SCOPE, SEQUENCE, and COORDINATION

A National Curriculum Project for High School Science Education

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SS&C

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NSTA National Science Teachers Association

SCOPE, SEQUENCE, and COORDINATION

National Science Education Standard—Physical Science

Motions and Forces

During the interaction of two systems, A and B, the force exerted by A on B is equal and opposite to the force eerted by B on A. Since the duration of the interaction provides the time interval, and the forces are equal in magnitude, the changes in momentum of the two systems must also be identical, but oppositely directed. The total momentum must therefore remain the same. This is the *law of conservation of momentum*.

Teacher Materials

Learning Sequence Item:

1012

Impulse, Momentum and the Conservation of Momentum

August 1996
Adapted by: Stephen Druger

Conservation of Momentum. Students should investigate momentum conservation in one-dimensional interactions. They should begin to examine problems involving collisions of two objects along a straight line in terms of momentum transfer, leading to the law of conservation of momentum. The qualitative concepts of impulse and momentum should be learned. (*Physics, A Framework for High School Science Education, p. 14.*)

Contents

Matrix
Suggested Sequence of Events
Lab Activities
1. When Ball Bearings Collide
2. Tabletop Collisions
3. Motion (almost) Without Friction—the Air Track
4. Stopping a Moving Object
5. The Water Rocket

Assessments
1. Collision Courses
2. Speeding Trains
3. Hammer Heads
4. Balancing Act

This micro-unit was adapted by **Stephen Druger** (Northwestern University, Evanston, Ill.)

1012

Learning Sequence

Conservation of Momentum. Students should investigate momentum conservation in one-dimensional interactions. They should begin to examine problems involving collisions of two objects along a straight line in terms of momentum transfer, leading to the law of conservaiton of momentum. The qualitative conceps of impulse and momentum should be learned (*Physics, A Framework for High School Science Education, p. 14).*

Science as Inquiry	Science and Technology	Science in Personal and Social Perspectives	History and Nature of Science
When Ball Bearings Collide **Activity 1** Tabletop Collisions **Activity 2** Motion (Almost) Without Friction—The Air Track **Activity 3** Stopping a Moving Object **Activity 4** The Water Rocket **Activity 5** Collision Courses **Assessment 1** Speeding Trains **Assessment 2** Hammer Heads **Assessment 3** Balancing Act Assessment 4			

Suggested Sequence of Events

Event #1

Lab Activity

1. When Ball Bearings Collide (40 minutes)

Alternative Activity

2. Tabletop Collisions (40 minutes)

Event #2

Lab Activity

3. Motion (Almost) Without Friction—The Air Track (1 hour)

Event #3

Lab Activity

4. Stopping a Moving Object (1 hour)

Event #4

Lab Activity

5. The Water Rocket (25 minutes)

Event #5

Readings from Science as Inquiry, Science and Technology, Science in Personal and Social Perspectives, and History and Nature of Science

Suggested readings:

Reed, William F., "Inside College Football," *Sports Illustrated*, Vol. 9, No. 19, Nov. 8, 1993, pp. 143–144.

"The Air Bag: An Exercise in Newton's Laws," *How Things Work*, American Association of Physics Teachers, 2nd printing, 1994, pp. 34–35.

Zim, Herbert S., "The Origin of the Rocket Idea," *Rockets and Jets*, New York: Harcourt, Brace and Co., 1945, pp. 26–36.

Assessment items are at the back of this volume.

Assessment Recommendations

This teacher materials packet contains a few items suggested for classroom assessment. Often, three types of items are included. Some have been tested and reviewed, but not all.

1. Multiple choice questions accompanied by short essays, called justification, that allow teachers to find out if students really understand their selections on the multiple choice.

2. Open-ended questions asking for essay responses.

3. Suggestions for performance tasks, usually including laboratory work, questions to be answered, data to be graphed and processed, and inferences to be made. Some tasks include proposals for student design of such tasks. These may sometimes closely resemble a good laboratory task, since the best types of laboratories are assessing student skills and performance at all times. Special assessment tasks will not be needed if measures such as questions, tabulations, graphs, calculations, etc., are incorporated into regular lab activities.

Teachers are encouraged to make changes in these items to suit their own classroom situations and to develop further items of their own, hopefully finding inspiration in the models we have provided. We hope you may consider adding your best items to our pool. We also will be very pleased to hear of proposed revisions to our items when you think they are needed.

Science as Inquiry

When Ball Bearings Collide

How do colliding balls behave?

Overview:

Students observe qualitatively that when a number (N) of metal balls collide together into the end of a line of identical metal balls suspended at the same height from strings, the effect is to knock exactly the same number (N) of metal balls out of position at the other end at apparently the same speed. They examine some qualitative features of momentum conservation, the dependence of momentum on mass, and the relation of momentum conservation to Newton's third law.

Materials:

Per lab group:
set of collision balls (also sold as commercial toy under the name "Newton's Cradle")
ruler

Procedure:

Students first try colliding one metal ball into another with the others held out of the way. They should observe that the first ball transfers all its motion to the second upon collision.

They next try this by letting one ball swing into a row of balls and notice that all the motion is transferred to the one ball at the far end. When they allow two balls to swing together into the end of the line, they observe that the motion is almost entirely transferred to two balls at the far end.

Finally, they release one ball at each end simultaneously in a symmetrical way, and observe the two bounce repeatedly together and apart in unison against the remaining balls in the middle which remain approximately stationary.

Background:

The systematic behavior of the colliding metal balls described above is likely to be unexpected, so students should not be told what to expect beforehand.

The behavior of the colliding balls is only partly a consequence of momentum conservation. Actually, it depends also on the high resiliency of the metal spheres so only a small fraction of the kinetic energy is lost as thermal energy and as sound in each collision.

Suppose one ball with momentum mv crashes into another at rest. One possible outcome of the collision clearly consistent with conservation of momentum and no loss of kinetic energy is for all the momentum to be transferred from the first ball to the second, so that the first is then stationary and the second is moving with the velocity the first one had before collision. Assuming there to be only one solution to the problem of how the stationary ball responds when the moving ball elastically collides dead center into it, we could conclude that this is *the* solution. This can be confirmed in detail by solving the equations that express, in terms of all the initial and final velocities, the requirement that the total kinetic energy remain unchanged at the same time that the total momentum remains unchanged.

For one or more balls crashing into the end of a line of balls, each experiences a force from the collision that it transmits to its neighbor. Similarly to before, a possible behavior that leaves both the kinetic energy and total momentum unchanged is for a certain number of balls at speed v hitting the line of balls to kick exactly the same number of balls forward with the speed v at the end of the line, and this can be shown to be the only physically realistic solution when there is no loss of kinetic energy or momentum.

Since the topic of kinetic energy is dealt with at the required level later, students at this point are expected merely to formulate conclusions about momentum and its conservation by observing that when a metal ball crashing directly into one end of the line of balls with velocity v is a simple multiple of the mass of each one of the balls, it knocks exactly the same total mass of balls strongly out of position at the far end with what seems to be about the same speed v.

In the third part, with two balls symmetrically released from opposite ends, has both metal balls at the end moving always with equal speeds in opposite directions. When directions are taken into account with a plus sign for motion to the right and a minus to the left to deal with velocities rather than speeds, so that momenta are treated properly as vectors in adding them, the resulting momenta always add to zero. Regrettably, the behavior observed in the present activity does not rule out conservation of momentum based on incorrectly adding the mass times speed as positive numbers, so a clear demonstration of the vector character of momentum in the conservation law is left to other activities.

Since the collisions are not perfectly elastic and kinetic energy is lost to heat and sound, the balls eventually stop bouncing off each other and, in the first two parts, the entire row of balls swings in unison. In the third case the balls in the center eventually start moving noticeably. Therefore, attention should focus on the initial effects within only a few bounces.

Note. The next activity, “Tabletop Collisions,” is intended as an alternative, and the questions asked largely duplicate those asked in this activity.

Variations:

Students try similar collisions with coins or other objects on a smooth surface on their own.

Adapted from:
Unknown.

an alternative activity for Event 1

Teacher Sheet

Science as Inquiry

Tabletop Collisions

How do colliding balls behave?

Overview:

One or more ball bearings together (or marble) striking the end of a row of others are seen to transfer all their motion to exactly the same number at the far end, as seen also for one coin or hockey puck sliding directly into another of the same mass on a smooth table. The results are interpreted in terms of momentum conservation and some of the qualitative features of momentum.

Materials:

Per lab group:

coins of various sizes
work tables with reasonably smooth surfaces (or air table if available)
plastic ruler of kind with groove in the center
about a dozen ball bearings or marbles of the same mass

Procedure:

Students roll one ball bearing (or two or three together) into a column of ball bearings of the same mass lined up in a groove, observing that all the momentum is transferred to the same number of ball bearings at the end of the column. They also try flicking one coin into a stationary coin of the same mass on a smooth surface, aiming so the coin slides dead-center into the other, observing that for like masses all the motion is transferred from the first coin to the second.

Background:

This activity largely duplicates Activity 1, involving collision balls. It is therefore offered as an alternative.

As noted earlier, both total momentum and kinetic energy remain unchanged if the result of N ball bearings of the same mass crashing into the column at speed v is to knock exactly N of the balls off the other end of the column at the same speed v, and this indeed can be shown to be the solution implied by requiring the same translational kinetic energy and momentum before and afterwards. Students are not expected to deal with the kinetic energy aspects of the problem at this point, but only with momentum.

The first part works best if the column contains 7 or so identical balls for up to 1 to 3 balls flicked together into one end of the column. Complications now include not only the small kinetic energy lost in the collision, but also that the balls can transfer their translational motion but are less effective at transferring their rotational motion. The result is that when this is tried for only one ball rolling into another, the motion can fail to be transferred completely, and the first one may continue to roll forward.

When one coin or hockey puck collides dead center with one that is stationary, the momentum is similarly entirely transferred. However, the usual condition for momentum conservation to apply is the absence of external forces (or more specifically that the total external force be zero). Some deviation from ideal results may occur because of the effect of frictional forces from the table on the sliding objects. It is usually still noticeable that the moving object stops abruptly while the other then takes up the motion for a distance before being stopped by friction. The corresponding experiment using an air table, or using battery powered air pucks when available, avoids this problem.

Variations:

Hockey pucks, pucks on an air table, or battery driven air pucks may be used in the second part instead of coins.

Adapted from:
Unknown.

Teacher Sheet

Science as Inquiry

Motion (almost) Without Friction—the Air Track

How do colliding carts on air-tracks behave?

Overview:

Collisions on an air track are employed to observe complete transfer of momentum from one object to another in an elastic collision with an object of identical mass and thereby to examine conservation of momentum, to examine the proportionality of the conserved momentum to both mass and speed by observing a completely inelastic collision with a stationary object, to verify the vector character of momentum addition by observing completely inelastic collisions in which objects move towards each other at equal speed.

Materials:

air track and air track cars
velcro or soft wax (to cause air carts to stick on contact)
meter stick
2 stop watches (or digital watches with usual stop watch feature available)

Procedure:

The activity can be done as a demonstration with student participation if necessary because of limited equipment availability.

Part A. A moving cart is set into motion and collides elastically with one that is stationary (with no Velcro or spring between them).

Part B. Velcro or a piece of soft wax is placed in position on the carts so they will stick when they collide. Then one cart is set in motion to collide with, and couple to, the other. Students with stop watches measure the speed of the single cart and the speed of the coupled pair by noting the time it takes to traverse points marked off with tape along the track. They can both estimate subjectively and by measurement how much the combined pair is slowed down relative to the original object.

Part C. The two carts are set into motion together using a stick resting on top of both to assure they move at the same speed, with Velcro or wax between them so that after one rebounds from the end of the track the two are moving towards each other at the same speed. The carts are observed to stick together at a dead stop upon collision. This is repeated with one cart twice as massive as the other, and the two are observed to stick together and continue moving at much less than the initial speed.

Background:

The air track suspends the aluminum cart on a cushion of air forced out through small holes, so that friction is negligible. Since a coordinated effort is needed by several students in Part A. to time the different motions, the students should be divided up into groups of at least three each or possibly larger. One possibility if only one or two air tracks are available is to have pairs of students in turn make merely qualitative observation of results in Parts A, B, and C and then for the measurements to be done with part of the class participating by timing the motion between marked points on the track before collision (Parts B and C) while others watch and time the motion after collision, with students within each part then averaging their timings.

In Part A, the only way for both kinetic energy and total momentum to remain unchanged in the collision is for the momentum to be transferred entirely from the one cart to the other with the first then stationary.

The actual measurement of speed in Part A is not absolutely essential, and can easily be skipped if desired, since it is reasonably apparent visually that the second cart after collision moves with the speed the first one had before collision.

In Part B, since only one cart is initially moving, the total momentum is its mass multiplied by the speed of the moving cart. After collision, the two move together. The total momentum must be the same, but the mass of the moving object is twice as great as the moving part of the system was before. Therefore, the speed must be half as great for the momentum to remain unchanged.

Such a collision is inelastic in the sense that kinetic translational energy is lost as thermal energy.

In Part C, the collision occurs between two carts that have equal mass and velocities of equal magnitude but in opposite directions, and therefore has zero total linear momentum.. If they had collided elastically, they would have simply both reversed their directions of motion. But when they latch together, they must still have total momentum of zero, meaning that they come to a stop. When done instead with one cart having twice the mass of the other, they collide with the same speed from opposite directions, with the more massive cart having twice the momentum as the other. The momenta no longer add to zero so the coupled carts keep moving, but at one third the initial speed. (This can be seen from the fact that for mass m and $2m$ moving towards each other at the same speed v_0 but in opposite directions, the total momentum before and therefore after is $2mv_0 - mv_0$, or mv_0. Dividing this total momentum by the total mass $3m$ of the coupled carts then gives their speed as $v_0/3$.) The explanation of Part C depends on taking account of the directions of the momenta and adding them as vectors, with momenta of equal magnitude but opposite direction adding to zero.

Variations:

None.

Adapted from:
Unknown.

Science as Inquiry

Stopping a Moving Object

How much force does it take to stop a moving object?

Overview:

This activity focuses on how the force and impulse required in trying to bring a moving object to a stop vary with its mass, speed, and stop distance, and thereby vary with its momentum and attempted stop time. Students try dropping different weights from varying heights with braking force provided by strings of various strengths, observing the height of fall needed to break the string, and compare with strings of the same composition tied to their rigid support by a heavy duty rubber band rather than directly.

Materials:

ring stand with clamp and rod (or other rigid support)
test masses, (one approximately twice the mass of the other, e.g., 200 g mass and 350 g mass), 2
monofilament fishing line, 3 different test strengths (4-, 8-, and 10-lb test)
rubber band, heavy duty
old newspaper (to place flat on floor as cushion where test mass would hit)
tape

Procedure:

When dropped as described below, the masses might bounce around erratically, especially when using the rubber band as an intermediary. Students should be told to keep heads and eyes away from where the string tends to stop the weights.

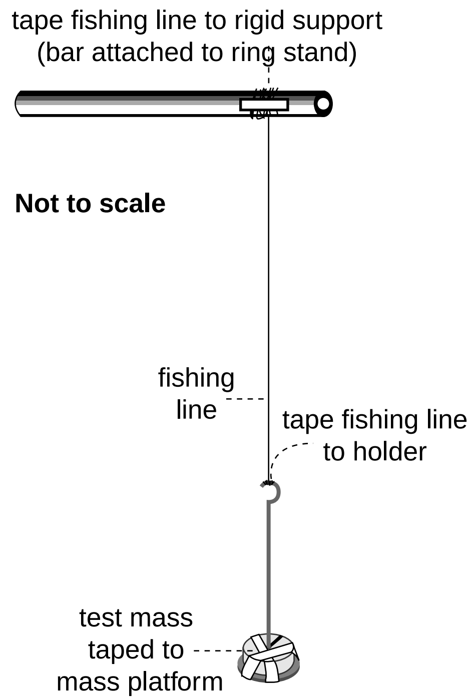
The rigid support, (or horizontal bar mounted on the ring stand), overhanging the edge of the table, should be more than 1.5 meter above the ground. If a ring stand is used, the vertical bar should be held firmly down in an approximately consistent way to avoid having the support move too much during impact.

Before having the class try this, cut a 1-m to 2-m piece of the weakest fishing line, tie one end to the rigid support and the other to the 200 g mass, and check that dropping the mass from just beneath the support to where it hangs freely from the string will cause the string to break. Similarly, a reasonable fall should break the other test lines. If the string does not break, increase the masses used.

In the procedure followed, students cut off enough of each kind of fishing line so it will hang somewhat above the floor when they tie one end to the rigid support and the other to the test mass, and try dropping the mass from 15 cm *above its rest level* at which the weight hangs freely from the string. They then try 30 cm, then 45 cm, etc., or some other convenient sequence of heights, to determine what approximate height of fall causes the string to break in trying to stop the falling mass. This is repeated using twice the mass (400 g).

Finally, a piece of the weakest string is tied a heavy rubber band and the rubber band in turn to the rigid support bar (taking care that there is adequate room below so that the weight will not hit the floor if the string fails to break). The 200 g mass is dropped through a distance that was already seen to break the line tied directly to the rigid bar, but the weight now is seen merely to bounce around without breaking the line.

Background:



The measurements are not intended to yield very precise measurements of drop heights for breaking each kind of support line. The goal is merely to determine overall whether the force in an abrupt stop increases or decreases as mass, speed, and stopping time separately are changed. Ordinary string, such as sewing thread and breakable twine, could be substituted for monofilament fishing line, but has the disadvantages of greater variation in composition and a tendency to set the suspended mass into rotation if the mass is left hanging, changing the properties of the string.

The monofilament fishing line line tends to break preferentially at a knot, depending on how the knot is tied. To avoid this problem, it is recommended that the line be attached to the rigid support bar without a knot—simply wind the line tightly around the bar (six or seven times) and secure with a small piece of tape (see illustration). The lower end of the line (attached to the hook of the weight holder) can be secured in the same manner.

The test masses should be released directly from below their point of support.

The last part of the experiment makes the strongest impression with the rubber band between the fishing line and the rigid support, rather than between the fishing line and the test mass, because this leaves less intuitive doubt that the fishing line bears all the force exerted by the mass.

The height through which the object falls determines how fast it is moving when the fishing line begins to stop its motion. The line may stretch slightly, and there is some yield in the support bar, but the time of the attempted stop is fairly short. The average stopping force for downward motion (plus the extra force of gravity) multiplied by the time it acts, gives the impulse. The basic relation from Newton's second law is:

Impulse = Force x time
= mass x acceleration x time
= mass x (change in velocity)
= change in momentum.

With $Ft = I$ for impulse I, the shortness of the time t during which the stop is attempted results in a force many time greater than the mere gravitational force. Because the momentum is the product of mass times velocity, and because of the increase in speed as the test mass falls, the momentum and therefore the impulse needed to reduce the momentum to zero increases with increased distance of fall. This means

[1] This follows because the speed attained by the object starting from rest and falling a distance h with constant acceleration g is $v = (2gh)^{1/2}$. The corresponding relation then holds for the (assumed) constant acceleration a that stops the object over a much smaller distance s from its speed v, namely $v = (2as)^{1/2}$. Setting $(2gh)^{1/2} = (2as)^{1/2}$, squaring both sides, solving for a, and therefore for the stopping force ma, yields the result that the stopping force ma is the weight mg multiplied by h/s.

that the force is greatest for a given mass after the longest distance of free fall. (More quantitatively, assuming uniform acceleration, the average stopping force can be shown to equal the weight *mg* multiplied by *h*/*s*, where *h* is the distance of fall and *s* is the stopping distance, showing that the very large value of *h*/*s* does imply a force many times that of gravity.[1]

For the stopping time rather than the stopping distance *s*, roughly constant, this result shows how the force varies. But if instead we assume the stopping distance roughly constant, the stopping time becomes even shorter for the faster moving objects, while the impulse required increases for faster moving objects the same as before. With impulse $I = Ft$, increasing I by increasing either mass or speed but now also decreasing t gives an even greater stopping force F for increased height of fall than already expected under the rough approximation of constant stopping time.)

The effect in the last part, where stretching the stop over a longer time and longer distance results in less force, so the string does not break, might surprise students, so they should not be told to expect this. The decreased force results because the average force multiplied by the time (the impulse) is equal to the same required change in momentum, except that now the distance and therefore the time of the stop are both much longer. With impulse $I = Ft$ the same, the much longer stopping time t produces a much smaller force F.

Variations:

None.

Adapted from:
None.
Illustration: M. S. Young

Science as Inquiry

The Water Rocket

What makes a rocket work?

Overview:

Students observe how the principle of momentum conservation applies in rocket propulsion, being led to conclude that it is the momentum of the exhaust ejected at high speed from the rocket, and the impulse it imparts to the rocket, rather than the pressure of exhaust acting on whatever is behind the rocket, that propels the rocket forward.

Materials:

water rockets (inexpensive commercial toy)

water

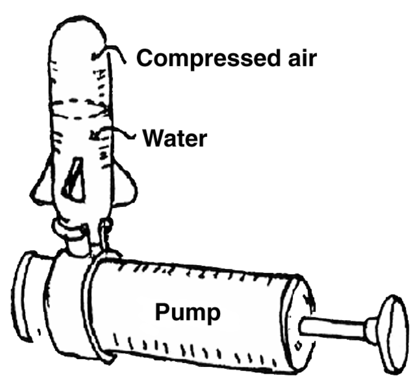
aluminum baking pans (or other large area vessel if done indoors to catch the water if lab sinks are not available)

Procedure:

Fill the water rocket partially with water to the lowest mark indicated on the rocket. Clamp the pump in place on the rocket and pump about six full thrusts of the pump handle to pressurize the inside. Aim the rocket upward and (with the unit held over a catch basin or sink if done inside) slip the latch mechanism to unclamp the rocket, watching it shoot into the ceiling. Then repeat the entire operation with exactly the same number of thrusts of the pump handle plus one or two extra to make up for the missing water. Only air is released, and the rocket moves only an inch or two into the air.

Background:

The water rocket is a commercial toy that can be purchased for about $2–5 each at retail stores. Each kit comes with a small funnel for pouring water into the rocket shell and a small specially designed air pump. The output end of the pump has a piece of movable plastic that clamps the rocket onto the pump until it is ready to be released by slipping back the plastic. The rocket shell has small mass and is unlikely damage anything if fired upwards inside with only a modest amount of water and moderate pressure. But care should be taken not to be firing the rocket into overhead light fixtures or anything else very breakable.



Available water rockets and the pumps sold with them vary greatly. If the activity is to be done indoors, test the units beforehand to assure that the instructions as given produce only moderate lift-off for the water-filled case. Alter the instructions if necessary to use fewer pump thrusts.

If it is possible, it is most desireable to do the experiment outdoors, where students can safely see how high the water rocket is capable of being launched. The water rocket reportedly can be fired as high as 150 feet.

Rocket propulsion is usually described in terms of the principle of conservation of total momentum. No matter what the forces within the rocket cause each specific amount of exhaust to be emitted with some particular momentum -*p* in a given short interval of time, conservation of the total momentum of rocket plus exhaust requires that the itself rocket must have been given an extra momentum +*p* in order for there to be no change in the total momentum of the rocket plus the emitted exhaust. The change in momentum *p* of the rocket is equal to the impulse imparted to it by ejecting the specific amount of exhaust.

A common notion, that the rocket propulsion is in general a result of exhaust pushing against the air behind the rocket, is easily recognized to be faulty by realizing that a rocket engine also can propel a vehicle in space, where there is nothing behind for exhaust to push against.

While momentum conservation implies that there has to be an impulse (equal to the average force multiplied by the time considered) imparted to any rocket by emitting mass at high speed, it leaves unanswered the question of exactly how this force arises. There are indeed necessarily forces within the rocket between the exhaust about to be emitted and the rocket itself. In fact, the design features, such as the shape of the nozzle, matter a great deal in determining how the exhaust is emitted and what thrust is obtained. But thanks to the principle of momentum conservation it is not necessary to know these details to see that expelling mass backward with substantial momentum must impart momentum in the forward direction to the rest of the system. This feature of conservation laws, of allowing us sometimes to reach general physical conclusions without needing to know as many details as necessary for direct application of Newton's laws of motion, deserves to be pointed out to students, because it occurs repeatedly later in applying other conservation laws.

In the case of the water rocket, the air pressure inside ejects the relatively massive water at high speed in a fraction of a second. The momentum of the water in the backward direction is the product of its mass and velocity, and by the principle of momentum conservation is the momentum imparted to the rocket, which is therefore the impulse imparted to the rocket, or average force on the rocket multiplied by time the force acts.

When the water rocket is launched without the water, air is pushed out instead with at least as great a velocity, but with relatively little mass. The unimpressive liftoff from air pressure alone makes clear that the mass of the water is essential in producing the observed effect.

Although momentum conservation principle is the point of this activity, students may still want an explanation in terms of forces. The compressed air inside the rocket acts as a spring through which the rocket body and the water exert forces on each other that are equal but oppositely directed according to Newton's third law. As the water is pushed out, that force is equal to the mass times the acceleration of the water and, because of the inertia of the water, the force persists for a certain brief time while the water is being expelled. But if the same volume of air alone, with its relatively negligible mass, is pushed out instead of water, the force of the rest of the air pressing on it is initially the same while its much smaller mass accelerates it out of the rocket faster, depleting the pressure inside much more rapidly. With the force between the rocket and exhaust acting for a much shorter time when the exhaust is air rather than water, the impulse, or equivalently the effect of the force in changing the momentum of the rocket, is much smaller.

In everyday terms, the compressed air acts as a spring between the water and the rocket shell tending to push both of them apart. If there is only relatively-low-mass air being expelled instead of water, then there is not as much inertial mass resisting acceleration for this ‘spring’ to push back against in order to push and accelerate the rocket forward. While this explanation is correct for the water rocket, it overlooks the generality of the principle of momentum conservation.

Variations:

There are rockets and launching devices that use air pressure as their source of thrust, but although the molecular velocity is high, the particle mass is small. However, they will not demonstrate the dependence of thrust on emitted mass as clearly as does the water rocket.

Adapted from:

Frier, G. D., and F. J. Anderson, A Demonstration Handbook for Physics, American Association of Physics Teachers, College Park, Maryland, 1981, p. M-23.

Science as Inquiry

Collision Courses

Item:

Three identical carts on an air track are lined up touching each other. A cart twice as massive as any one of the others collides at speed v into the line of carts. The result of the collision would be:

A. The more massive cart bounces and moves at the same speed as before but in the opposite direction, while the other carts remain stationary.

B. Two carts at the other end continue forward at speed v while the more massive cart stops.

C. The more massive cart bounces and moves just as fast as before but in the opposite direction, while two carts on the other end move forward at that same speed.

D. The more massive cart stops but the three carts then move together all with speed v.

Justification:

This is the same situation as in the Activity in which two metal balls collided into a line of metal balls, and momentum was conserved by two balls at the other end continuing on while the first two stopped.

Alternative justification. The total momentum of the system afterwards must be the same as before, and that is true only for choice B.

Answer:

B.

Science as Inquiry

Speeding Trains

Item:

Two identical railroad freight cars coupled together are stationary on a level track with their brakes off when a third identical car bumps into the others and latches to them. The speed of the coupled cars afterwards, compared with the speed of the car that struck the others, is:

A. One third as fast.
B. Half as fast.
C. Three times as fast.
D. Twice as fast.

Justification:

The momentum along the track stays constant, and since the mass that is moving increases by a factor of 3, the speed must decrease to $^1/_3$ of its previous value to keep the momentum mv the same.

Answer:

A.

Science as Inquiry

Hammer Heads

Item:

Explain why a hammer with a head made out of reasonably heavy material would tend to exert a greater force when driving a nail into a wooden board than one made of equally hard but less massive material.

Answer:

The momentum of the hammer head for the same speed is greater if its mass it greater, so the force between the hammer and the nail in changing the hammer's momentum to zero would be greater.

Science as Inquiry

Balancing Act

Item:

Suppose you are standing on a ledge overlooking the abyss below while holding a large rock. You lose your balance and are starting to fall forward over the edge. The best reaction to avoid falling into the abyss would be:

A. Throwing the rock upwards as hard as possible.
B. Doing nothing with the rock.
C. Letting go of the rock.
D. Throwing the rock forward as hard as possible.

Justification:

Conservation of momentum implies that if the rock is pushed forward, it will produce an impulse changing your momentum toward the backward direction. The harder the rock is pushed forward, the greater the momentum it is given, and the greater the impulse pushing you back to safety.

Alternative Justification. If you push the rock forward, it pushes back on you just as hard as you push on it.

Answer:

D.

Consumables

Item	Quantity (per lab group)	Activity
monofilament fishing line	3 different strengths, 4, 8 and 10 lb	4
tape	—	4
velcro (or soft wax)	—	3
water	—	5

Nonconsumables

Item	Quantity (per lab group)	Activity
air track w/air track cars	1	3
ball bearings or marbles (same mass)	1 set of 12	2*
collision balls, set	1 set	1
coins of various sizes	—	2*
meter stick	1	3
ring stand with clamp and rod	1	4
rubber band, heavy duty	1	4
ruler, plastic (w/groove in the center)	1	1, 2*
stop watch	2	3
test mass	1 ea. 200 g and 350 g	4
water rockets	1	5

*indicates alternative or additional activity

Key to activities:
1. When Ball Bearings Collide
2. Tabletop Collisions
3. Motion (almost) Without Friction—the Air Track
4. Stopping a Moving Object
5. The Water Rocket

Activity Sources

Frier, G. D., and F. J. Anderson, A Demonstration Handbook for Physics, American Association of Physics Teachers, College Park, Maryland, 1981, p. M-23.