Collisions (L8)
- Collisions can be very complicated
- Two objects bang into each other and exert strong forces over short time intervals
- Fortunately, even though we usually do not know the details of the forces, we know from the 3rd law that they are equal and opposite.

Momentum and Collisions
- The concept of momentum is very useful when discussing how 2 objects interact.
- Suppose two objects are on a collision course. \( A \rightarrow B \)
- We know their masses and speeds before they hit
- The momentum concept helps us to see what can happen after they hit.

Conservation of Momentum
- One consequence of Newton’s 3rd law is that if we add the momentum of both objects before the collision it MUST be the same as the momentum of the two objects after the collision.
- This is what we mean by conservation: when something happens (like a collision) something doesn’t change — that is very useful to know because collisions can be very complicated!

Momentum, \( p \)
- Is mass times velocity \( p = m \times v \)
- A 1 kg object moving at 1000 m/s has the same momentum as a 1000 kg object moving at 1 m/s (\( p = 1000 \text{ kg m/s} \))
- If either objects gives its momentum to another object over the same time interval, they both exert the same force on that object

Football provides many collision examples to think about!

Colliding players exert equal forces and equal impulses on each other in opposite directions
Before the collision

- Momentum of running back is $100 \times 5 \text{ m/s} = 500 \text{ kg m/s}$
- Momentum of linebacker is $75 \times (-4 \text{ m/s}) = -300 \text{ kg m/s}$
- Total momentum is $500 - 300 = +200 \text{ kg m/s (to the right)}$

After the collision

Momentum of the two players before and after the collision is the same (200 kg m/s)

Momentum must be $200 \text{ kg m/s} = \text{ total mass } \times \text{ final velocity}$

$200 = 175 \times \text{ final velocity } \Rightarrow \text{ final velocity } = \frac{200}{175} = 1.14 \text{ m/s}$

to the right

elastic collisions

<table>
<thead>
<tr>
<th>before</th>
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<tbody>
<tr>
<td>after</td>
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momentum before = $m \ v$
momentum after = $m \ v$

inelastic collisions – objects stick together

<table>
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<tr>
<th>before</th>
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<tr>
<td>after</td>
<td>m</td>
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momentum before = $m \ v$
momentum after = $2m \ v/2 = m \ v$

How much momentum did the stationary object get in the collision?

- In the elastic collision the object that was initially at rest got a momentum = $m \ v$
- In the inelastic collision the object that was at rest got only $m \ v/2 \rightarrow$ half as much!
- This is another example of the fact that more force is involved between bouncy objects (elastic) compared to non-bouncy objects (inelastic)
non-violent collisions

• Two stationary ice skaters push off
• both skaters exert equal forces on each other
• however, the smaller skater acquires a larger speed than the larger skater.
• momentum is conserved!

Recoil

• The momentum before a gun is fired is zero.

Recoil in action → Rockets

hot gas ejected at very high speed

after the cannon is fired

After firing momentum = 0
Since the cannon ball goes to the right, the cannon must go to the left. The speed of the cannon ball is much larger than the recoil speed of the cannon because

\[ m_{\text{cannonball}} v_{\text{cannonball}} = m_{\text{cannon}} v_{\text{cannon}} \]
or small mass x big speed = big mass x small speed

Work and Energy

These terms have a common meaning in everyday language which are not the same as the physics definitions
If we have “energy” we can do things
Energy is the capacity to do work
But what is energy?

What is work?

• According to the physics definition, you are NOT doing work if you are just holding the weight above your head
• you are doing work only while you are lifting the weight above your head
Work requires two things

- 1) force
- 2) motion in the direction of the force

\[ \text{Work} = \text{force} \times \text{distance} = F \times d \]

If I carry a box across the room I do not do work on it because the force is not in the direction of the motion.

Who’s doin the work around here?

A ramp can reduce the force

\[ \text{WORK DONE} = \text{big force} \times \text{little distance} \text{ or little force} \times \text{big distance} \]

Ramps are useful machines!

- A machine is any device that allows us to accomplish a task more easily.
- It does not need to have any moving parts.
- Work = force \times distance

Kinetic energy

- If something moves in any way, it has kinetic energy.
- Kinetic energy is energy of motion.
- If I drive my car into a tree, the kinetic energy of the car can do work on the tree – it can knock it over.
Potential energy

- If I raise an object to some height \((h)\) it also has energy – potential energy.
- If I let the object fall it can do work.
- We call this gravitational potential energy\(= m \times g \times h = m \, g \, h\)
- the higher I lift the object the more potential energy it has.
- example: pile driver

Conservation of energy

- if something has energy it doesn’t loose it.
- It may change from one form to another (potential to kinetic and back).
- example – roller coaster.
- when we do work in lifting the object, the work is stored as potential energy.

Amusement park physics

- the roller coaster is an excellent example of the conversion of energy from one form into another.
- work must first be done in lifting the cars to the top of the first hill.
- the work is stored as gravitational potential energy.
- you are then on your way!

Up and down the track

- PE
- Kinetic Energy

If friction is not too big the ball will get up to the same height on the right side.

Loop-the-loop

- Here friction works to our advantage. Without it the ball slides rather than rolls.
- A ball won’t roll without friction!
- The ball must start at a height \(h\), at least \(2 \frac{1}{2}\) times \(R\) to make it through the loop.