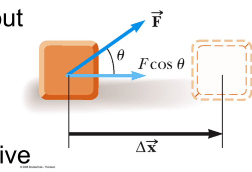
Period & Frequency

- Period (T): Time to complete one full rotation
- Frequency (f): Number of rotations completed per second.
- $f = 1/T$, $T = 1/f$
- $v = 2\pi R/T$

Work and Energy

- Work: $W = F \bullet d$ (picks out parallel components)
- F → Force on object
- d → displacement
- **Direction** of force relative to motion matters!



- Units: 1 Joule = 1 kg m^2/s^2

Energy

- Several different varieties of energy, depending on what the object is doing, where it is located, what it interacts with, etc.

- Kinetic Energy (motion): $KE = ½ mv^2$
- Rolling Kinetic Energy: $KE_{rot} = ½ I\omega^2$
- Gravitational Potential Energy: $U_g = mgh$
- Elastic Potential Energy (springs): $U_{sp} = ½ kx^2$
- All have the same units as work (Joules)

Methods of Energy Transfer:

- By work from a force
- By radiating heat
- By wave propagation (either physical waves or electromagnetic waves)

- All energy comes from/goes SOMEwhere! It's never destroyed, but can become less "useful".

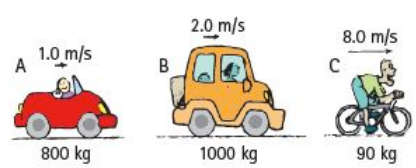
Work-KE Theorem

- Work is done on or by objects/systems
- Energy is an internal property that objects/ systems posess

$$W = \Delta KE$$
$$F \bullet d = ½ m_f v_f^2 – ½ m_i v_i^2$$

Work (+ or -) done on an object causes changes in its KE (increase or decrease).

Ranking: Which has the greatest kinetic energy?



Types of Forces

- There are two general kinds of forces
  - Conservative: Work and energy associated with the force can be recovered (Example: Gravity
  - Nonconservative: forces are dissipative and work done against it cannot easily be recovered (Example: Friction)

Conservative Forces

- A force is conservative if the work it does on an object moving between two points is **independent of the path** the objects take between the points
  - The work depends only upon the initial and final positions of the object
  - Any conservative force can have a potential energy function associated with it

More About Conservative Forces

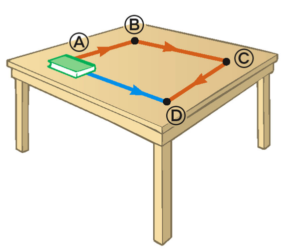
- Examples of conservative forces include:
  - Gravity
  - Spring force
  - Electromagnetic forces
- Potential energy is another way of looking at the work done by conservative forces

Nonconservative Forces

- A force is nonconservative if the work it does on an object **depends on the path** taken by the object between its final and starting points.
- Examples of nonconservative forces
  - kinetic friction, air resistance

Friction Depends on the Path

- The blue path is shorter than the red path
- The work required is less on the blue path than on the red path
- Friction depends on the path and so is a non-conservative force



Work-Energy Theorem, Extended

- The work-energy theorem can be extended to include potential energy:

$$W_{nc} = (KE_f - KE_i) + (PE_f - PE_i)$$

- If other conservative forces are present, potential energy functions can be developed for them and their change in that potential energy added to the right side of the equation

Conservation of Energy, cont.

- Total mechanical energy is the sum of the kinetic and potential energies in the system

$$E_i = E_f$$
$$KE_i + PE_i = KE_f + PE_f$$

  - Other types of potential energy functions can be added to modify this equation

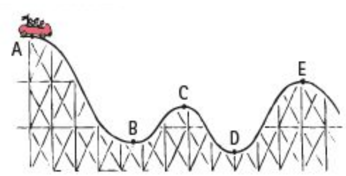
Problem Solving with Conservation of Energy

- Define the system
- Select the location of zero gravitational potential energy
  - Do *not* change this location while solving the problem
- Identify two points the object of interest moves between
  - One point should be where information is given
  - The other point should be where you want to find out something

Problem Solving, cont

- Verify that only conservative forces are present
- Apply the conservation of energy equation to the system
  - Immediately substitute zero values, then do the algebra before substituting the other values
- Solve for the unknown(s)

Example: Rollercoasters



- Where is the cart going the fastest?
- Could the cart ever get higher than point A on its own?

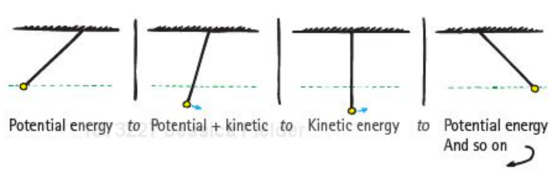
Example: Problem 7.24

A 0.14-kg pinecone falls 16m to the ground while feeling significant air resistance, where it lands with a speed of 13 m/s.

a. With what speed would the pinecone have landed if there had been no air resistance?
b. Did air resistance do positive or negative work on the pinecone?
c. How much work did air resistance do on the pinecone?

Conservation of Energy

- Energy cannot be created or destroyed; it may be transformed from one form into another or flow in/out of objects, but the total amount of energy never changes



Power

- Often also interested in the *rate* at which the energy transfer takes place
- *Power* is defined as this rate of energy transfer

$$P = \frac{W}{t}$$

- SI units are Watts (W), 1 W = 1 J/s

Momentum and Impulse

- Momentum: $\mathbf{p} = m\mathbf{v}$
- p has units of [kg m/s]
- $\mathbf{p}_{tot} = m_1\mathbf{v}_1 + m_2\mathbf{v}_2 + m_3\mathbf{v}_3 + \ldots$

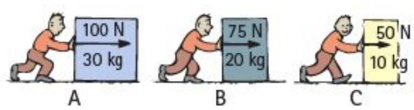
- Impulse: $\mathbf{I} = \mathbf{F}_{avg}\Delta t$
- Units of impulse: [kg m/s] → same as momentum!

Momentum-Impulse relationship

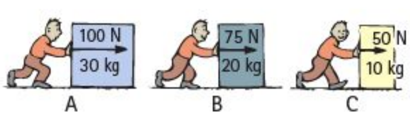
- Impulses cause changes in the momentum of an object or system:
- $\mathbf{F}_{avg}\Delta t = \mathbf{p}_f - \mathbf{p}_i$

- This is an alternative way of expressing the same concept in Newton's second law.
- Momentum is a vector quantity, so we can write this for x- and y- directions.

A crate is pushed across the floor for 3 seconds, starting at rest with net force shown. Which crate has the largest impulse delivered?



A crate is pushed across the floor for 3 seconds, starting at rest with net force shown. Which crate ends up with the fastest final speed?



Conservation of Momentum

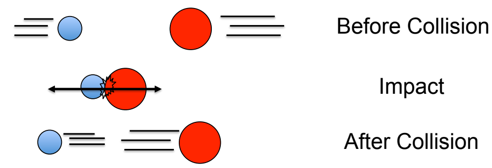
The principle of conservation of momentum states: When there is no net external force on a system of objects, the total momentum of the system does not change.

We say that the momentum of such a system is conserved since it does not change.

A 0.145 kg baseball is travelling at a speed of 30 m/s. The batter hits the ball, and the ball and the bat are in contact for 0.25 s. If the ball ends up going the same speed in the opposite direction, how strong was the force that the bat exerted on the ball?

Collisions

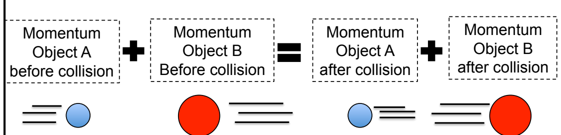
- When two objects collide, impulse is equal and opposite for the two objects if there is no net external force.



- Each object has equal and opposite change in momentum.
- The momentum of the system of 2 objects is conserved.

Collisions

- The change of momentum of the two objects in a collision is equal and opposite -- the momentum gained by one object is the amount lost by the other.

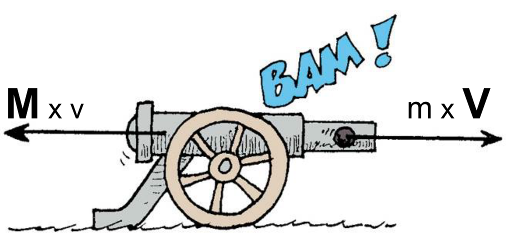


Collisions

1. Elastic collision: Objects rebound without deforming or generating heat
   – Billiard balls
2. Inelastic: objects hit, but deform and/or generate heat
   – Tennis ball being hit by a racket
3. Perfectly inelastic: Objects hit and stick together

- Momentum is conserved, whether collision is elastic or inelastic, as long as there's no net external force!

Recoil: Also explained by conservation of momentum



Momentum Example

Two hockey players, one 72 kg travelling at 2.3 m/s and the other 58 kg travelling at 3.1 m/s are skating towards each other. If the angle between their initial directions is 120º and they stick together after the collision, what is their speed after the collision?