ANSWER KEY. Values match the simulation readouts for the settings given in each step.

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Collision Carts Virtual Lab

Physics | ANSWER KEY

Open **activities.zornscience.org/collision-carts/** and follow each step. Right is positive. Show your work with units.

Objective

Use two carts on a track to test whether the **total momentum** and the **total kinetic energy** of a two-cart system stay the same in elastic and inelastic collisions.

NGSS alignment: HS-PS2-2. Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system.

Practices and concepts: Using mathematics and computational thinking; Analyzing and interpreting data; Systems and system models; Energy and matter (conservation).

Meet the simulation

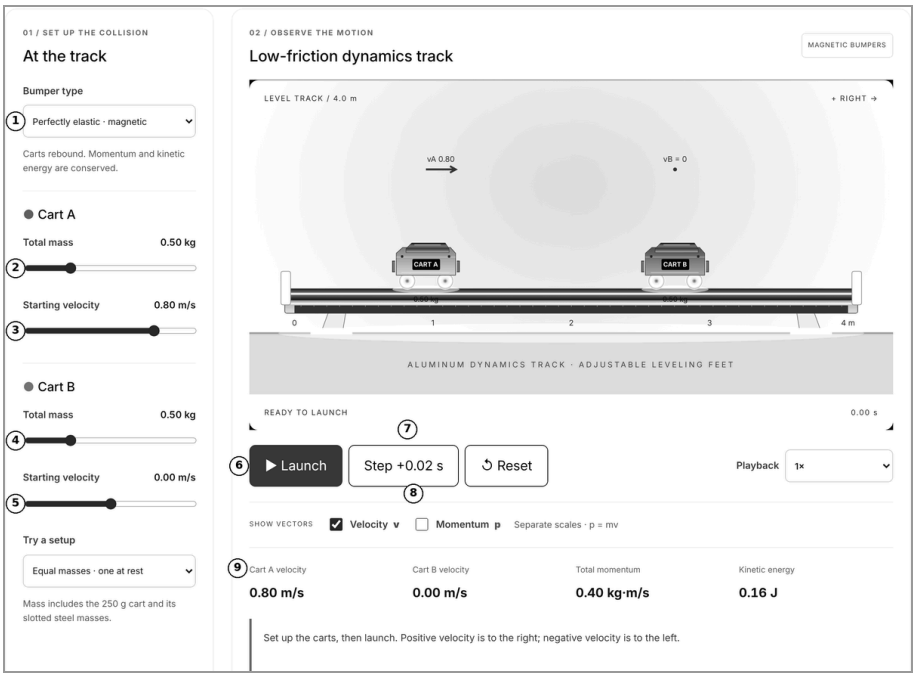


Figure 1. The lab (dark track scene inverted for printing).

① Bumper type: elastic (magnetic) or inelastic (hook and loop, carts stick).

② Cart A total mass. ③ Cart A starting velocity.

④ Cart B total mass. ⑤ Cart B starting velocity.

⑥ Launch, pause and resume. ⑦ Step forward 0.02 s.

⑧ Show velocity and momentum arrows.

⑨ Readouts: each cart's velocity, total momentum, kinetic energy.

Masses move in 0.25 kg steps and velocities in 0.1 m/s steps. Changing a setting resets the carts.

Pre-lab

1. A 0.50 kg cart moves at 0.80 m/s to the right. Calculate its momentum and its kinetic energy.

$p = mv = (0.50\ kg)(0.80\ m/s) =$ <u>0.40 kg·m/s</u> to the right; $KE = \frac{1}{2}mv^2 = \frac{1}{2}(0.50\ kg)(0.80\ m/s)^2 =$ <u>0.16 J</u>

2. Two 0.50 kg carts move toward each other, one at +0.80 m/s and one at −0.80 m/s. What is the total momentum of the two-cart system? Why can momentum be zero when both carts are moving?

$p_{total} = (0.50\ kg)(0.80\ m/s) + (0.50\ kg)(-0.80\ m/s) =$ <u>0 kg·m/s</u>. Momentum is a vector: equal momenta in opposite directions add to zero. Kinetic energy has no direction, so it is not zero.

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Part A. Elastic collisions

1. Set **Bumper type** to **Perfectly elastic · magnetic**. Check the **Momentum** box.
2. Set the masses and starting velocities for each trial. Record total momentum and kinetic energy **before** you launch.
3. Select **Launch**. After the collision, select **Pause** (or wait for the run to stop) and record the readouts **after**.

Trial	Settings				Before		After			
	m_A (kg)	m_B (kg)	v_A (m/s)	v_B (m/s)	p_{total} (kg·m/s)	KE (J)	v_A' (m/s)	v_B' (m/s)	p_{total} (kg·m/s)	KE (J)
1	0.50	0.50	0.80	0.00	**0.40**	**0.16**	**0.00**	**0.80**	**0.40**	**0.16**
2	0.50	0.50	0.80	−0.80	**0.00**	**0.32**	**−0.80**	**0.80**	**0.00**	**0.32**
3	1.00	0.25	0.80	0.00	**0.80**	**0.32**	**0.48**	**1.28**	**0.80**	**0.32**
4	0.25	1.00	0.80	0.00	**0.20**	**0.08**	**−0.48**	**0.32**	**0.20**	**0.08**

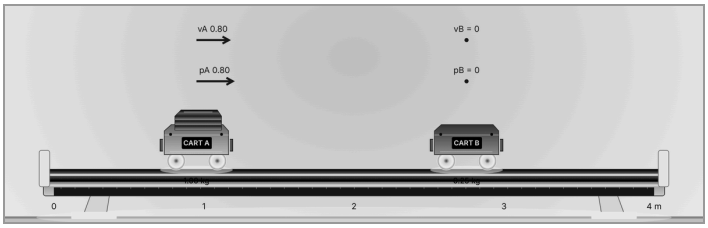


Figure 2. Trial 3 before the collision.

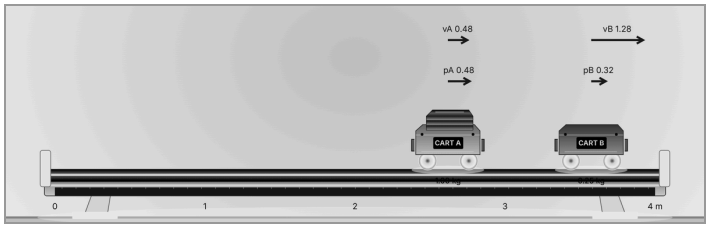


Figure 3. Trial 3 after the collision.

3. Describe what happens to each cart in trials 1 and 2 (equal masses). What pattern do you see?

Trial 1: cart A stops and cart B moves off at 0.80 m/s. Trial 2: both carts bounce back with their speeds unchanged. Equal masses in an elastic collision swap velocities.

4. For trial 3, calculate the momentum of each cart after the collision. Show that they add to the total momentum before the collision. Compare with the pA and pB momentum arrows on the screen after the collision.

p_A' = (1.00 kg)(0.48 m/s) = 0.48 kg·m/s; p_B' = (0.25 kg)(1.28 m/s) = 0.32 kg·m/s. Total = 0.48 + 0.32 = <u>0.80 kg·m/s</u>, the same as before (1.00 kg)(0.80 m/s) = 0.80 kg·m/s. The arrows read pA 0.48 and pB 0.32 (Figure 3).

5. In trial 4 a light cart hits a heavy cart at rest. Which way does cart A move afterward? How can total momentum stay +0.20 kg·m/s when cart A moves backward?

Cart A bounces back to the left (−0.48 m/s). Its momentum is (0.25 kg)(−0.48 m/s) = −0.12 kg·m/s, and cart B's is (1.00 kg)(0.32 m/s) = +0.32 kg·m/s. The total is −0.12 + 0.32 = +0.20 kg·m/s.

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Part B. Inelastic collisions

1. Set **Bumper type** to **Perfectly inelastic · hook & loop**. The carts stick together when they collide.
2. Run each trial the same way as Part A and record the readouts before and after.

Trial	Settings				Before		After		
	m_A (kg)	m_B (kg)	v_A (m/s)	v_B (m/s)	p_{total} (kg·m/s)	KE (J)	v′ of joined carts (m/s)	p_{total} (kg·m/s)	KE (J)
5	0.50	0.50	0.80	0.00	**0.40**	**0.16**	**0.40**	**0.40**	**0.08**
6	1.00	0.25	0.80	0.00	**0.80**	**0.32**	**0.64**	**0.80**	**0.26**
7	0.25	1.00	0.80	0.00	**0.20**	**0.08**	**0.16**	**0.20**	**0.02**
8	0.50	0.50	0.80	−0.80	**0.00**	**0.32**	**0.00**	**0.00**	**0.00**

6. For trial 6, use conservation of momentum to predict the final velocity of the joined carts. Show your setup with units, then compare with the simulation.

$m_Av_A + m_Bv_B = (m_A + m_B)v'$
(1.00 kg)(0.80 m/s) + (0.25 kg)(0 m/s) = (1.25 kg)v′, so v′ = 0.80 kg·m/s / 1.25 kg = <u>0.64 m/s</u>.
It matches the simulation.

7. For trial 5, what fraction of the kinetic energy was lost? Where did that energy go?

Lost = 0.16 J − 0.08 J = 0.08 J; fraction = 0.08 J / 0.16 J = <u>0.50</u> (half). It became internal (thermal) energy and sound as the hook-and-loop pads deformed and stuck.

8. In trial 8, all the kinetic energy disappears. Does this break conservation of momentum? Explain.

No. Total momentum was 0 kg·m/s before (equal and opposite momenta) and is 0 kg·m/s after. Momentum is conserved; only kinetic energy is not conserved in an inelastic collision.

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9. Look at all eight trials. Which quantity was conserved in **every** trial? Which was conserved only in elastic collisions?

Total momentum was the same before and after in all eight trials. Total kinetic energy was the same only in the elastic trials (1 to 4); it decreased in every inelastic trial (5 to 8).

10. In trial 3, cart B speeds up and cart A slows down. Use Newton's third law to explain why the momentum cart A loses equals the momentum cart B gains.

During the collision, A pushes on B and B pushes back on A with an equal and opposite force for the same time. So the impulses ($F\Delta t$) are equal and opposite: A loses $0.80 - 0.48 = 0.32$ kg·m/s and B gains 0.32 kg·m/s.

11. The simulation track has no friction, and the run pauses before a cart hits an end stop. Why are both needed to keep momentum conserved? How would results on a real track differ?

Momentum is conserved only when no outside (net external) force acts on the two-cart system. Friction and an end stop push on the carts from outside. On a real track, friction would slow the carts, so the momentum measured after would be a little smaller than before, and real "elastic" bumpers would lose a little kinetic energy.

Conclusion

12. Write a claim that answers the objective. Support it with specific numbers from one elastic and one inelastic trial, then explain your reasoning.

Claim: Total momentum is conserved in both elastic and inelastic collisions. Kinetic energy is conserved only in elastic collisions.
Evidence: Trial 3 (elastic): p = 0.80 kg·m/s and KE = 0.32 J both before and after. Trial 6 (inelastic): p stayed 0.80 kg·m/s, but KE dropped from 0.32 J to 0.26 J.
Reasoning: The forces the carts exert on each other are equal and opposite (Newton's third law) and act for the same time, so their momentum changes cancel. With no outside force, total momentum cannot change. In an inelastic collision, some kinetic energy is changed into internal energy as the carts stick.

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