Work and Mechanical Energy

Grade 11 Physics
Unit 4

Energy

- Kinetic Energy
  - The energy of motion
- Potential Energy
  - Energy that is stored
- Sound, light electrical energies all fit into one of these two categories.
- Focus on **Mechanical Energy for now**

Work

- Lifting boxes, work out, solving hard physics problems.
  - All requires energy
  - Need to be precise

Work (Cont.)

- Work (Not energy itself, otherwise we would call it energy)
  - Transfer of mechanical energy
  - Force x Displacement

$$W = F_{\parallel}\Delta d$$

Quantity	**Symbol**	**SI unit**
magnitude of the force (parallel to displacement)	$F_{\parallel}$	N (newton)
magnitude of the displacement	Δd	m (metre)
work done	W	J (joule)

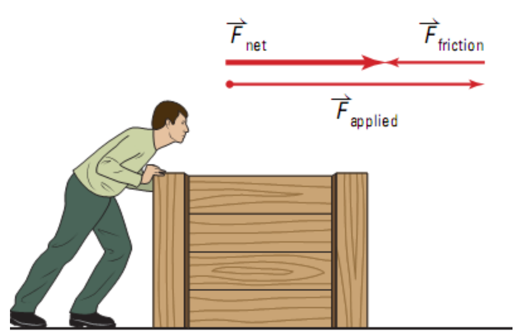
Work (Cont.)

$$W = F_{\|}\Delta d$$

Note: Both force and displacement are vector quantities, but their product, work, is a scalar quantity. For this reason, vector notations will not be used. Instead, a subscript on the symbol for force will indicate that the force is parallel to the displacement.

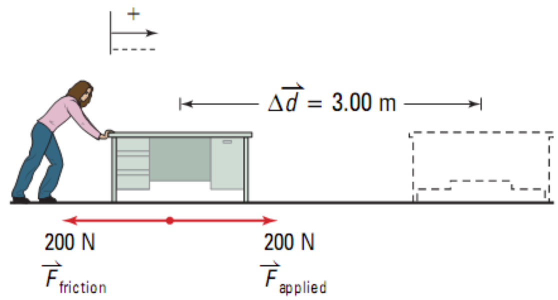
Work (Cont.)

- When we were determining the motion of objects in the previous lecture, we used the net force acting on the object. The **net force** is really **the vector sum** of all of the forces acting on the object when calculating work, we determine the work down by **one specific force**, not the net force unless otherwise stated.



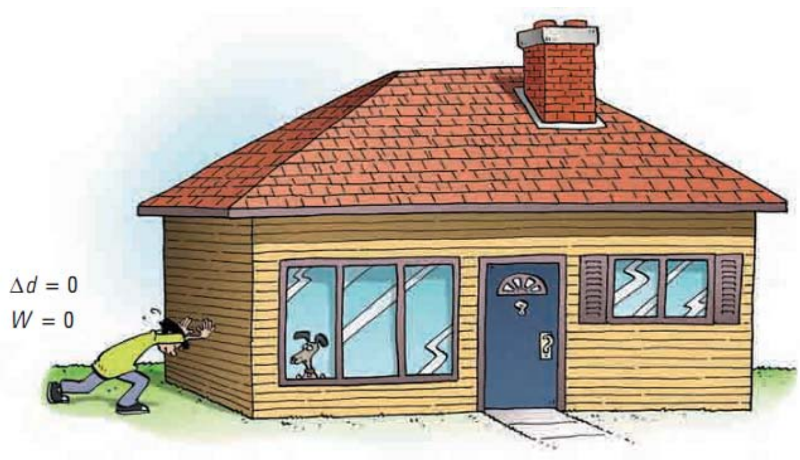
Example Problem

- EX1:
  - A Physics student is rearranging her room. She decides to move her desk across the room, a total distance of 3.00m. She moves the desk at a constant velocity by exerting a horizontal force of 2.00×10^2N. Calculate the amount of work the student did on the desk in moving it across the room.



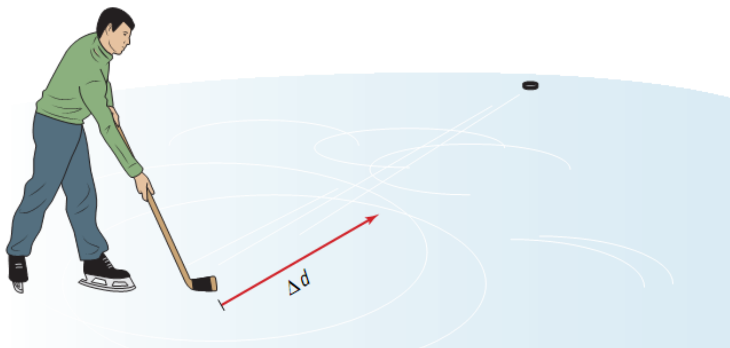
Work (Cont.)

- Counter intuitive case 1:
  - Applying a Force that Does Not Cause Motion.



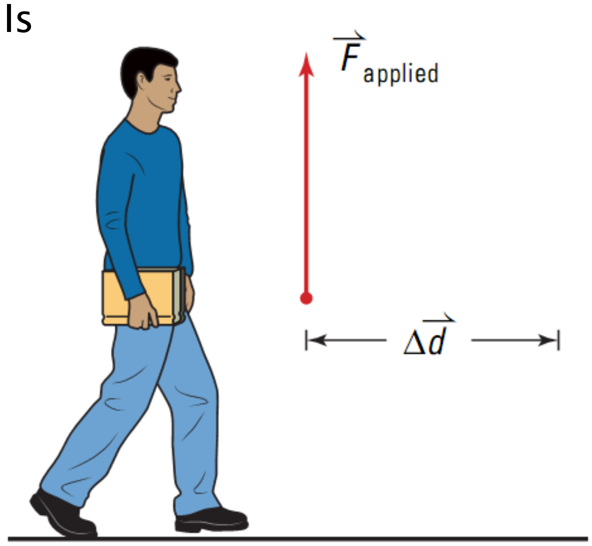
Work (Cont.)

- Counter intuitive case 2:
  - Uniform Motion in the Absence of a Force
    - Assume frictionless
    - Force is required to start the motion only



Work (Cont.)

- Counter intuitive case 3:
  - Applying a Force That Is Perpendicular to the Motion

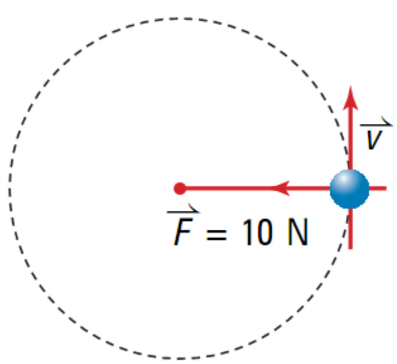


Work (Cont.)

- Counter intuitive case 4:
  - Applying a Force Which Causes the Object Goes Back to the Starting Point

Example Problem

- EX2:
  - A child ties a ball to the end of a 1.m string and swings the ball in a circle. If the string exerts a 10N force on the ball, how much work does the string do on the ball during a swing of one complete circle?

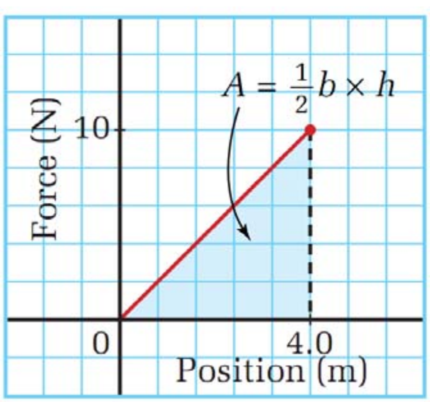


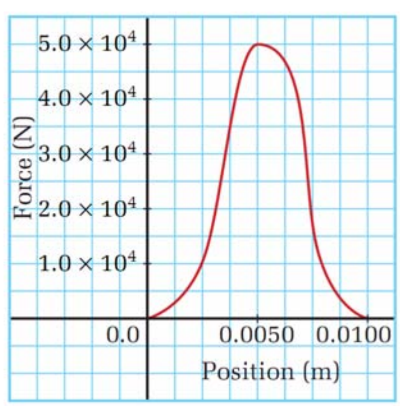
Example Problem

- EX3:
  - The Voyager space probe has left tour solar system and is travelling through deep space, which can be considered to be void of all matter. Assume that gravitational effects may be considered negligible when Voyager is far from our solar system.
    - How much work is done on the probe if it covers 1.00×10^{6}km travelling at 3.00×10^{4}m/s?
    - Explain the results obtained in part a).

Work (Cont.)

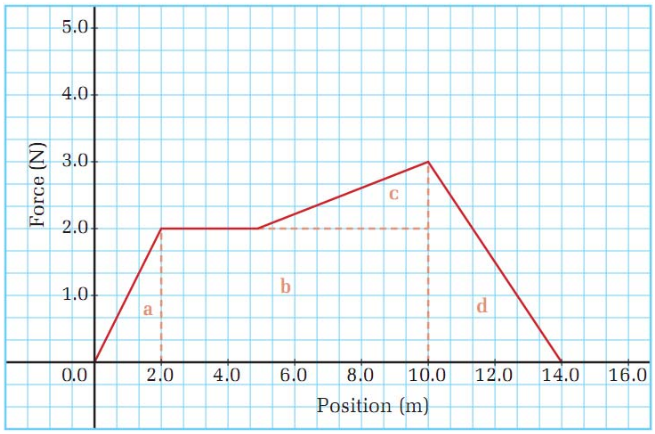
- Work Done by Various Forces.
  - Area under the curve (line) of a Force vs Displacement graph.





Example Problem

- EX4:
  - Determine the amount of work done by the changing force represented in the Force vs Position plot shown here.



Work (Cont.)

- Work on An Angle:

Work done when the force and displacement are *not* parallel and pointing in the same direction

$$W = F\Delta d \cos\theta$$

θ is the angle between the force and displacement vectors.

Note: Since work is a scalar quantity and only the magnitudes of the force and displacement affect the value of the work done, vector notations have been omitted.

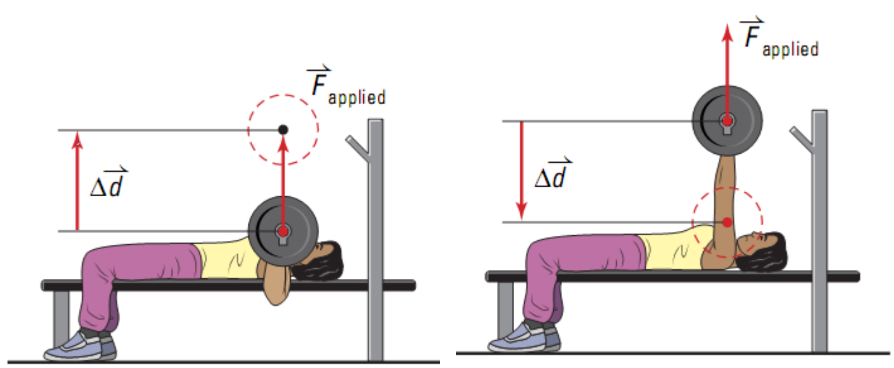
Work (Cont.)

- Negative Work
  - Reduces the energy of a object
  - Energy does not disappear
  - Lost to the surrounding in sound, light, thermal energy, etc.

- Positive Work
  - Adds energy to an object

Example Problem

- EX5:
  - Consider a weight lifter bench-pressing a barbell weighting 6.50×10^2N through a height of 0.55m. There are two distinct motions: (1) when the barbell is lifted up and (2) when barbell is lowered back down. Calculate the work done on the barbell during each of the two motions.



Kinetic Energy

- Kinetic Energy
  - The energy of motion
  - One half the product of an object's mass and the square of its velocity.

$$E_k = \frac{1}{2}mv^2$$

Quantity	Symbol	SI unit
kinetic energy	E_k	J (joule)
mass	m	kg (kilogram)
velocity	v	$\frac{m}{s}$ (metres per second)

Example Problem

- EX6:
  - A 0.200kg hockey puck, initially at rest, is accelerated to 27.0m/s. Calculate the kinetic energy of the hockey puck
    - At rest
    - In motion.

The Work-Kinetic Energy Theorem

- The Work-Kinetic Energy Theorem
  - State that work equals to changing kinetic energy

$$W = \Delta E_{\mathrm{k}}$$

$$\mathrm{W} = E_{\mathrm{k2}} - E_{\mathrm{k1}}$$

Example Problem

- EX7:
  - A Physics student does work on a 2.5kg curling stone by exerting 4.0x10N of force horizontally over a distance of 1.5m.
    - Calculate the work done by the student on the curling stone.
    - Assuming that the stone started from rest, calculate the velocity of the stone at the point of release. (Consider the ice surface to be effectively frictionless.)

Example Problem

- EX8:
  - A 75 kg skateboarder (including the board), initially moving at 8.0m/s, exerts an average force of 2.0×10^2N by pushing on the ground, over a distance of 5.0m. Find the new kinetic energy of skateboarder if the trip is completely horizontal.

Potential Energy

- Gravitational Potential Energy
  - Mass x Gravitational Acceleration x Height

$$E_g = mg\Delta h$$

Quantity	Symbol	SI unit
gravitational potential energy	E_g	J (joule)
mass	m	kg (kilogram)
acceleration due to gravity	g	$\frac{\text{m}}{\text{s}^2}$ (metres per second squared)
change in height (from reference position)	Δh	m (metre)

Example Problem

- EX9:
  - You are about to drop a 3.0kg rock onto a tent peg. Calculate the gravitational potential energy of the rock after you lift it to a height of 0.68m above the tent peg.

The Work-Potential Energy Theorem

- The Work-Potential Energy Theorem
  - State that work equals to changing potential energy

$$W = mg\Delta h_2 - mg\Delta h_1$$

$$W = E_{g2} - E_{g1}$$

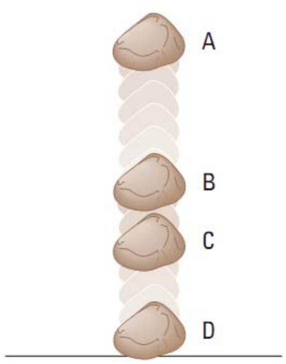
$$W = \Delta E_g$$

Example Problem

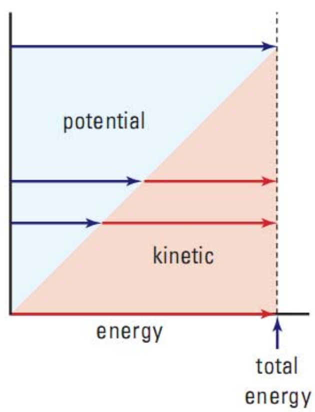
- EX10:
  - A 65.0kg rock climber did 1.60×10^4J of work against gravity to reach a ledge. How high did the rock climber ascend?

Conservation of Energy

- Conservation of Energy



Gravitational potential energy is being transformed into kinetic energy.



The graph shows the amount of potential and kinetic energy of the rock at different positions, up to the moment before it hits the ground.

Conservation of Energy (Cont.)

- Law of Conservation of Mechanical Energy
  - The total mechanical energy of a system always remains constant if work is done by conservative forces.

$$E_T = E_g + E_k$$

where $\begin{cases} E_T \text{ is the total mechanical energy of the system.} \\ E_g \text{ is the gravitational potential energy of the system.} \\ E_k \text{ is the mechanical kinetic energy of the system.} \end{cases}$

Example Problem

- EX11:
  - A crane lifts a car, with a mass of 1.5×10^3kg, at a constant velocity, to a height of 14m from the ground. It turns and drops the car, which then falls freely back to the ground. Neglecting air friction, find
    - The work done by the crane in lifting the car
    - The gravitational energy of the car at its highest point, in relation to the ground
    - The velocity of the car just before it strikes the ground after falling freely from 14m

Example Problem

- EX12:
  - A 65.0kg skydiver steps out from a hot air balloon that is $5.00x10^2$m above the ground. After free-falling a short distance, she deploys her parachute, finally reaching the ground with a velocity of 8.00m/s (approximately the speed with which you would hit the ground after having fallen for a distance of 3.00m).
    - Find the gravitational potential energy of the skydiver, relative to the ground, before she jumps
    - Find the kinetic energy of the skydiver just before she lands on the ground.
    - How much work did the non-conservative frictional force do?