Lab 7 - Collision and Momentum.

OBJECTIVES

After successfully completing this laboratory, you should be able to:

- Use the concept of linear momentum in describing the interactions of objects in contact with each other.
- Understand the difference between conservation of energy and conservation of momentum, and how to use energy and momentum together.
- Understand the relation between the force during a collision, the time duration of the collision, and the velocity change during the collision.

Recommended Reading: Giancoli 9.1–9.6. Walker 5.4, 9.1–9.6.

EQUIPMENT

You will have a 2 m track, a metal "asteroid" cart, a plastic "impactor" cart, a scale, four black cart masses, a set of brass weights, collision kit for 2 carts (not the "stationary" kit), and tape. The impactor cart is a wireless smart cart equipped with built-in velocity and force sensors.

PROBLEM

NASA has detected an asteroid whose orbit will lead to a collision with Earth. The agency is exploring ways to deflect the asteroid's trajectory by hitting it with an impactor rocket that will stick to the asteroid after the collision. The kinetic energy available for the impactor is fixed, but this energy can be implemented as a small mass with high velocity, or as a large mass with low velocity. You have been tasked with exploring this trade-off and with selecting the optimum impactor mass.

You have decided to model the system using your test carts and track. The plastic smart cart will represent the impactor. It has a spring-loaded piston that can be used to launch it from the end of the track. The metal cart will serve as the asteroid, which you can take to be stationary. (Of course the actual asteroid is moving, but the plan is to deflect it at right angles to its initial trajectory, so the velocity along the relevant coordinate will be zero.)

It occurs to you that if the force from the collision is too large, the asteroid may break into pieces that could still strike the earth. You therefore decide to also measure how the force on the asteroid cart depends on the impactor parameters.

WARM-UP

1. How does the speed of an object depend on its kinetic energy? If the kinetic energy is fixed and the mass is varied, how does the speed of the object vary? What are some ways to impart a fixed kinetic energy to an object, independent of its mass?
2. What is linear momentum and how is it defined? How does the total momentum of a closed system change as objects in the system interact with each other? How does the momentum of a given object in the system change? Explain.
3. If an object with mass m_1 and kinetic energy E_1 hits and sticks to a stationary object of mass m_2, what is the final velocity of the stuck-together pair? If E_1 and m_2 are fixed, what mass m_1 leads to the largest final velocity? How does this optimum mass depend on E_1 and m_2?
4. What is the relation between the change in momentum of an object and the force that caused that change? Does the force depend on the time duration of the collision? What might the time duration of a collision depend on?

PREDICTIONS

Predict how the final velocity of the asteroid-impactor pair will depend on the mass of the impactor and the initial kinetic energy of the impactor. For a given kinetic energy, calculate the optimum impactor mass to give the largest asteroid deflection. Again for a given kinetic energy, predict how the peak force on the asteroid will vary with the mass of the impactor.

EXPLORATION

Practice using the spring piston to “launch the impactor cart. Does it provide a repeatable launch velocity? If you vary the mass, does it provide a repeatable kinetic energy? Does friction cause the energy to decrease significantly as the cart moves? Explore how to use the smart cart sensors to address these questions. Decide also on a way to estimate your measurement uncertainties.

Four cart weights are available to vary the mass of the impactor. When using more than two, secure the weights using tape. Note that when using the maximum weight, some care is required when pressing the launch button: make sure that the piston fully extends during the launch.

Develop a plan for the impactor measurement. Given your predictions and the available impactor masses, what is a good mass to use for the asteroid cart? The brass weights can be used to set this mass; secure them with tape as well.

Practice the impactor experiment under various conditions. Does the final velocity depend on the impactor mass? Is the final velocity maximized for the mass you expect?

Use the force sensor to measure the force on the asteroid cart during the collision. Pay attention to the sampling rate for the experiment: the collision is fast, but the measurement won’t work if the sampling rate is set too high. You can either measure the force and the final velocity simultaneously, or measure them in separate experiments. Is there a reason to prefer one method to the other?

Once you have decided on a measurement plan for the experiment, check in with your instructor.

MEASUREMENT

Conduct your measurements according to your plan. Make sure that you obtain enough data to test your predictions, and also to estimate your measurement uncertainty. If your uncertainties are too large to test your predictions, you may need to revise your plan.

ANALYSIS AND RESULTS

For what impactor mass is the final velocity maximized? What is your experimental uncertainty for this optimum mass?

Plot your measurements of final velocity vs. impactor mass, along with the analytical result you predicted. Alternatively, fit your data with your analytical theoretical function and use the fit parameters in your analysis. Explain how the initial kinetic energy is used in this plot, how it was determined, and how its uncertainty impacts your result.

Make a similar plot of the peak force on the asteroid cart vs. impactor mass, and discuss its uncertainties. Describe or show examples of how the force varies in time during the collision.

CONCLUSION

Does the dependence of the final velocity on the impactor mass agree with your prediction, within your estimated uncertainty? Does the optimum mass agree with your prediction? What are the most significant sources of uncertainty in the measurements?

What is your advice for the impactor design?

It is interesting to compare the optimum mass determined here to that for a perfectly elastic collision. Specifically, in an elastic collision at fixed incident energy, what impactor mass is needed to maximize the energy transferred to the target?

Does the dependence of the collision force agree with your predictions? For what conditions is the peak force on the asteroid largest? Is the force the largest under the same conditions that the momentum transfer is largest? What role does the duration of the collision play in determining the peak force?

Based on your measurements, is momentum conserved in the collision process here?

BONUS

If the bonus part is completed and written up in the report correctly, your lowest scored section of the report will be bumped up by one category (normally 1 or 2 points). The bonus part can go over 1 page limit and should be a concise (no more than 2 paragraphs) description of your results. The bonus part doesn't have to follow a more rigid structure of the main report (overview, prediction, results, conclusion) and should be straight to the point of answering the bonus question.

The impulse J from a time-dependent force $F(t)$ is defined as $J = \int F(t)\,dt$ or as a sum $\Sigma F_i \Delta x_i$ over the small enough regions Δx_i where force F_i can be considered constant. How does the impulse acting on an object relate to its momentum?

Use the Capstone software to integrate one of your $F(t)$ curves. Does the resulting impulse value agree with your measured momentum values?

Please clean up your lab area.