Collisions- Momentum and Kinetic Energy (2h 10 min.) (1/12/2017)

Introduction

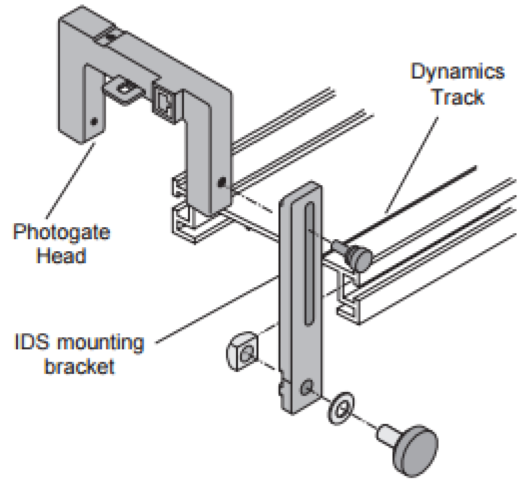
In this lab we consider impacts that are of such large force and brief duration that the effect of any *net external force* on the colliding objects may be considered negligible. We refer to such impacts as *collisions*. An *elastic* collision is one in which the objects bounce off of each other without change of their total mechanical kinetic energy. An *inelastic* collision is one in which some of the mechanical kinetic energy of the colliding objects is converted into other forms of energy. For example, friction forces may result in the creation of kinetic energy on the molecular scale where it is known as thermal energy (i.e. heating). A collision is referred to as *totally inelastic* when the two colliding objects continue to stick together after the collision.

Equipment

- 2.2 meter dynamics track with feet.
- 250-g mass bar
- 2 PAScar 250-g
- 2 photo-gates
- Picket Fence

Physical Setup

Carts moving along a low-friction track provide an opportunity to study collisions in one-dimension. Begin by setting up the track and photogates. Plug the photogate cables into channels 1 & 2 on the Pasco interface. (Make sure the interface is on.) Insert “bumper” accessories (with rubber bands horizontal) into the stops on both ends of the air track. Hook and loop fasteners on each car allow for inelastic collisions. Magnets (repulsive) on each car allow for elastic collisions. Built in spring plungers allow for the investigation of internal forces (explosions). Attach picket fences to the tops of both cars and adjust the heights of the photogates so the 2.5cm portion of the flags pass through them as shown. As the flags pass through the photogates they should block the infrared light beams, during which time (when blocked) the red light on the top illuminate corresponding measuring the time the photogate beam is blocked. If the length of the flag Δx = (2.5cm = 0.025m) and duration of time, in seconds, when the beam is blocked are known, the speed of the cart can be calculated using the equation, $v = \Delta x / \Delta t$. The height of the photogate can be adjusted by loosening the set screw connecting the photogate head and the mounting bracket.



It is very important that the track be level. Use a spirit level and/or a cart to level the track. You can see if the track is approximately level by placing a cart on the track midway between the photogates then turning the air supply on and seeing if it drifts to one side or the other. The cart may drift back and forth slightly due to random fluctuations in the air supply but should not favor one direction over the other. If the cart drifts toward one end, use the adjustable feet on the legs of the air track to make it level. First unlock the feet by turning the two knobs in opposite directions to separate them, then, adjust the heights of the bottom knobs until the cart no longer drifts in either direction. (Also make sure the track is not tilting and causing the cart to lean to one side.) Lock the feet in position by twisting the top knob into the bottom one when you are finished leveling. Be patient! You are not likely to get very accurate results if your track is not level.

Software Setup

Open Capstone (It should be on your computer desktop.) and double-click on "Hardware Setup" on the tools palette (on left). A picture of the interface you are using should show on the screen. Be sure the interface shown (500/750/850/etc.) matches the one connected to your computer, if not, choose the correct interface. Click on the "Channel 1" port of the interface and select the "photogate" sensor. Click on the "Channel 2" port and select the "photogate" sensor.

We want to measure the time that elapses as the flag on a cart passes through a photogate (i.e. blocks the infrared light beam). To measure this time we need to activate each timer when its beam is blocked, and stop each timer when its beam is unblocked. To do this, click on "Timer Setup" (on right). Set up "Preconfigured Timers" and check Photogates 1 and 2, and then click next. Select "Two Photogates with a Single Flag", then click next. A list will populate; on this list select Speed in Gate for Photogate 1 and 2, deselect all other quantities, and then click next. Assign a flag length of 0.025m (2.5cm). If so desired, name the file and click finish. Close the timer setup by clicking the "Timer Setup" tab in the Tools palette (on left).

Drag and drop a data table from the display palette (on right). Select both Speed in gate 1 and Speed in gate 2 and press Record. Leave the data collection running throughout the experiment. Each time the photogate beam is blocked by the picket fence attached to the cart, Capstone will calculate the speed of the cart based on the picket fence distance and the duration of time the beam is blocked.

Procedure

Click on “Record” (on top left of screen) then block and unblock the photogates with your hand. Look at the data displaying in Tables 1 & 2. Continue doing this until you understand how the times are recorded and what they are measuring, then click on “Stop”. Discuss your interpretation with your lab partner(s) until you reach a consensus. Clear the data from your tables by clicking on “Delete Last Run” button on the Controls palette (on bottom).

Under the assumptions to be made in the following experiments (i,e, negligible friction and a level track) a cart rolling untouched through both photogates should have constant speed and take the same amount of time to pass through each photogate. In reality there is always some friction which tends to slow the cart down. Therefore, we should expect to observe a slight slowing down as the cart proceeds along a level track, resulting in successively longer passage times thru the photogates. If successive elapsed times show a decrease, it suggests that the speed of the cart has increased, which suggests it has gone downhill between gates. To determine if the track is effectively level between the photogates, place Cart A on the track to the left of gate 1. Click on “Start” (on top left of screen), then turn on the air supply and give the cart a push so it coasts through both photogates after release, and continues to bounce (off the bumpers) back and forth thru the gates at least 10 times, observing successive elapsed times as they are tabulated. Click on “Stop”, and review the data that has been tabulated for Timers 1 & 2. Are the successive elapsed times for passages between the 2 gates very nearly the same (within, say 2%), validating our assumption of negligible friction? Do successive elapsed times (in both directions) consistently increase, validating our assumption that the track is level? If friction seems to be having to large an effect, try starting your cart at a different speed. If there is consistently a speeding up between gates in one direction, it signifies the cart is going downhill and your track needs to be leveled more precisely. When your track is sufficiently level and you know about how fast the cart needs to be going to make friction effects negligible, you will be ready to do Part A.

Some Relevant Equations

Momentum:

$$\vec{p} = m\vec{v} \qquad \vec{p}_{total} = \sum m_i \vec{v}_i$$

$$\%\Delta\vec{p} = \frac{\vec{p}_{final} - \vec{p}_{initial}}{\vec{p}_{initial}} \times 100\%$$

KineticEnergy:

$$K = \tfrac{1}{2} mv^2 \qquad K_{total} = \sum \tfrac{1}{2} m_i v_i^{\,2}$$

$$\%\Delta K = \frac{K_{final} - K_{initial}}{K_{initial}} \times 100\%$$

<u>Part A: Totally Inelastic collisions, only one cart moving before the collision</u>

Case 1: Totally Inelastic collision with carts of equal mass

<u>Make & Record Your Predictions</u>: In this experiment Cart A with mass *M* will collide with Cart B, of nearly equal mass. Initially, Cart A will be moving with velocity v_0 and Cart B will be stationary. The carts will stick together after the collision, moving with velocity $v_{(A+B)}$.

The total momentum before the collision will be $p_{initial} = M \cdot v_0 + M \cdot 0 = M \cdot v_0$. The final momentum, after collision, will be $p_{final} = (M + M) \cdot v_{(A+B)} = 2M \cdot v_{(A+B)}$.

Assuming momentum is conserved in the collision predict the velocity of the carts after the collision. Will they speed up? Slow down? What will the ratio of $v_{(A+B)}$ to v_0 be?

Do the Experiment: Clear the data from tables 1 & 2 and check your predictions experimentally. Place Cart A (with picket fence and hook and loop *Velcro*) near the left end of your air track, and Cart B (with picket fence and hook and loop *Velcro*) midway between the photogates. Click on "Record". With Cart B stationary, give Cart A push to the right, making sure to remove your hand before it begins to pass through photogate 1. Let it collide with (and stick to) Cart B, observing qualitatively how the speeds of the carts change as a result of the collision. Let both carts pass thru photogate 2 before clicking "Stop". (If you do not click "Stop" right away, you will simply get additional, unneeded data in your tables as the carts go back through them.) Repeat the experiment to see how repeatable your results are. Record your qualitative observations and the corresponding data recorded by Timers 1 & 2 on the appropriate data sheet on page 7. (Ideally, the elapsed times for the passages of Carts A & B, which are connected via Velcro, through photogate 2 should be identical. If they are not, simply average them.) Is there reasonable agreement between your predictions and your observations? (If not, why not?)

Make at least two trials for this type of collision, record the relevant elapsed times and calculate the velocities. Calculate the momentum and the kinetic energy for both trials. Compare your results to your qualitative observations and prediction. Do they make sense?

Determine whether momentum is reasonably well conserved in this collision by calculating the percentage change in total momentum for each trial separately. (Note: Do not average the different trials since you cannot control the initial velocities to be identical.)

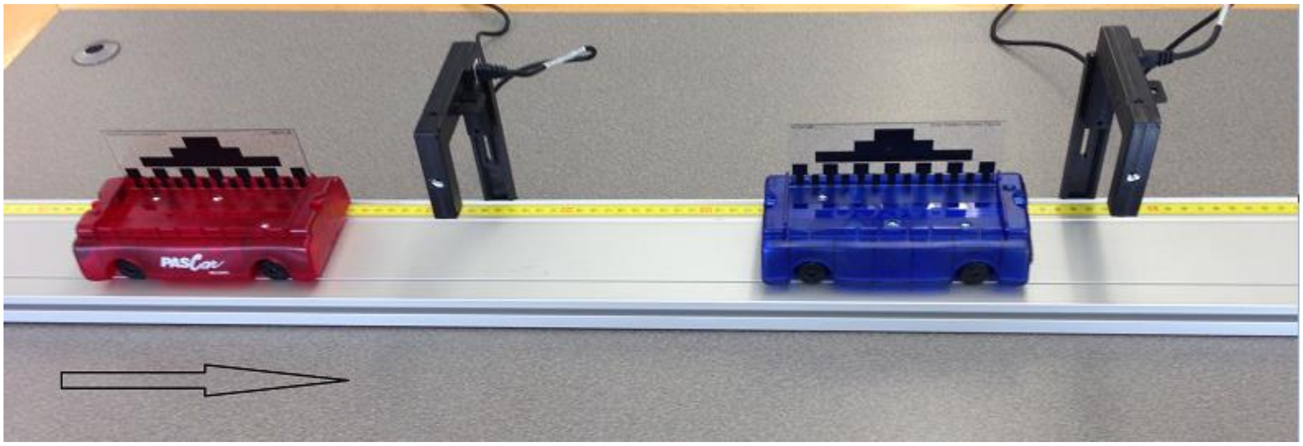
Calculate the percentage change in kinetic energy for each trial collision.

Case 2: Totally Inelastic collision with carts of unequal mass

Repeat the procedure of Part 1 with carts of different masses by placing a mass bar (250-g) on (in) Cart B. (Although there is only one final velocity once the carts are stuck together you can again determine whether they are speeding up or slowing down significantly by comparing the elapsed times of passage of the two carts through photogate 2.)

First make and record your predictions (p.8) then do the experiments and record your qualitative observations and elapsed time data. Make at least two trials. Calculate velocities (remember to account for the direction of motion +/-), momenta (remember sign +/-), kinetic energies and percentage changes in total momentum and kinetic energy for each trial. Compare your qualitative observations and calculated results to your predictions.

Part B: Nearly Elastic collisions, only one cart moving before the collision.



Case 1: Elastic collisions with carts of equal mass

Set up an elastic collision between two carts of equal mass. Place the ends of the PAScar with magnets facing each other. Place Cart A before the first photogate. Cart B should be stationary between the photogates, as shown in the image above.

Make a Prediction: Predict, qualitatively what will happen if you give Cart A a push toward Cart B. What do you expect the relative values of v_A and v_B will be after the collision?

Do the Experiment: Give Cart A a push and observe the changes in motion each cart experiences as a result of the elastic collision. Record your qualitative observations of v_A and v_B before and after the collision. (Note: Low velocities give better results for elastic collisions. Higher velocities give better results for inelastic collisions.)

Calculate the velocities: There are up to three relevant time intervals for this type of collision. Cart A initially passes through photogate 1 so the first time interval corresponds to its initial velocity. Cart B is initially stationary so its initial velocity is not recorded. After the collision Cart B passes through photogate 2 and the time interval corresponds to its final velocity. Cart A may a) rebound and pass through Gate #1 again, b) stop, or c) follow Cart B through Gate #2. In cases a) and c) the respective time interval corresponds to its final velocity. Make at least two trials and record the velocities before and after the collisions. For initial or final velocities that are zero, no time will be recorded and you should just record your observation that the velocity is zero.

Compare your results to your predictions and qualitative observations.

For each of the trials, calculate the percent change in total momentum before and after the collision. Is momentum conserved (within experimental uncertainty)?

Calculate the percentage change in kinetic energy for this type of collision. (The smaller the percentage change in kinetic energy, the closer this collision is to being perfectly elastic.)

Case 2: Elastic collisions with carts of unequal mass

Repeat the above procedure for carts with unequal masses, with the lighter cart initially at rest.

Part C: Nearly Elastic head-on collisions, both carts initially moving.

Head-on collisions

Set up the carts as shown in the image above. (You may choose either equal or unequal masses for the carts.) Push the carts toward each other at approximately the same time so that initially Cart A passes thru Gate #1 and Cart B passes thru Gate #2, and the collision takes place entirely while between the photogates. What happens after the collision will depend on the masses of the carts, their initial velocities, and the nature of the collision. If the collision is elastic and they both rebound, then Cart A will again pass thru Gate #1 and Cart B will again pass thru Gate #2. They could also both travel to either the left or the right, or one cart could stop (or move so slowly that no elapsed time is recorded). (If they both came to a stop, could it still be considered a nearly elastic collision?)

Make a trial run for this type of collision to figure out which columns will record which elapsed times, then determine the "before" and "after" velocities (+/-) for each cart. Calculate the initial and final momenta. (Remember that velocities are positive if in the same direction as Cart A's initial velocity and negative if in the same direction as Cart B's initial velocity, *even though all times recorded are positive*. Either or both carts may have a negative final velocity.)

For trial 2, use two carts of equal mass and try setting up a collision that has zero total momentum both before and after the collision. Make your prediction, then, record your results and observations. How do they compare? Discuss possible reasons for any discrepancies.

***Questions* -** Answer the following questions in your write-up:

1. How do your results compare to both your predictions and your qualitative observations?

    Discuss possible sources or error or uncertainty.

2. In the first few collisions one cart was initially at rest and then it was moving after the collision. What caused the acceleration of this cart?

    What effect did this have on the other cart?

3. Which type of collision (nearly elastic or totally inelastic) causes a greater change in total kinetic energy?

4. Do your results support the principle of Conservation of Momentum? (If not, try to explain any discrepancies.)

5. Does the validity of the principle of Conservation of Momentum depend on the relative masses of the colliding objects?

    ….on the nature of the collision (i.e. elastic vs. inelastic)?

    ….on the relative velocities of the colliding objects?

    ….on the validity of Newton's 3rd Law?

6. What other condition must always be satisfied for the total momentum to be conserved in a collision?

Data for Part A, Case 1: Totally Inelastic Collision with Carts of *Equal* Mass

Length of flags:	Mass of cart A (initially moving):	Mass of cart B (initially at rest)
Prediction:		
Qualitative Observations:		

Trial 1 Data Table with Time Intervals Copied Directly from Computer

	Gate #1		Gate #2	
Row	**Δ t1, sec**	**Velocity 1, m/sec**	**Δ t2, sec** (ave.)	**Velocity 2, m/sec**
1				

Trial 1 Your Data and Calculations for This Collision (Show your work.)

	Before the collision	After the collision	% Diff.
Mass A=	v_A=	v_A'=	
Mass B=	v_B=	v_B'=	
	$p_{initial}$=	p_{final}=	% Δp=
	$K_{initial}$=	K_{final}=	% ΔK=

Trial 2 Data Table with Time Intervals Copied Directly from Computer

	Gate #1		Gate #2	
Row	**Δ t_1, sec**	**Velocity 1, m/sec**	**Δ t_2, sec** (ave.)	**Velocity 2, m/sec**
1				

Trial 2 Your Data and Calculations for This Collision (Show your work.)

	Before the collision	After the collision	% Diff.
Mass A=	v_A=	v_A'=	
Mass B=	v_B=	v_B'=	
	$p_{initial}$=	p_{final}=	% Δp=
	$K_{initial}$=	K_{final}=	% ΔK=

Data for Part A, Case 2: Totally Inelastic Collision with Carts of ***Unequal*** Mass

Length of flag:	Mass of Cart A (initially moving):	Mass of Cart B (initially at rest)
Prediction:		
Qualitative Observations:		

Trial 1 Data Table with Time Intervals Copied Directly from Computer:

	Gate #1		Gate #2	
Row	**Δ t_1, sec**	**Velocity 1, m/sec**	**Δ t_2, sec**	**Velocity 2, m/sec**
1				

Trial 1 Your Data and Calculations for This Collision (Show your work.)

	Before the collision	**After the collision**	**% Diff.**
Mass A=	v_A=	v_A'=	
Mass B=	v_B=	v_B'=	
	$p_{initial}$=	p_{final}=	% Δp=
	$K_{initial}$=	K_{final}=	% ΔK=

Trial 2 Data Table with Time Intervals Copied Directly from Computer:

	Gate #1		Gate #2	
Row	**Δ t1, sec**	**Velocity 1, m/sec**	**Δ t2, sec**	**Velocity 2, m/sec**
1				

Trial 2 Your Data and Calculations for This Collision (Show your work.)

	Before the collision	**After the collision**	**% Diff.**
Mass A=	v_A=	v_A'=	
Mass B=	v_B=	v_B'=	
	$p_{initial}$=	p_{final}=	% Δp=
	$K_{initial}$=	K_{final}=	% ΔK=

Data for Part B, Case 1: Nearly Elastic Collision with Carts of Equal Mass

Length of flag:	Mass of Cart A:	Mass of Cart B:
Prediction:		
Qualitative Observations:		

Trial 1 Data Table as Copied Directly from Computer (*Cross out any irrelevant times.*)

	Gate #1		**Gate #2**	
Row	**Δt_1, sec**	**Velocity 1, m/sec**	**Δt_2, sec**	**Velocity 2, m/sec**
1				
2				

Trial 1 Your Data and Calculations for This Collision (Show your work.)

	Before the collision	**After the collision**	**% Diff.**
Mass A=	v_A=	v_A'=	
Mass B=	v_B=	v_B'=	
	$p_{initial}$=	p_{final}=	% Δp=
	$K_{initial}$=	K_{final}=	% ΔK=

Trial 2 Data Table as Copied Directly from Computer (*Cross out any irrelevant times.*)

	Gate #1		**Gate #2**	
Row	**Δt_1, sec**	**Velocity 1, m/sec**	**Δt_2, sec**	**Velocity 2, m/sec**
1				
2				

Trial 2 Your Data and Calculations for this Collision (Show your work.)

	Before the collision	**After the collision**	**% Diff.**
Mass A=	v_A=	v_A'=	
Mass B=	v_B=	v_B'=	
	$p_{initial}$=	p_{final}=	% Δp=
	$K_{initial}$=	K_{final}=	% ΔK=

Data for Part B, Case 2: Nearly Elastic Collision with Carts of Unequal Mass

Length of flag:	Mass of Cart A:	Mass of Cart B:
Prediction:		
Qualitative Observations:		

Trial 1 Data for Time Intervals as Copied from Computer

	Gate #1		Gate #2	
Row	**Δt_1, sec**	**Velocity 1, m/sec**	**Δt_2, sec**	**Velocity 2, m/sec**
1				
2				

Trial 1 Your Data and Calculations for This Collision (Show your work.)

	Before the Collision	**After the Collision**	**% Diff.**
Mass A=	v_A=	v_A'=	
Mass B=	v_B=	v_B'=	
	$p_{initial}$=	p_{final}=	% Δp=
	$K_{initial}$=	K_{final}=	% ΔK=

Trial 2 Data for Time Intervals as Copied from Computer:

	Gate #1		Gate #2	
Row	**Δt_1, sec**	**Velocity 1, m/sec**	**Δt_2, sec**	**Velocity 2, m/sec**
1				
2				

Trial 2 Your Data and Calculations for This Collision (Show your work.)

	Before the collision	**After the collision**	**% Diff.**
Mass A=	v_A=	v_A'=	
Mass B=	v_B=	v_B'=	
	$p_{initial}$=	p_{final}=	% Δp=
	$K_{initial}$=	K_{final}=	% ΔK=

Data for Part C: Nearly Elastic Head-on Collisions

Length of flag:	Mass of cart A:	Mass of cart B:
Prediction:		
Qualitative Observations:		

Trial 1 Data for Time Intervals as Copied from Computer

	Gate #1		Gate #2	
Row	**Δt_1, sec**	**Velocity 1, m/sec**	**Δt_2, sec**	**Velocity 2, m/sec**
1				
2				

Trial 1 Your Data and Calculations for This Collision (Show your work.)

	Before the collision	**After the collision**	**% Diff.**
Mass A=	v_A=	v_A’=	
Mass B=	v_B=	v_B’=	
	$p_{initial}$=	p_{final}=	% Δp=
	$K_{initial}$=	K_{final}=	% ΔK=

Trial 2 Data for Time Intervals as Copied from Computer

	Gate #1		Gate #2	
Row	**Δt_1, sec**	**Velocity 1, m/sec**	**Δt_2, sec**	**Velocity 2, m/sec**
1				
2				

Trial 2 Your Data and calculations for this collision. Show your work.

	Before the collision	**After the collision**	**% Diff.**
Mass A=	v_A=	v_A’=	
Mass B=	v_B=	v_B’=	
	$p_{initial}$=	p_{final}=	% Δp=
	$K_{initial}$=	K_{final}=	% ΔK=