

Workshop Tutorials for Introductory Physics

Solutions to MI9: Collisions

A. Review of Basic Ideas:

Collisions

A .22 rifle bullet and a pitched baseball have roughly the same **kinetic** energy - a hundred or so joules. Which would you rather catch? How can a rocket engine accelerate a space shuttle in outer space where there's nothing to **push** against? To answer these and similar questions we need two new concepts, momentum and impulse, and a new conservation law, conservation of momentum. The validity of this **conservation** principle extends far beyond the bounds of classical mechanics to include relativistic mechanics (the mechanics of the very fast) and quantum mechanics (the mechanics of the very small).

To most people the term 'collision' is likely to mean some sort of automotive disaster. We'll use it in that sense, but we'll also broaden the meaning to include any strong interaction between two bodies that lasts a relatively **short** time. So we include not only car accidents but also balls hitting on a billiard table, the slowing down of neutrons in a nuclear reactor, a bowling ball striking the pins, and the impact of a meteor on the surface of the Earth.

Conservation of momentum is true for any isolated system. If the interaction forces are much **larger** than the net external force, we can model the system as an isolated system, neglecting the external forces entirely. Two cars colliding at an icy intersection provides a good example. Even two cars colliding on dry pavement can be treated as an isolated system during the collision if, as happens all too often, the interaction forces between the cars are much larger than the **friction** forces of pavement against tyres.

If the interaction forces between the bodies are **conservative**, the total kinetic energy of the system is the same after the collision as before. Such a collision is called an elastic collision. A collision between two hard steel balls or two billiard balls is almost completely **elastic**, and collisions between subatomic particles are often, though not always, elastic. A collision in which the total kinetic energy after the collision is less than that before the collision is called an **inelastic** collision. If the colliding bodies stick together and move as one body after the collision, for example the fenders of two colliding cars lock together, then kinetic energy is not conserved and these collisions are often referred to as completely inelastic. In an isolated system the **momentum**, unlike the mechanical energy, is conserved regardless of whether the collision is elastic or inelastic.

Discussion question

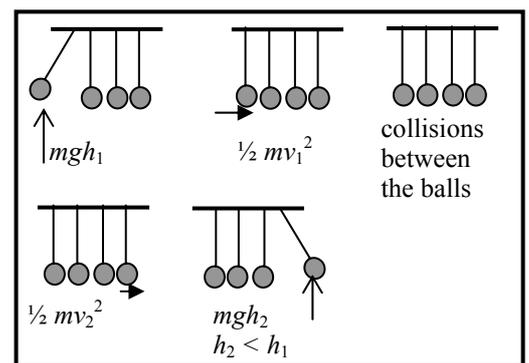
Collisions between cars are usually highly inelastic, as the cars deform and lose a lot of mechanical energy as heat and sound.

B. Activity Questions:

1. Newton's cradle – different balls

Steel balls have almost elastic collisions, in which both kinetic energy and momentum are conserved. The lead balls have inelastic collisions in which only momentum is conserved.

Both energy and momentum conservation are needed to explain the behaviour of the balls. Energy conservation is needed to account for the KE of the ball at the time of impact. The collisions obey conservation of momentum.

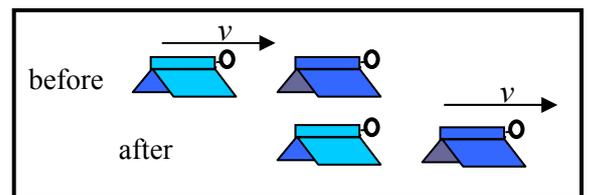


2. Air track

See opposite. The second, initially stationary, glider will move away. If the two gliders have equal masses the first glider will stop, transferring all its momentum to the second glider.

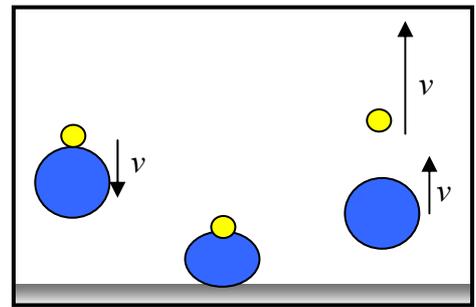
If the first glider has a smaller mass than the second it will bounce back, if it has a greater mass it will continue to move forward but at a lower speed.

The metal loops help make the collisions elastic and prevent the gliders sticking to each other.



3. Bouncing balls II

- a. The small ball held over the big ball bounces off higher as some momentum is transferred from the big ball to the small ball, increasing its velocity. Momentum has been conserved during the collision and the change in momentum of the small ball is large.
- b. If the balls are switched around the momentum is still conserved, but the transfer of momentum from the small to the big ball makes little difference to the big ball's velocity due to its large mass.



C. Qualitative Questions:

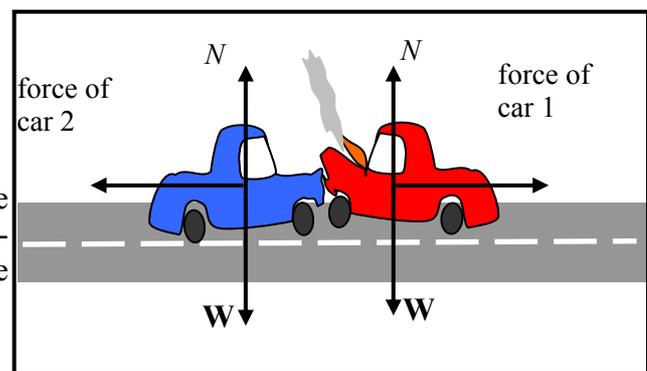
1. Cars colliding.

a. Two cars on an icy intersection is a better approximation of an isolated system than cars on a dry intersection because the external forces due to friction are very small, and the vertical forces (gravity and the normal force) balance. This means that the external forces are very small compared to the internal forces due to the collision, and the only important interactions are those between the cars.

b. See diagram. The forces are all internal forces, if the system is the two cars and the road. If you take the system as the two cars, then N and W are external forces, but they cancel out giving no *net* external force.

c. The normal and weight forces are conservative forces. The force of one car on the other is non-conservative. (Any frictional forces due to the road are also non-conservative.)

d. The net force on each car during the collision is that due to the other car.



2. Your hand must do work on the ball to change its kinetic energy from $\frac{1}{2}mv^2$ to 0. The work done is given by the force times the distance, so if you increase the distance over which your hand applies the force to stop the ball, the force required is less. If the force on the ball by your hand is less then the force by the ball on your hand will also be less. You can also consider this in terms of impulse – which is the change in momentum - $\Delta p = F\Delta t$ – make the time bigger then the force is smaller for the same Δp .

D. Quantitative Question:

At position A, the ball has no kinetic energy and potential energy = m_1gh

At position B, just before the collision, the ball's gravitational potential energy is zero and the kinetic energy is $\frac{1}{2}m_1v_{1i}^2$.

Using conservation of energy, $m_1gh = \frac{1}{2}m_1v_{1i}^2$

and $v_{1i} = \sqrt{2gh}$

$$= \sqrt{2 \times 9.8 \text{ m.s}^{-2} \times 10 \text{ m}} = 14 \text{ m.s}^{-1}$$

The collision is inelastic so we cannot use conservation of mechanical energy, but momentum is still conserved.

We know that the ball and car move off together, so from conservation of momentum : $m_1v_{1i} = (m_1 + m_2)v_f$

Rearranging we obtain

$$v_f = \frac{m_1 v_{1i}}{m_1 + m_2} = \frac{200\text{kg} \cdot 14\text{m.s}^{-1}}{200\text{kg} + 1000\text{kg}} = 2.33 \text{ m.s}^{-1}$$

