay blob and the superball have the same mass, and that you throw them with the same velocity, which would you throw to close the door? The clay blob will stick to the door and the superball will bounce back with almost the same speed as it had before it collided with the door. Give reasons for your choice using any notions you already have or any new concepts developed in physics, such as force, energy, momentum, or Newton's laws. If you think that there is no difference, justify your answer.

+0.5 pt.

Super ball – greater change in momentum

2. *Prediction 2*: What will happen to the maximum force that the clay exerts on the door if you keep the mass of the clay constant and you increase the velocity of the clay?

+0.5 pt.

Force increased

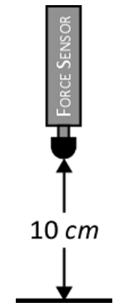
3. *Prediction 3*: What will happen to the maximum force that the clay blob exerts on the door if you increase the mass of the clay and keep the velocity of the clay constant?

+0.5 pt.

Force increased

[1] This experiment is adapted from **Realtime Physics** by David Sokoloff, Ronald K. Thornton and Priscilla W. Laws.

Simulation: You can test your predictions by dropping a force sensor with a bouncy rubber tip on its end (instead of a superball), and then dropping the force sensor with a clay ball of approximately the same mass on its end. We can associate the maximum force read by the force sensor with the maximum force a thrown ball can exert on the door. If the sensor is dropped from the same height, the velocity will remain constant. We will later investigate how the force is related to the change in momentum of the ball in each case. To do the simulation you will need the following equipment:



- Force sensor, set to ±50N
- Rubber tip & clay holder for the force sensor
- Large ball clay & meter stick
- Small ball of clay with the same mass as the rubber tip

NOTE: DO NOT DISCONNECT THE FORCE SENSORS TO MEASURE THEIR MASS! KEEP ALL WIRES CONNECTED WHILE LOGGER PRO IS RUNNING. USE THE ELECTRONIC SCALE ON YOUR LAB BENCH FOR MEASUREMENT!

4. *Try it*:
   a. Set the switch on the force sensor to ±50N; start Logger Pro and open the file on the T: drive called “Clay vs. Superball SLU”. This will set up the computer to collect and graph force data at 4000 points per second, and configures the sensor to read a ‘push’ on the tip as positive. You will record forces for the different situations listed in the table below.

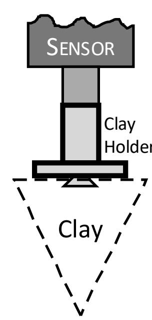
   b. Screw the rubber tip on the end of the force sensor. ***Zero the force sensor*** while holding it in a vertical position with the tip pointing down by clicking the **Zero** button next to the green Collect button, at the top of the window. You must zero the force sensor before each drop!

   c. Hold the rubber tip of the force sensor 10 *cm* above the table. Begin graphing by clicking the **teal Collect** button. Just after the Collect button turns **brown** (**Stop)**, drop the sensor (*you will need to hesitate a brief moment after the button turns red before dropping the sensor*). **Don’t click the Stop button!** Be sure that the force sensor falls vertically downward and does not tip on its side.

   d. Find the maximum force applied to the force sensor for each drop by clicking the **Analyze** menu, and then **Examine**. Moving the cursor until it is at the peak of the curve will display the maximum force.

   e. Collect three good trials of data. On the last run for each situation, store the graph by clicking the **Experiment** menu and then **Store Latest Run**. This will keep the stored graphs displayed on your screen for comparison.

   f. When using clay, unscrew the rubber tip from the force sensor, and then screw on the clay holder (*figure at right*). Form the clay into a ball, and ***reform before each drop***. Use 20 *cm* for the larger height in the third case to increase the velocity.



Crappy data: -0.5
No graph: -1
No peak labels: -0.25

   g. Choose **File → Page Setup**, click the **Landscape** button, and then **OK**. Then print a graph which contains one sample from each case. When you print, you can put your names in the name field in the footer. Label each peak that appears on the printout.

+2 pt.

	Mass (*kg*) (force sensor + tip)	Height (*m*)	Maximum force (*N*) Three trials			Avg. force (*N*)
#1. Rubber tip, 10 *cm* height	0.0941	0.10	26.055	27.644	28.400	27.060
#2. Small clay ball, 10 *cm* height	0.0920	0.10	16.761	15.358	18.22	20.560
#3. Small clay ball, **20 *cm*** height	0.0920	0.20	26.345	18.548	21.807	22.233
#4. Massive clay ball, 10 *cm* height	0.1491	0.10	25.522	24.687	24.862	24.960

5. *Question 1*: Did your observations of drops #1 and #2 agree with *Prediction 1*? Which resulted in a bigger maximum force – the rubber tip or the clay?

The rubber tip (drop #1) resulted in larger maximum

6. *Question 2*: Based on your observations of drops #1 and #2, which should you throw at the door – the superball or the clay? Explain.

Throw the superball! Larger force, better to close the door

7. *Question 3*: Compare your results from drops #2 and #3. Did your observations agree with *Prediction 2*? What about your results from drops #2 and #4 – did they agree with *Prediction 3*? Summarize your observations: what factors seem to determine the force exerted on the sensor?

Both mass and velocity determine the force exerted on the probe

Investigation 2: Momentum Change

In the next activity you will find out how momentum changes in two types of collisions. During elastic collisions the objects bounce off one another and during inelastic collisions objects stick together. Recall that momentum (p) is a vector quantity equal to the mass (m) times the velocity (v). The change in momentum is also a vector quantity.

$$\Delta\vec{p} = \vec{p}_f - \vec{p}_i$$
$$\vec{p} = m\vec{v}$$

1. *Prediction 1*: Which object undergoes the greater momentum change during the collision with a door – the clay blob or the superball? Carefully explain your reasoning.

+0.5 pt.

Superball – twice the momentum of the clay ball
$v_f = 0$ for clay

2. *Calculations*: Now you will check your prediction by doing some calculations.
   a. Calculate the initial momentum of the small clay ball plus the force sensor just before it hits the table from a height of 10 *cm*. *Assume that the upward direction is positive.* (Hint: You will need to recall from kinematics that $v_y^2 = v_{oy}^2 + 2gh$ where v_{oy} is zero, $g = 9.8\, {}^{m}\!/_{s^2}$ and h is the height.)

+2 pt.

Wrong: -1
Only calculated v: -0.5
Missing negative: -0.5
Calculation error: -0.2
Units: -0.25

$$v_y = \sqrt{2gh}, \quad so:$$
$$p_i = mv_y = m\sqrt{2gh}$$
$$= 0.0950\sqrt{2 \cdot g \cdot 0.10}$$
$$= -0.133\, {}^{kg\cdot m}\!/_{s}$$

Upward is + direction
This is falling down (-)!

   b. What is the final momentum of the clay ball and force sensor after it collides with the table? Explain.

+2 pt.

Wrong: -1
No explanation: -0.5

$p_f = 0$ {since $v_f = 0$}

c. What is the change in momentum of the clay ball and force sensor? Be careful of the sign.

+1 pt.

Units: -0.25

$$\Delta p = p_f - p_i = 0 - (-0.133) = +0.133\, {}^{kg\cdot m}/_{s}$$

d. Repeat these three steps to find the change in momentum for the rubber tip and force sensor assuming the tip bounces off the table with the same magnitude of velocity as it hit the table.

+2 pt.

Right answer but dropped sign: -0.2

$$p_i = mv_i = m\sqrt{2gh} = 0.0930\sqrt{2\cdot g\cdot 0.10} = -0.130\, {}^{kg\cdot m}/_{s} \quad \{moving\ down\}$$

$$p_f = mv_f = +0.130\, {}^{kg\cdot m}/_{s} \quad \{moving\ up\}$$

$$\Delta p = p_f - p_i = 0.130 - (-0.130) = 0.260\, {}^{kg\cdot m}/_{s}$$

3. *Question 1*: Compare your calculated change in momentum to your predictions. Do they agree? Which had the larger change in momentum: the rubber tip, or the small clay ball?

+1 pt.

$$Clay: \quad \Delta p = +0.133\, {}^{kg\cdot m}/_{s}$$

$$Rubber\ tip: \quad \Delta p = +0.260\, {}^{kg\cdot m}/_{s}$$ ← Greater change in momentum!

4. *Question 2*: How does change in momentum seem to be related to the maximum force applied to the ball?

+1 pt.

Greater change in momentum, larger maximum force!

{F = Δp/Δt}

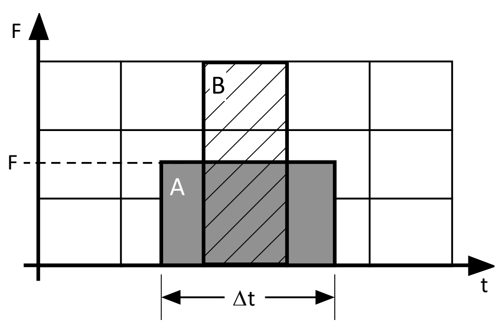
Investigation 3: Impulse, Momentum and Collisions

A quantity called impulse is defined as the product of the applied force and the time interval over which it acts.

$$\text{Impulse} = F\Delta t$$

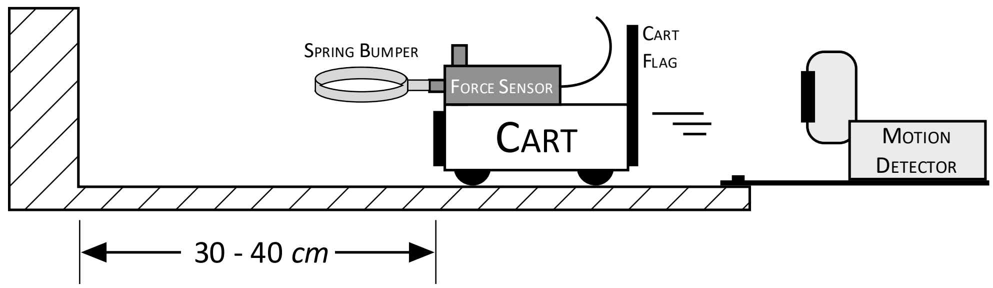
Note that $F\Delta t$ is equal to the area under a force vs. time graph. In the graph below the force is held constant for a time interval Δt. The gray shaded area (A) represents the impulse.

As you can see from the graph, a larger time produces a larger impulse, and a larger force produces a larger impulse. A large force acting over a small time (*area B*) can have the same impulse as a small force acting over a large time. Even if the force isn't constant, the area under the curve in a force vs. time graph is still the impulse.



1. *Simulation*: We can create this graph using the following equipment

• Low-friction cart	• Motion detector & cart flag
• Level track	• Force sensor with spring bumper



2. *Try it*: You will try to create a nearly perfect elastic collision where the object will bounce back at the same magnitude of velocity and momentum as it had before the collision. Your collision will only be nearly perfect.
   a. Unscrew the rubber tip from the force sensor, and replace it with a spring bumper. The loop of the spring bumper will be parallel to the track. *The spring bumper uses a locking screw to hold it tightly on the force sensor; if needed, ask your instructor for assistance.*
   b. Set the switch on the force sensor to ±10N, and attach the sensor to the post on the cart. Make sure the sensor is against the front edge of the cart so that it doesn't move.
   c. Attach the motion detector and flag to the cart as shown above. Be sure that the track is level.
   d. Measure and record the mass of the cart and force sensor combination.

+1 pt.

Mass = 610.9 g = 0.6109 kg

   e. Open the experiment file on the T: drive called **Impulse and Momentum SLU**. This experiment has been set up to record force and motion data at 50 data points per second. Because the positive direction is toward the right, the software has been set up to record a push on the force sensor as a positive force and velocity toward the motion detector as positive.
   f. Position the cart between 30 and 40 *cm* from the wall (the actual distance does not matter). Position the wire from the force sensor so that it won't be picked up by the motion detector.
   g. Practice pushing the cart toward the wall and watch it bounce off. Find a way to push without putting your hand between the motion detector and the cart.
   h. When you are ready, ***zero the force sensor and motion detector*** (the detector will click slowly a few times). Zero the sensor and detector, and then click the green **Collect** button; when you hear the motion detector clicking, give the cart a push toward the wall, release it, and let it collide. Note that you only have 2 seconds to record data from the time the motion detector turns on. A peak impact force between 4 *N* and 5 *N* will give reasonably good results.
   i. Repeat until you get a good set of graphs, i.e., a set where the motion detector saw the relatively constant velocities of the cart as it moved toward the wall and as it moved away.

3. Use the analysis feature in Logger Pro to measure the velocity of the cart as it approached the wall and the velocity as it moved away from the wall: Click the velocity graph and choose **Analyze**, and then **Examine**, then place the cursor on the portions of the curve *just before* and *just after* the collision (look at the force graph to determine these positions; check with your instructor if you're unsure of the appropriate positions). Be sure to include the sign!

+1 pt.

   a. Velocity *toward* the wall: -0.490 m/s = v_i
   b. Velocity *away from* the wall: +0.487 m/s = v_f

No units: -0.5 *each*
No sign: -0.5

4. Calculate the change in momentum of the cart. Show your calculations:

+2 pt.

$$\begin{aligned}\Delta p &= p_f - p_i \\ &= m\left(v_f - v_i\right) \\ &= 0.6109\left(0.487 - (-0.490)\right) \\ &= +0.597\, kg \cdot {}^{m}\!/\!_{s}\end{aligned}$$

5. Use the integration routine in Logger Pro to find the impulse (the area under the force-time graph). Click the Force graph, and then highlight the region you want to measure by clicking and dragging. Choose the **Analyze** menu, and then **Integral**. You can drag the left and right brackets that appear on the curve to change the area of integration.

+1 pt.

Impulse = 0.5611 N·s

6. Show that the units of the impulse (*step 5*) are equivalent to the change in momentum (*step 4*) units.

+1 pt.

$$(N)s = \left(kg\frac{m}{s^2}\right)\cancel{s} = kg\frac{m}{s}$$

7. Print your graph from this experiment, again making sure that it will print in *Landscape* mode.

8. Write the following labels on the printout of your velocity graph: The point where the push starts; where the push stops; where the collision with the wall starts; and where the collision stops.

Labeled graphs on next page!

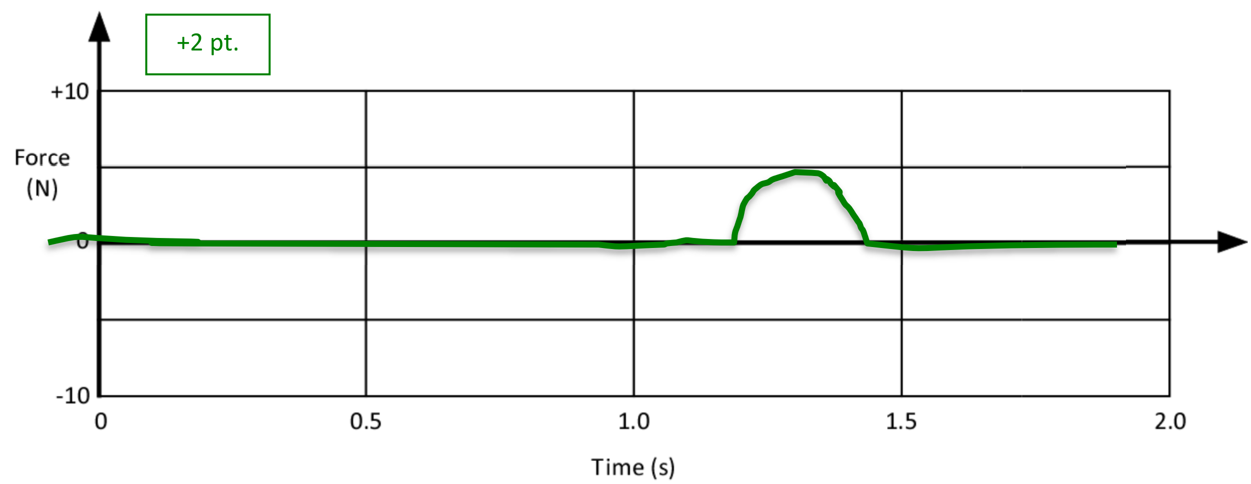
9. *Question 1*: Calculate the % difference between the calculated change in momentum of the cart and the measured impulse applied to it by the wall. Compare these two methods of measuring impulse. Are they reasonably equal (within a few percent)? Briefly discuss the agreement of your results, and the possible cause of any discrepancy.

+2 pt.

Δp = 0.597 kg·m/s
Impulse = 0.5611 N·s

6% difference

No discussion: -1



10. *Question 2*: The force graph above is an interaction between what two objects?

+1 pt.

The spring bumper and the 'wall'

Wrong: -0.5

+1 point for each attached graph!

WHEN YOU ARE FINISHED, PLEASE SHUT DOWN THE COMPUTER, REMOVE ALL ACCESSORIES FROM THE FORCE SENSOR, AND RETURN THE SPRING BUMPERS, RUBBER TIP, CLAY AND CLAY HOLDER TO THE SMALL BOX ON THE BENCH!