

Relating equations to common sense: “Oomph”

This tutorial introduces *momentum conservation*. Equally important, using momentum as an example, this tutorial explores the extent to which formulas relate to common sense.

I. What's your view?

- A. (*Work individually*) Which of the following best expresses your view about the relationship between physics formulas and common sense? (You can choose more than one.)
- Many physics *concepts* make a lot of sense and connect to everyday experience; but *formulas* are more of a problem-solving tool than a sense-making tool.
 - It really depends on the formula. Some of them make sense, but you shouldn't expect them to make sense as a general rule.
 - In general, physics formulas express some kind of common-sense ideas.
- B. Compare your answers with the rest of your group. If there was disagreement, have a debate—not to convince each other, but to understand each others' views. If someone makes a good point that disagrees with what you initially thought, summarize that point here.

II. Figuring out the formula for oomph

An important physical quantity, the name of which we'll give later, corresponds to the intuitive idea of *oomph*. The more oomph something has, the harder it is to stop, and the more ability it has to knock other things over. Let's figure out the formula for oomph. *If you already know the formula from a previous class, please “play along” and don't give it away.* We've structured this tutorial so that you'll learn something even if you already know the formula. We know some of you don't like mucking around with intuitions, but trust us, in this tutorial it'll lead somewhere quickly, and you'll end up practicing some physics.

- A. (*Work together*) A small pebble and a larger rock are thrown at the same speed.

- Which one has more oomph? Why?

Large rock

- The rock is twice as massive as the pebble. *Intuitively*, how does the rock's oomph compare to the pebble's oomph? Is it twice as big? Half as big? Three times as big?

Twice as big

- B. (*Work together*) Picture two identical bowling balls, one of which is rolling faster than the other.

- Which ball, the faster or slower one, has more oomph? Why?

Faster one

- The faster ball is exactly 7 times as fast as the slower one. Intuitively, how does the faster ball's oomph compare to the slower ball's oomph?

Seven times as much

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(*Work together*) The physics concept corresponding to oomph is *momentum*. Building on your above answers, figure out a formula for momentum (oomph) in terms of mass and velocity. Explain how the formula expresses your intuitions from parts A and B above. (For nutty historical reasons, physicists use the letter p for momentum.).

$$p = mv$$

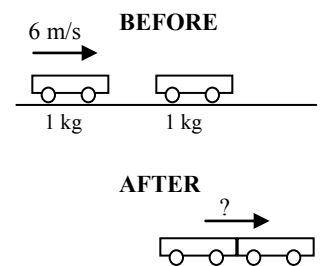
III. Intuitions about collisions

Above, your intuitions about *oomph* led to a formula for momentum. Now let's see if your intuitions about collisions lead to similar progress.

- A. (*Work together*) A 1 kg cart, rolling with negligible friction at 6 meters per second, collides with and sticks to an identical cart. So, after colliding, the carts roll together as a single unit.

1. Using your intuitions, guess the post-collision speed of the two carts. Briefly explain your reasoning.

3 m/s because the oomph is shared between the two carts now.



2. According to the intuitive guess you just made, is the overall momentum of the two-cart system after the collision greater than, less than, or equal to the overall momentum before the collision? Work this out using the momentum formula you figured out above and plugging in the relevant numbers.

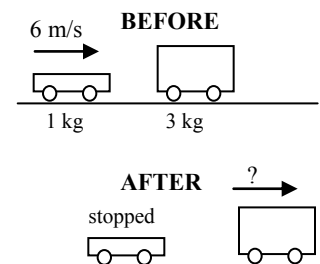
$$\text{Equal; } p_{\text{before}} = 1\text{ kg} \times 6\text{ m/s} + 1\text{ kg} \times 0\text{ m/s} = 6\text{ kgm/s}$$

$$p_{\text{after}} = 2\text{ kg} \times 3\text{ m/s} = 6\text{ kgm/s}$$

- B. (*Work together*) In a similar experiment, the 1 kg cart collides with a 3 kg cart but doesn't stick to it. Instead, the 3 kg cart gets knock forward by the 1 kg cart, which comes to rest after the collision.

1. Again using intuitions, guess the post-collision speed of the 3 kg cart.

2 m/s



2. According to the intuitive guess you just made, is the overall momentum of the two-cart system after the collision greater than, less than, or equal to the overall momentum before the collision?

equal

- C. (*Work together*) Based on your work above, state a general rule about how the total momentum of a system changes during a collision.

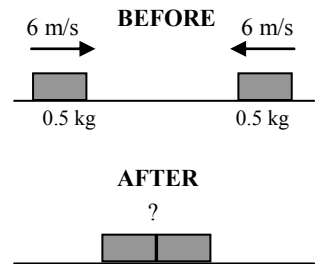
The total momentum of a system remains the same during a collision

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Let’s look at one more collision. Two identical blocks, both of mass 0.5 kg and covered with Velcro™, slide toward each other at equal speeds, 6 m/s. The blocks stick together.

1. *Intuitively*, after the collision, how fast do the blocks move and in what direction?

They are stopped



2. In the cart collisions from parts A and B above, momentum was *conserved*; it was the same before and after the collision. Because conserved quantities are useful in problem-solving, it would be cool if we could define momentum in such a way that it’s *always* conserved in collisions (between objects that are free to move). Is there some way to modify or clarify the momentum formula you figured out at the top of page 2 so that momentum *is* conserved in the head-on collision between the two blocks? (*Hint: Maybe oomph “cares” about direction.*)

Make it a vector $\vec{p} = m\vec{v}$

★ [Consult an instructor before you proceed.](#)

IV. Conservation of momentum

Conservation of momentum is a fundamental physical law. Among other things, it says that when two objects collide, the total momentum of the system immediately after the collision equals the total momentum of the system immediately before the collision:

$$\text{Conservation of momentum: } m_1 \vec{v}_{1 \text{ before}} + m_2 \vec{v}_{2 \text{ before}} = m_1 \vec{v}_{1 \text{ after}} + m_2 \vec{v}_{2 \text{ after}}$$

In lecture, we’ll clarify exactly when momentum is and is not conserved.

Since $\vec{p} = m\vec{v}$, and since velocity “cares” about direction, so does momentum. So, a negative oomph (momentum) can partially or fully cancel a positive oomph, as the Velcro™ blocks demonstrated.

- A. (*Work together*) Let’s practice using momentum conservation. On a safety test course, a 1000 kg car heading north at 5 m/s collides head-on with an 800 kg car heading south at 4 m/s. At these low speeds, the new high-tech bumpers prevent the cars from crumpling; they bounce off each other. After the bounce, the 1000 kg car is heading southward at 1 m/s. We’re going to ask you for the post-collision speed and direction of motion of the other car.

1. What’s a good first step in this problem, one that will help you avoid mistakes? After coming to consensus, do that step.

A good first step is to draw a diagram indicating the direction of each car before and another diagram for after.

North is positive and South is negative

Without doing calculations, “guess” the final direction of motion of the lighter car. Briefly explain your reasoning.

It sounds like they bounced off each other so I’ll say the lighter car will be heading North.

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Now calculate the lighter car’s speed and direction of motion after the collision. Make sure everyone in the group is comfortable with this.

North is positive and South is negative

$$1000\text{kg } 5 \text{ m/s} + 800\text{kg } (-4 \text{ m/s}) = 1000\text{kg } (-1 \text{ m/s}) + 800\text{kg } v_{\text{after}}$$

$$5000 \text{ kgm/s} - 3200\text{kgm/s} = -1000\text{kgm/s} + 800\text{kg } v_{\text{after}}$$

$$1800 \text{ kgm/s} + 1000 \text{ kgm/s} = 800\text{kg } v_{\text{after}}$$

$$\frac{2800 \text{ kgm/s}}{800\text{kg}} = v_{\text{after}} = 3.5 \text{ m/s}$$

2. If you didn’t already do so, check for consistency between your intuition in question 2 and your formal answer in question 3.

Yup it’s positive so heading to the North

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- B. (*Work together*) Two students, after listening to one of their physics professor’s sermons about sense-making, are arguing about the conservation of momentum equation from the previous page (in the gray box).

FRANK: I don’t think the equation expresses common sense, because if it did, then we could have used common sense directly—instead of the equation—to solve the problem about the colliding cars. But we really needed the equation there to get the exact numbers.

ERNEST: Sure we needed the equation. But the equation kind of expresses the common-sense idea that oomph stays the same in a collision. The whole point of expressing common-sense ideas in equations is to get something more generally useable, something we can use when common sense alone can’t deal with the situation.

FRANK: You’re admitting that the equation goes beyond common sense, because we can use it when common sense alone wouldn’t get us anywhere. So, at least in those cases, the equation doesn’t express common sense!

In what ways do you agree or disagree with Frank? With Ernest? What’s your stance on this issue?

For me this is too much math to do in my head but that doesn’t mean it goes against common sense. The equation just helps me keep track of all the numbers and the directions.