TOPIC 1.3: MOMENTUM

S4P-1-10 Derive the impulse-momentum equation from Newton's second law.

S4P-1-11 Determine impulse from the area under a force-time graph.

Include: constant positive and negative force, uniformly changing force

S4P-1-12 Experiment to illustrate the Law of Conservation of Momentum in one and two dimensions.

S4P-1-13 Solve problems using the impulse-momentum equation and Law of Conservation of Momentum.

S4P-1-14 Relate the impulse-momentum equation to real-life situations.

Examples: hitting a ball, catching a ball

GENERAL LEARNING OUTCOME CONNECTION

Students will…

Recognize that scientific knowledge is based on evidence, models, and explanations, and evolves as new evidence appears and new conceptualizations develop (GLO A2)

SPECIFIC LEARNING OUTCOME

S4P-1-10: Derive the impulse-momentum equation from Newton's second law.

SUGGESTIONS FOR INSTRUCTION

Entry Level Knowledge

Students have studied momentum qualitatively in Senior 2 Science and are familiar with Newton's second law.

Prior Knowledge Activity

Now is a good time to use the SYSTH Activity: KWL Plus, p. 9.24, to access students' prior knowledge.

Notes to the Teacher

Relate impulse-momentum to Newton's second law with the following derivation.

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

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

Newton stated his three laws of motion in his book *Principia Mathematica.* Although Newton's second law is given as $F_{net} = ma$ in textbooks, Newton actually stated that "the change of motion is proportional to the motive force impressed." By the word "motion," Newton meant the quantity that today we call "momentum." Thus, in his original statement, "the motive force" acts to change the momentum of a body.

Teacher Demonstrations

Blow a dry ink marker through a short tube and then do it again through a longer tube. The force with which the marker is blown should be the same for both the small tube and the longer tube. Students should note that as Δt is increased, then $m\Delta v$ will increase.

Accelerate a cart with one elastic, then replace with two elastics. Elastics must be stretched the same amount. Students should note the differences in the change in momentum of the two cases (time interval is the same for both cases).

A student standing on a skateboard throws a massive object (medicine ball) at another student, standing on the floor, who catches the object. Students can visualize the recoil velocity of the student on the skateboard.

SKILLS AND ATTITUDES OUTCOMES

S4P-0-2c: Formulate operational definitions of major variables or concepts.

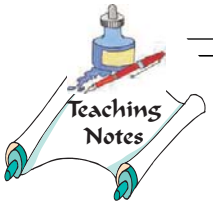
S4P-0-2g: Develop mathematical models involving linear, power, and/or inverse relationships among variables.

GENERAL LEARNING OUTCOME CONNECTION

Students will…

Describe and appreciate how the natural and constructed worlds are made up of systems and how interactions take place within and among these systems (GLO E2)

SUGGESTIONS FOR INSTRUCTION



SUGGESTIONS FOR ASSESSMENT

Pencil-and-Paper Task

Students derive the impulse-momentum equation.

GENERAL LEARNING OUTCOME CONNECTION

Students will…

Demonstrate appropriate scientific inquiry skills when seeking answers to questions (GLO C2)

SPECIFIC LEARNING OUTCOME

S4P-1-11: Determine impulse from the area under a force-time graph.

Include: constant positive and negative force, uniformly changing force

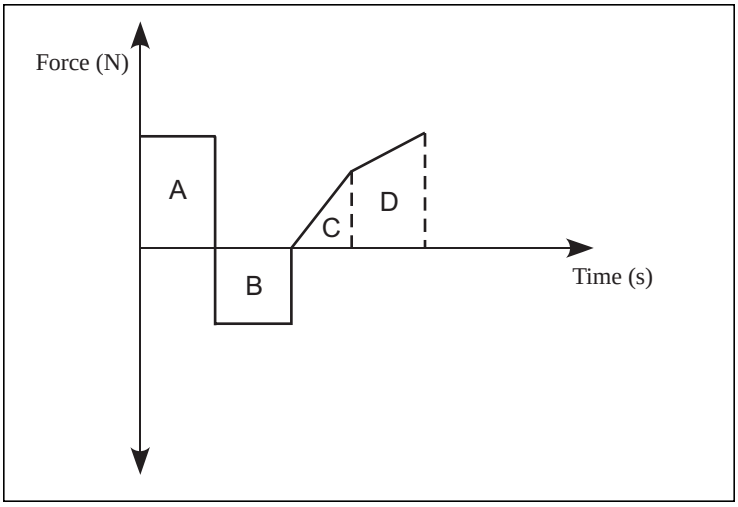
SUGGESTIONS FOR INSTRUCTION

Entry Level Knowledge

The techniques for determining the impulse from the area under a force-time graph are similar to the techniques used for determining the displacement from the area under a velocity-time graph. Students have experienced calculating areas under a curve with various shapes; i.e., rectangular shape, triangular shape, trapezoidal shape.

Class Discussion

Students analyze force-time graphs to determine the impulse. See diagram below:



Force-Time Graph

- Area A represents positive area (constant force)
- Area B represents negative area (constant force)
- Area C represents positive area (triangle) (constantly changing force)
- Area D represents positive area (trapezoid) (constantly changing force)

Student Activity

Compare/contrast (SYSTH) impulse and change in momentum.

SKILLS AND ATTITUDES OUTCOME

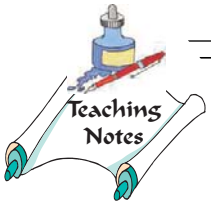
S4P-0-2a: Select and use appropriate visual, numeric, graphical, and symbolic modes of representation to identify and represent relationships.

GENERAL LEARNING OUTCOME CONNECTION

Students will…

Understand how stability, motion, forces, and energy transfers and transformations play a role in a wide range of natural and constructed contexts (GLO D4)

SUGGESTIONS FOR INSTRUCTION



SUGGESTIONS FOR ASSESSMENT

Pencil-and-Paper Task

Students calculate impulse or change in momentum from different graphs to determine the impulse.

SUGGESTED LEARNING RESOURCES

BLM 29-1: F-t Graphs and Impulse, *Physics: Concepts and Connections*, Irwin Publishing Ltd., 2003

GENERAL LEARNING OUTCOME CONNECTION	SPECIFIC LEARNING OUTCOME	SKILLS AND ATTITUDES OUTCOMES
Students will… Demonstrate curiosity, skepticism, creativity, open-mindedness, accuracy, precision, honesty, and persistence, and appreciate their importance as scientific and technological habits of mind (GLO C5)	**S4P-1-12: Experiment to illustrate the Law of Conservation of Momentum in one and two dimensions.**	**S4P-0-2b:** Propose problems, state hypotheses, and plan, implement, adapt, or extend procedures to carry out an investigation where required. **S4P-0-2d:** Estimate and measure accurately using SI units.

SUGGESTIONS FOR INSTRUCTION

To introduce the concept of the Law of Conservation of Momentum, students demonstrate the following:

A student standing on a skateboard throws a massive object (medicine ball) at another student, standing on another skateboard, who catches the object.

Students visualize the effects of throwing the massive object on both boarders. The idea of an isolated system is demonstrated by this action. A system is made up of two or more objects. An isolated system is one that is not acted upon by a net external force.

Students videotape a collision and analyze the tape (use an air track, a dynamic cart on a level table, a billiard table, curling rink, or ball bearings on a smooth track). Assume that friction is negligible and the time interval is of short duration.

Use *Interactive Physics* simulation software to simulate collisions between objects in one dimension and two dimensions. (See Appendix 1.6 for sample activity.)

STSE: Police Analysis of Car Accidents (*Physics: Concepts and Connections*, p. 302, Irwin Publishing Ltd., 2003)

SKILLS AND ATTITUDES OUTCOMES

S4P-0-2e: Evaluate the relevance, reliability, and adequacy of data and data-collection methods.

Include: discrepancies in data and sources of error

S4P-0-2f: Record, organize, and display data using an appropriate format.

Include: labelled diagrams, tables, graphs

S4P-0-2h: Analyze problems using vectors.

Include: Adding and subtracting vectors in straight lines, at right angles, and at non-orthogonal angles

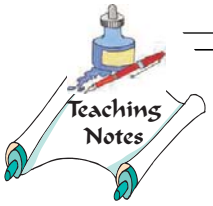
S4P-0-4a: Demonstrate work habits that ensure personal safety, the safety of others, and consideration of the environment.

GENERAL LEARNING OUTCOME CONNECTION

Students will…

Describe and appreciate how the natural and constructed worlds are made up of systems and how interactions take place within and among these systems (GLO E2)

SUGGESTIONS FOR INSTRUCTION



SUGGESTIONS FOR ASSESSMENT

Laboratory Report

Provide a written lab report with complete analysis.

SUGGESTED LEARNING RESOURCES

Lab 8.1: Conservation of Linear Momentum, p. 314, *Physics: Concepts and Connections*, Irwin Publishing Ltd., 2003

Physics Lab: The Explosion, p. 213, *Physics: Principles and Problems*, Glencoe, 2002

Lab 8.2: Linear Momentum in One Dimension: Dynamic Laboratory Carts, pp. 315–316, *Physics: Concepts and Connections*, Irwin Publishing Ltd., 2003

Lab 8.3: Linear Momentum in Two Dimensions: Ramp and Ball, p. 317, *Physics: Concepts and Connections*, Irwin Publishing Ltd., 2003

Investigation 10-B: Collisions in Two Dimensions, p. 516, *Physics 12*, McGraw-Hill Ryerson, 2003

GENERAL LEARNING OUTCOME CONNECTION

Students will…

Recognize both the power and limitations of science as a way of answering questions about the world and explaining natural phenomena (GLO A1)

SPECIFIC LEARNING OUTCOME

S4P-1-13: Solve problems using the impulse-momentum equation and the Law of Conservation of Momentum.

SUGGESTIONS FOR INSTRUCTION

Provide students with a variety of situations to problem solve. For example, students analyze a force-time graph to calculate the impulse, the change in momentum, the change in velocity, the final velocity, and the average force.

Other examples are: bullet being fired from a rifle, bullet getting embedded in a block of wood, ballistic pendulum, hitting a golf ball or tennis ball, or the recoil of an astronaut.

For the Law of Conservation of Momentum in one dimension and two dimensions, the approach to solving the problems follows this sequence.

- Establish a coordinate system.
- Show the initial and final states.
- Draw and label the two objects and their velocities.
- Substitute into the equation below and calculate the momentum of each individual object.

$$\vec{p}_{\text{total initial}} = \vec{p}_{\text{total final}}$$
$$\vec{p}_{1\text{initial}} + \vec{p}_{2\text{initial}} = \vec{p}_{1\text{final}} + \vec{p}_{2\text{final}}$$
$$m_1\vec{v}_{1\text{initial}} + m_2\vec{v}_{2\text{initial}} = m_1\vec{v}_{1\text{final}} + m_2\vec{v}_{2\text{final}}$$

Draw a vector diagram for the total momentum and calculate the missing momentum or velocity.

Illustrative examples are included in Appendix 1.5 and Appendix 1.6.

SKILLS AND ATTITUDES OUTCOMES

S4P-0-2g: Develop mathematical models involving linear, power, and/or inverse relationships among variables.

S4P-0-2h: Analyze problems using vectors.

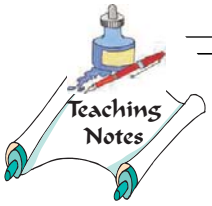
Include: Adding and subtracting vectors in straight lines, at right angles, and at non-orthogonal angles

GENERAL LEARNING OUTCOME CONNECTION

Students will…

Recognize that characteristics of materials and systems can remain constant or change over time, and describe the conditions and processes involved (GLO E3)

SUGGESTIONS FOR INSTRUCTION



SUGGESTED LEARNING RESOURCES

BLM 25-1: Elastic and Inelastic Collisions in Two Dimensions, *Physics: Concepts and Connections*, Irwin Publishing Ltd., 2003

BLM 31-1: Momentum and Simple Collisions, *Physics: Concepts and Connections*, Irwin Publishing Ltd., 2003

SUGGESTIONS FOR ASSESSMENT

Science Journal Entries

Students write process notes to describe their step-by-step, problem-solving approach to the Law of Conservation of Momentum problems.

Visual Displays

Students create a concept map showing all variables involved and how they are linked to solve conservation of momentum questions.

Pencil-and-Paper Tasks

Students solve a variety of problems for momentum:

1. one dimensional
2. two dimensional

For complex problems, students break the problem down to solve for the following components:

1. momentum
2. change in momentum for one object
3. total initial momentum for a system of two objects
4. total final momentum for a system of two objects
5. impulse applied
6. average force
7. final velocities for a system of two objects and as an extension
8. describe the motion of the centre of mass

GENERAL LEARNING OUTCOME CONNECTION

Students will…

Recognize that science and technology interact with and advance one another (GLO A5)

Evaluate, from a scientific perspective, information and ideas encountered during investigations and in daily life (GLO C8)

SPECIFIC LEARNING OUTCOME

S4P-1-14: Relate the impulse-momentum equation to real-life situations.

Examples: hitting a ball, catching a ball

SUGGESTIONS FOR INSTRUCTION

Entry Level Knowledge

Students are familiar with the application of momentum in car crashes from Senior 2 Science. They are aware of the first collision (car to car) and the second collision (driver to steering wheel/air bag).

Notes to the Teacher

In real-life examples, forces often vary during a collision between objects. Attempting to measure such a change in force is very difficult. Consequently, the average force of an interaction for some interval is generally determined by analyzing the motion.

Hitting a ball involves exerting a force with one object, a bat or racquet, on another object, the ball. To increase the final velocity of the struck object, the impulse applied must be increased. Since impulse is the product of force and time, we can increase the force by hitting harder (build up your muscles!) or by lengthening the time interval during which the object is struck. Athletes train to increase their power and they are coached to practise a correct technique of hitting objects by increasing the time interval of contact (in the coach's terms, "follow through"). Once maximum force is achieved, the technique focusses on lengthening the time interval for contact between objects.

Students' prior knowledge from Senior 2 Science includes analysis of how an air bag is able to stop a person during a very short time interval. This would require tremendous forces to achieve a change in momentum. The air bag lengthens the stopping distance and the time interval to lessen the force. Catching a ball requires the same cushioning effect as an air bag. While catching a ball, the person moves his or her hands in the same direction as the ball is moving. This lengthens the stopping time interval and lessens the force directed on the hands.

Students can research car accidents with regards to the first collision (two vehicles hitting) and also the second collision (driver/passenger within vehicle).

In Senior 4 Physics, the mathematical model is a point of emphasis so any analysis should contain the calculations involved for the driver/passenger's stopping during the second collision.

SKILLS AND ATTITUDES OUTCOMES

S4P-0-3b: Describe examples of how technology has evolved in response to scientific advances, and how scientific knowledge has evolved as the result of new innovations in technology.

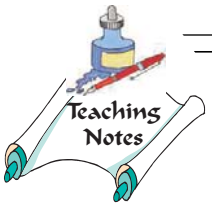
S4P-0-4b: Work co-operatively with a group to identify prior knowledge, initiate and exchange ideas, propose problems and their solution, and carry out investigations.

GENERAL LEARNING OUTCOME CONNECTION

Students will…

Demonstrate a knowledge of, and personal consideration for, a range of possible science- and technology-related interests, hobbies, and careers (GLO B4)

SUGGESTIONS FOR INSTRUCTION



SUGGESTIONS FOR ASSESSMENT

Science Journal Entries

Students prepare two lists of events in their journals. One list includes events in which the momentum of objects changes over a short Δt. The other list includes events that have a significant longer Δt. Students describe the consequences of the magnitude of each event's Δt.

Research Report/Presentation

Students prepare a report on how the impulse-momentum theorem can be illustrated with examples from sports. Students describe the circumstances requiring long impulse times and those requiring short impulse times. How does impulse time affect what the athlete does or what equipment the athlete uses in the sport?

Students investigate the safety aspects of bike helmets. Are helmets still safe after the helmet has sustained an impact?

SUGGESTED LEARNING RESOURCES

STSE Interrelationships, pp. 302–303, *Physics: Concepts and Connections*, Irwin Publishing Ltd., 2003

NOTES