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Conservation of linear momentum - became the first great conservation law in physics (before energy). Because momentum (mv) is a vector quantity, it stands apart from energy with a different meaning. (Students must understand vectors first; review if necessary.) When introducing the law, linear or straight-line momentum (mv) is the least complex place to start. Always in the "mix", of course, is impulse (F t) where the momentum originates and which helps to transfer momentum during collisions or contacts. See the topic, "Impulse, the momentum changer", elsewhere on this website.

The law, in its simplest form, is $\sum m\vec{v}_{before} = \sum m\vec{v}_{after}$.

The development of very low friction gliders on air tracks and low friction carts on tracks along with high tech timing and measuring devices has advanced the study of this topic considerably. However, a qualitative introduction to the law can still be made with a series of demonstrations using fairly simple, inexpensive apparatus.

(a) These "collision" demonstrations require a pair of PSSC carts of nearly equal mass (cart B has a spring), masses, and a "wall" of somekind. Something solid clamped to the end of a table top should do as a "wall".

<u>Warning</u>: <u>Practice</u> all of these demonstrations beforehand to get them right, or the students won't be convinced.

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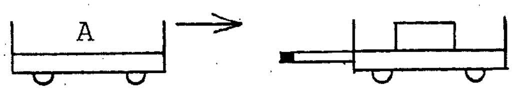
2) 

3) 

4) 

5) 

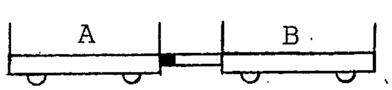
1) Propel cart A to the right against cart B at rest.
Result: Cart A nearly stops and cart B gains most of cart A's velocity to the right. Thus, momentum is transferred and conserved.

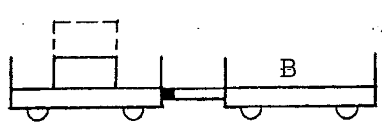
2) Double cart A's mass by adding mass to it and propel it against cart B at rest.
Result: Cart A is slowed considerably having transferred most of its mv to cart B, which takes off with nearly twice the original velocity of cart A.

3) Switch the added mass to cart B and propel cart A to the right.
Result: Cart A nearly stops and cart B moves to the right at about half of cart A's original velocity.

4) With equal velocities, propel cart A and cart B toward each other.
Result: They appear to bounce or repel off of each other, or cancel each other out. But that would <u>not</u> conserve the original momentum during the collision. The momentum of each is conserved by transferring each one's momentum <u>through</u> the impulse (F ave t) in the spring. Cart A's mv continues in cart B to the right and cart B's mv to cart A to the left.

5) With the added mass on cart A, equally propel the two carts toward each other.
Result: Cart A is slowed moving to the right while cart B moves to the right much faster than the original velocity of cart A.

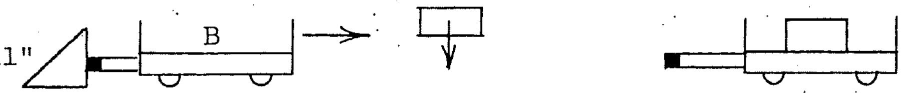
6) 

7) 

6) Line up the carts with the spring cocked; hit the trigger.
Result: They accelerate and coast in opposite directions, one positive, the other negative. Momentum doesn't appear to be conserved from before the trigger was struck when they were both at rest. However, added vectorially, positive and negative, the sum is still zero and the momentum of the system is conserved.

7) Repeat the above demo with added mass on cart A; cock and hit the trigger.
Result: Cart A moves to the left (negative) at half the velocity of cart B moving to the right (positive). The sum of their momentums is still zero as before.

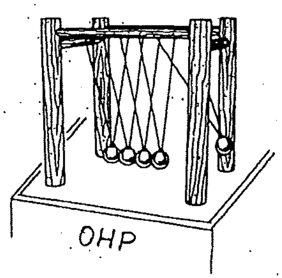
If you add still more mass to cart A, it will roll back even slower and stop sooner. In the 17th-19th centuries, cannon were purposely made massive to reduce the recoil velocity and stopping distance, especially naval cannon.

8) "wall" 

8) Switching to a <u>different</u> kind of two-body system that uses only <u>one</u> cart, begin in step 1 with cart B cocked and against the "wall". Hit the trigger. The spring provides the impulse to give cart B its momentum to the right.
Result: Cart B takes off to the right at a good velocity (and Momentum).
Now, in step 2, reset the above situation and hit the trigger again. This time, after the spring (plunger) has cleared the wall, drop (free-fall) a mass about <u>equal</u> to the cart's mass onto the cart.
Result: The cart's original velocity to the right before the drop should be reduced to about half with the added mass. (Doubling the mass should cut the velocity to the right in half, thus the original momentum to the right before the drop is conserved.)
<u>Warning</u>: If you don't <u>practice</u> the "drop" correctly, you won't get the desired result. What's the "catch"? You must <u>not</u> move the "dropped" mass <u>along</u> to the right with the cart while dropping it on the cart. (You would be giving the "dropped" mass a horizontal velocity to the right equal to the cart's.) Instead, it must be a straight down, vertical drop onto the cart or v horiz.= 0; it <u>will</u> hit hard! The vertically dropped mass acts as a <u>retarding force</u> as it <u>scuffs</u> briefly on the cart, reducing its velocity to the right. At the same time, the dropped mass's horizontal velocity to the right is being <u>accelerated</u> from v horiz.= 0 up to the cart's final, but lower, velocity to the right. It looks like a "velocity trade-off" between the two bodies. In the end, the original, starting, horizontal momentum to the right is conserved.

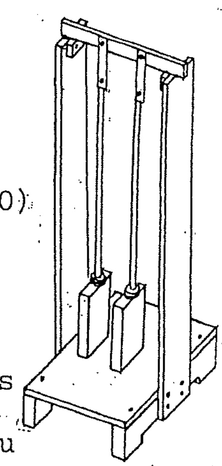
(b) Many of the above demos can be performed on large, low-friction carts with students standing or kneeling on them. The carts may be purchased or homemade. Plastic milk jugs filled with sand could be the added or subtracted masses where applicable. One of the special aspects of this arrangement is the students' ability to catch and toss the jugs in different situations (studies) to demonstrate different principles.

(c)

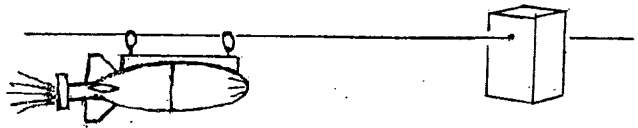
9) 

See "Demonstrations with the overhead projector" on this website for info on the "Original Swinging Wonder", the unsurpassed apparatus for demonstrating the Law of Conservation of Momentum 9). 55+ years and still going (swinging!) strong!

(d) See "Resonance pendulums" on this website for info on another superb piece of apparatus for demonstrating the Law of Cons. of mv 10).

10) 

(e) A small, plastic air and water rocket can be modified for classroom use to demonstrate the Law of Cons. of mv dramatically and safely. The set-up requires a wire stretched tightly across the classroom that the rocket can easily "ride" from end to end. If the rocket is designed to spiral in its flight, you must trim off the vanes that cause the spiraling. To control its "flight" along the wire, a small piece of wood must be shaped and attached (epoxied) to the top side of the rocket 11). The wood must accept two small screw eyes. On the far end of the wire, attach a sponge (cushion) to stop the rocket safely. Follow the original instructions given when filling the rocket with water.

11) 

$m_1 \overleftarrow{v_1} = m_2 \overrightarrow{v_2}$

First, m_1 is air; then m_1 is water. The rocket is m_2 each time.

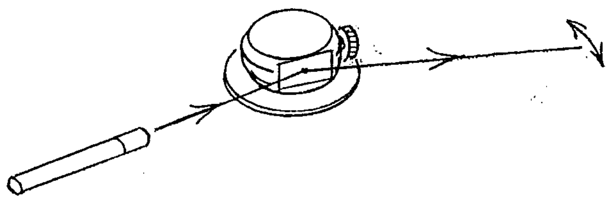
Presentation: When all is ready, pump only air (fuel) into the rocket and fire.

Result: The rocket hardly moves. Compared to the rocket's mass, the air's mass is so small that the rocket can't attain any real velocity from the "explosion", regardless of the air's velocity.

Repeat the procedure with water as the "fuel" this time. The water's mass is far greater than air's and even greater than the plastic rocket. When fired, the rocket takes off at high speed and leaves the water behind (on you?); the Law is well-demonstrated. Hopefully, the students can better understand the purpose of the huge booster rocket at the base which is throwing down tons of mass (molecules) in a very short time to push the upper part of the rocket on its way.

(f) Two principles are demonstrated with a small mirror epoxied on the side of an inverted, stem-wound pocket watch, cons. of mv and amplification via the optical lever 12). The latter has been used in laboratories since the 18th century (?) but is now much easier because of the laser. Place the watch on its crystal (face) on a clean, inverted watch glass or convex surface. Aim the laser at the mirror so its reflection is cast upon a wall; adjust for maximum effect. Wind the watch and position it as before. The beam (image) on the wall should oscillate back and forth with the watch case but 180° out of phase with the balance wheel rotating back and forth inside.

12)



All of the above suggests that Newton must have had a premonition of the Law of cons. of mv when he formulated his third law of motion (forces), i.e., action and reaction. He doesn't get the credit for discovering the Law, but he certainly was getting close!

In conclusion, in a dynamic world where everything is forever moving, from subatomic particles to huge celestial bodies, momentum (mv) is always present and impulse (F t) is providing the constant changes in their motion and momentum.