

Unit IX: Impulsive Force Model

Instructional Goals

1. Momentum

Define momentum and distinguish between momentum and velocity.

momentum = (mass)(velocity)

2. Impulse

Define impulse; distinguish between impulse and force.

$$I = F\Delta t$$

Determine the impulse acting on an object

via a F vs t graph

given the change in momentum.

Determine the force acting on an object, given its change in momentum.

$$F = \frac{m\Delta v}{\Delta t}$$

3. Conservation of Momentum

Show that the system momentum before a collision is equal to the system momentum after the collision. system momentum = constant

Show that the total system momentum after an explosion remains zero.

Distinguish between elastic and inelastic collisions ($\sim E_{k1} > \sim E_{k2}$)

Use conservation principles to solve momentum problems involving elastic and inelastic collisions for initial velocity, final velocity or mass, given the other values.

Overview

This is the final unit in the mechanics portion of the curriculum. The subject of this unit is a second conserved quantity, momentum, and the conditions under which it can change. In this unit, students will see that the momentum of a system is constant unless subject to an outside force. While it has been well established in units 4 and 5 that a force is required to change the motion of an object, there has been no mention of time variation of force. Students are now introduced to the concept of impulse - that quantity that produces a *change* in momentum $\bar{F}\Delta t = m\Delta\vec{v}$. An examination of a force vs time graph reveals yet another example of the area under the curve representing a physical quantity.

After a demonstration and worksheet 1, students examine how momentum changes during a variety of collisions. While the momentum of individual bodies in the system may change, the sum of these momenta remains constant, barring interactions with external agents. Students learn to distinguish between elastic collisions (in which kinetic energy is also conserved) and inelastic collisions. This is another opportunity to reinforce the idea that while a particle model is appropriate to describe some interactions, it is not adequate to describe others.

Instructional Notes

Demonstration - Impulse and Change in Momentum

Apparatus

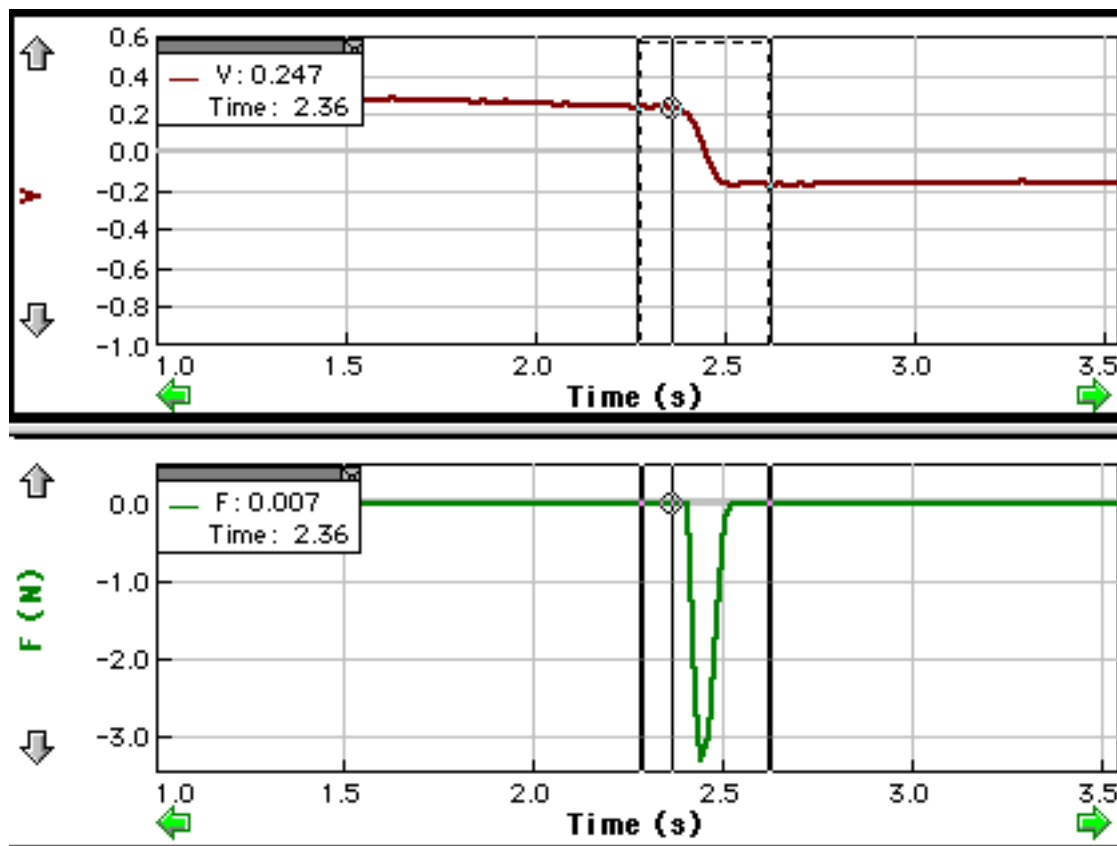
One dynamics cart, with spring plunger (PASCO recommended)
one force sensor attached to a ring stand
lab interface (LabPro, ULI, Data Studio) with appropriate software
masses
Motion Detector

Pre-demo discussion

¥ Place a dynamics cart (with plunger extended) on a track and give it a push toward the force sensor, but stop it before it strikes the sensor. Ask students to describe the velocity of the cart after you have given it a push. They should respond that, neglecting friction, the cart will roll at constant velocity.



- ¥ Ask students to predict how the velocity will change when its plunger strikes the fixed force sensor. They will agree that the cart will reverse direction, but will not be sure what the velocity vs time graph will look like.
- ¥ Start collecting data and roll the cart toward the sensor. If done properly, the cart should accelerate smoothly while the plunger is in contact with the sensor and return to its original position with a relatively constant, but somewhat lower speed.
- ¥ Below is a sample graph for such an interaction. Note that the velocity of the cart is relatively constant when the force is zero, but changes during the interval over which the sensor applies a force to the plunger.



- ¥ It is worth examining the shape of the force vs time curve and pointing out that the negative values indicate that the force was applied in the direction opposite the initial motion (+). Students should note that the velocity after the cart is no longer in contact with the sensor is also negative.
- ¥ Rearrange Newton's Second Law such that the students can see that:

$$F = m \frac{\Delta v}{\Delta t}$$

$$F\Delta t = m\Delta v$$

- ¥ Define impulse as:

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

therefore; impulse change equals a change in momentum.

If you have practiced this demonstration in advance and have checked the values, you might wish to use the motion software's integrating capability to determine the area under the F vs t curve and then compare that to the change in momentum of the cart. It is possible to obtain agreement between $F\tilde{t}$ and $m\tilde{v}$ within 10% if the experiment is performed carefully.

Worksheet 1

Quiz 1

Lab - Cart collisions

Apparatus

Two dynamics carts (PASCO recommended)
Graphical Analysis
masses
photogates with lab interface and software (LabPro, ULI Timer, Science Workshop)

Pre-lab discussion

- ¥ Having established that an impulse produces a change in momentum, show students the lab apparatus and ask them to predict what will happen to the momentum of the *system* when a collision occurs.
- ¥ Ask the students for examples of types of collisions. Record the examples then divide them into several categories (elastic vs inelastic, varying mass of the carts, initial velocity of the carts, etc)
- ¥ Indicate that what we are investigating is how the system momentum after a collision compares to the system momentum before the collision.

Lab performance notes

- ¥ There are at least two possibilities for performing the lab. You could have each group of students perform about thirty different cart collisions. They must record the mass of the carts, the magnitude and the direction. They need to be aware that each photogate may record more than one speed during one collision (e.g., a cart passes through the gate in one direction, then back again after the collision). Keeping track of the direction and speed of each cart during a collision requires some concentration.
- ¥ Another possibility is to assign a smaller set of collisions to each group and have them post the data in a common place for the class to share.
- ¥ In the folder is an Excel spreadsheet to use as a model to help students organize their data.
- ¥ Be sure that the collision between the carts, with attached flags (about 1.5 cm in width) takes place as close as possible to the location of the photogates. In the experiment set-up be sure to specify flag width so the software can calculate the speed of the cart during each pass.

Post-lab discussion

- ¥ The students should graph system momentum *after* the collision vs system momentum *before* the collision. This graph should be linear with a slope of approximately one.
- ¥ The students will need to decide what this slope means; generally, when the units cancel and the value of the slope approaches unity, the variables are equal. In this case, the system momentum remains unchanged no matter what type of collision occurs.

Alternative to lab - Using Interactive Physics to examine collisions

Apparatus

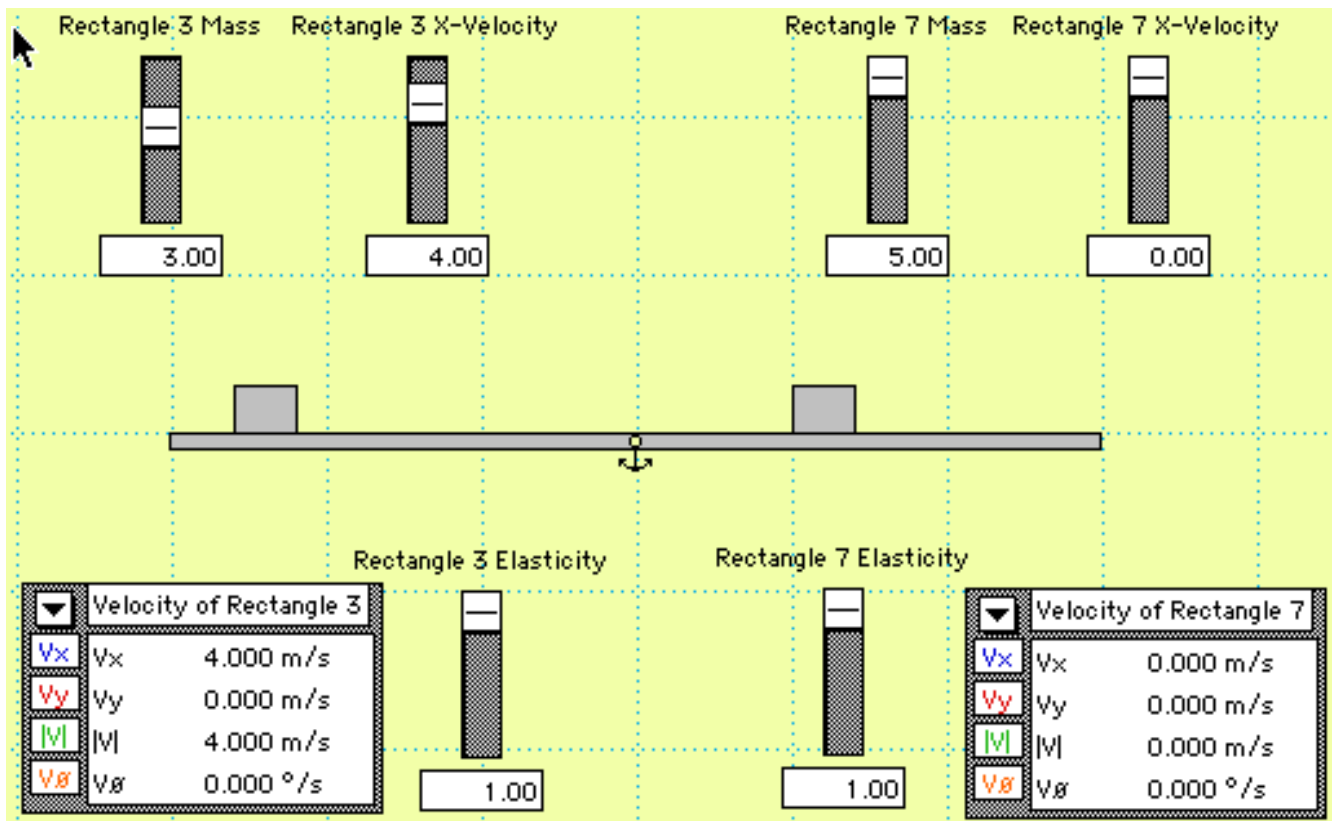
- Two dynamics carts (PASCO recommended)
- Graphical Analysis
- masses
- photogates with lab interface and software
- Interactive Physics

Pre-simulation discussion

Set up the apparatus and guide the students through the same discussion as you would if they were actually performing the lab.

Simulation performance notes

Running the simulation is not as valuable as actually performing the lab. However, if you are pressed for time or your students have serious difficulty managing the data collection, the simulation at least enables them to view a variety of collisions.



Students can vary the mass and initial velocity of the two blocks, hit [Run] and record the velocities of the blocks after the collision. They can perform the analysis of "data" to show that a graph of the momentum after the collision vs the momentum before is linear with a slope of 1.0.

Worksheet 2

Worksheet 3

Quiz 2

Lab Practicum - Mass of unknown object

Apparatus

2 PASCO carts (one with plunger) and track
photogates, interface and timing software
indeterminate mass

Practicum performance notes

Demonstrate an explosion. Both carts are adjacent and motionless with their flags within 10 cm of the photogates. Trigger the spring-loaded plunger so that both carts pass through the photogates in opposite directions. Label each cart with its mass (to the nearest 0.1 g). Place an object of unknown mass (should be 200-300 g and not so tall that it triggers the photogate).



The challenge for the students is to determine the mass of the unknown object using conservation of linear momentum.

Unit Test