Unit 5: Energy

Where does energy come from and where does it go?

What is Energy?

- Energy: The ability to do work
  - Energy is a SCALAR quantity
- Two main types of energy we will be dealing with in this class: kinetic and potential
- Kinetic Energy: energy of motion
- Potential Energy: stored energy

Kinetic Energy

- An object has kinetic energy when it is in motion

Definition of Kinetic Energy

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

Object A and B have the same speed, but A is twice as massive as B. How do their kinetic energies compare?

Object C and D have the same mass, but C is moving twice as fast as D. How do their kinetic energies compare?

The unit for kinetic energy is the Joule (J).

Potential Energy

- An object has gravitational potential energy due to its location in the Earth's gravitational field.

Definition of Gravitational Potential Energy

$$PE_g = mgh$$

- The height "h" is measured from an arbitrary zero level
- Heights above the zero level are positive; heights below the zero level are negative

The unit for potential energy is also the Joule (J).

- A 2-kg book sits on top of a 0.8-m tall table on the second story of a building. The floor of the second story is 4 meters above the ground. What is the potential energy of the book (a) relative to the second floor? (b) relative to the ground?

(a) $PE_g = mgh = (2\text{ kg})(9.8\text{ m/s}^2)(0.8\text{ m}) = 15.68\text{ J}$

(b) $PE_g = mgh = (2\text{ kg})(9.8\text{ m/s}^2)(4.8\text{ m}) = 94.08\text{ J}$

- The book is dropped out a window and lands on the ground. What is the potential energy of the book (a) relative to the second floor? (b) relative to the ground?

(a) $PE_g = mgh = (2\text{ kg})(9.8\text{ m/s}^2)(-4\text{ m}) = -78.4\text{ J}$

(b) $PE_g = mgh = (2\text{ kg})(9.8\text{ m/s}^2)(0\text{ m}) = 0\text{ J}$

Regardless of reference level, the change in Potential Energy between the two heights is the SAME ($\Delta PE = -94.08$ J)!

Work: A Physics Concept

- Work: the transfer of energy from one object to another or from one form to another
- When a force "*F*" causes a displacement "*s*", we say that work has been done

Definition of Work

$$W = (F\cos\theta)s$$

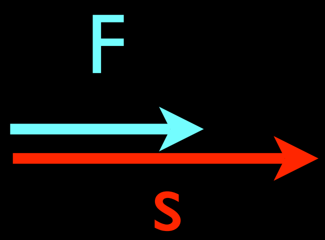
Units:
$N \cdot m$ = Joule (J)

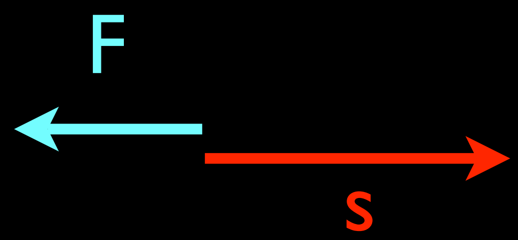
W: Work done
F: Magnitude of force applied
s: Magnitude of displacement
θ: Angle between force and displacement

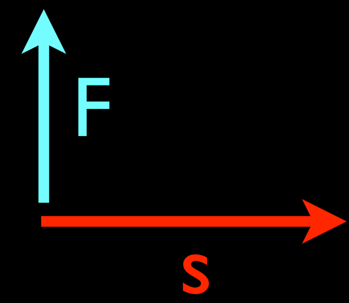
Work: A Physics Concept

- What role does the angle play?

$$W = (F\cos\theta)s$$







θ = 0 degrees

$\cos\theta = 1$

Work is Positive

θ = 180 degrees

$\cos\theta = -1$

Work is Negative

θ = 90 degrees

$\cos\theta = 0$

Work is Zero

- A 30-kg suitcase is pulled by a horizontal force of 45 N across a horizontal distance of 75 m.
  (a) How much work is done by the horizontal force?

  (b) How much work is done by gravity?

  (c) How much work would the 45-N force do if it was at an angle of 50 degrees above horizontal?

(a) $W = (F\cos\theta)s$ = (45 N)(1)(75 m) = 3375 J

(b) $W = (F\cos\theta)s$ = 0 (angle between F and s is 90)

(c) $W = (F\cos\theta)s$ = (45 N)(cos 50)(75 m) = 2170 J

- A 120-kg crate accelerates at a rate of +1.5 m/s^2 while undergoing a displacement of +65 m. How much total work is done on the crate?

To find the total (net) work done on an object, we use the net force ($\sum F$) in the definition of work.

$$\sum F = ma = 180 \text{ N}$$

$$W_{NET} = (\sum F \cos\theta)s = (180 \text{ N})(1)(65 \text{ m}) = 11700 \text{ J}$$

You could also find the individual work done by each force, then add to get net work!

What does Work have to do with Energy?

- The total work done on an object by a net external force is equal to that object's change in kinetic energy.

Work-Energy Theorem

$$W_{NET} = \Delta KE$$

- The work-energy theorem can be used to solve dynamic problems more simply.

- A 0.075-kg arrow is fired horizontally. The bowstring exerts a net horizontal force of 65 N on the arrow over a horizontal distance of 0.90 m. With what speed does the arrow leave the bow?

$$W_{NET} = (\sum F\cos\theta)s = (65\text{ N})(1)(0.90\text{ m}) = 58.5\text{ J}$$

$$W = \Delta KE$$

$$58.5\text{ J} = KE_f - 0$$

$$KE_f = 58.5\text{ J}$$

$$58.5\text{ J} = \frac{1}{2}mv_f^2 \rightarrow v_f = 39.5\text{ m/s}$$

- A 5-kg book is released from rest from the top of a 10-m tall building. Use the work-energy theorem to determine the speed of the book the moment before it hits the ground.

$\sum F = Weight = 49 \text{ N}$

$W_{NET} = (\sum F \cos \theta)s = (49 \text{ N})(1)(10 \text{ m}) = 490 \text{ J}$

$$W_{NET} = \Delta KE$$

$$490 \text{ J} = KE_f - 0$$

$$490 \text{ J} = \frac{1}{2} m v_f^2 \quad \rightarrow \quad v_f = 14.0 \text{ m/s}$$

- An 80-kg bungee jumper drops from a 182-m high platform. If the jumper falls to within 68 m of the ground, how much work is done by the bungee cord on the jumper during his descent?

-8.94×10^4 J (–89.4 kJ)

- Suppose that durng the jumper's descent, at a height of 111 m above the ground, the cord has done –21.7 kJ of work on the jumper. What is the jumper's speed at that moment?

29.1 m/s

- A 6-kg crate is initially at rest on a 25° inclined plane. After sliding 3.2 m down the ramp, the crate is traveling at 4.4 m/s. Determine the amount of work done by each force exerted on the crate.

$$W_{NET} = \Delta KE$$

$$W_{NET} = KE_f - 0$$

$$W_{NET} = 58.1\ \text{J}$$

$$W_{gravity} = (F_g \cos\theta)s = (58.8\ \text{N})(\cos 65°)(3.2\ \text{m}) = 79.5\ \text{J}$$

$$W_{normal} = (F_N \cos\theta)s = (F_N)(\cos 90°)(3.2\ \text{m}) = \text{Zero}$$

$$W_{friction} = W_{NET} - W_{gravity} = -21.4\ \text{J}$$

Conservation of Energy

- "Energy cannot be created or destroyed, but it can be converted from one form to another."
- In the absence of non-conservative forces (such as friction), the total mechanical energy (KE + PE) in a system remains constant.
  - The glider's PE was converted into KE.

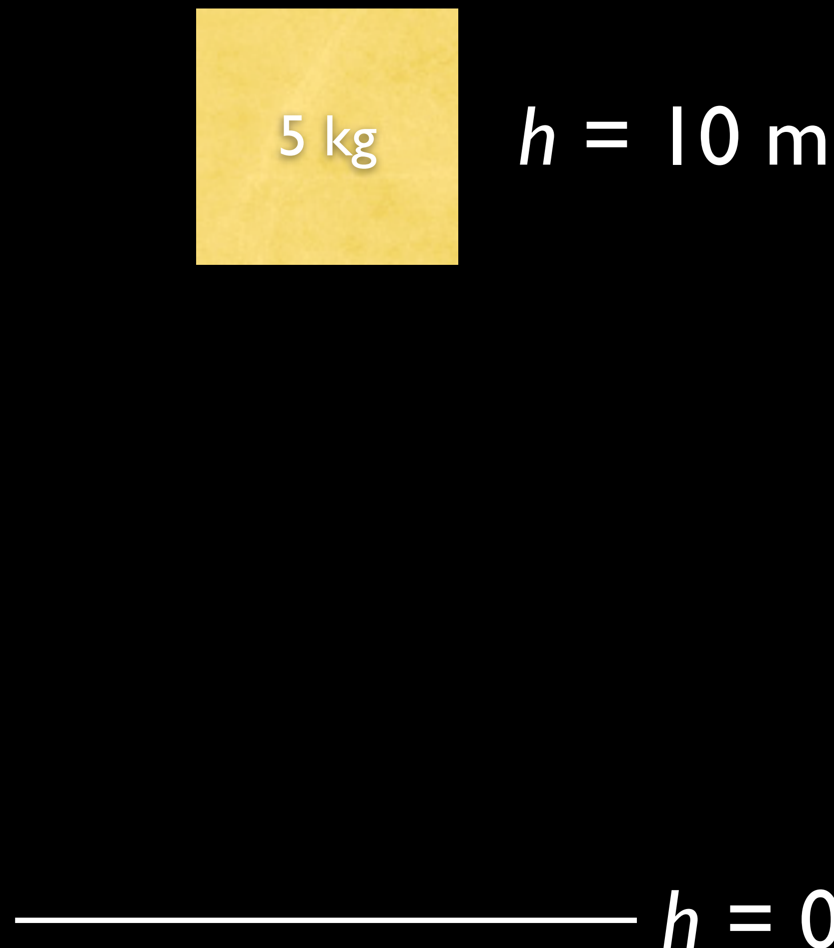
Conservation of Energy

Energy Before = Energy After

$$KE_i + PE_i = KE_f + PE_f$$

Using Conservation of Energy

- A 5-kg block is dropped from a height of 10 m. How fast is it going right before hitting the ground?



Energy before = Energy after

$$\cancel{KE_i} + PE_i = KE_f + \cancel{PE_f}$$

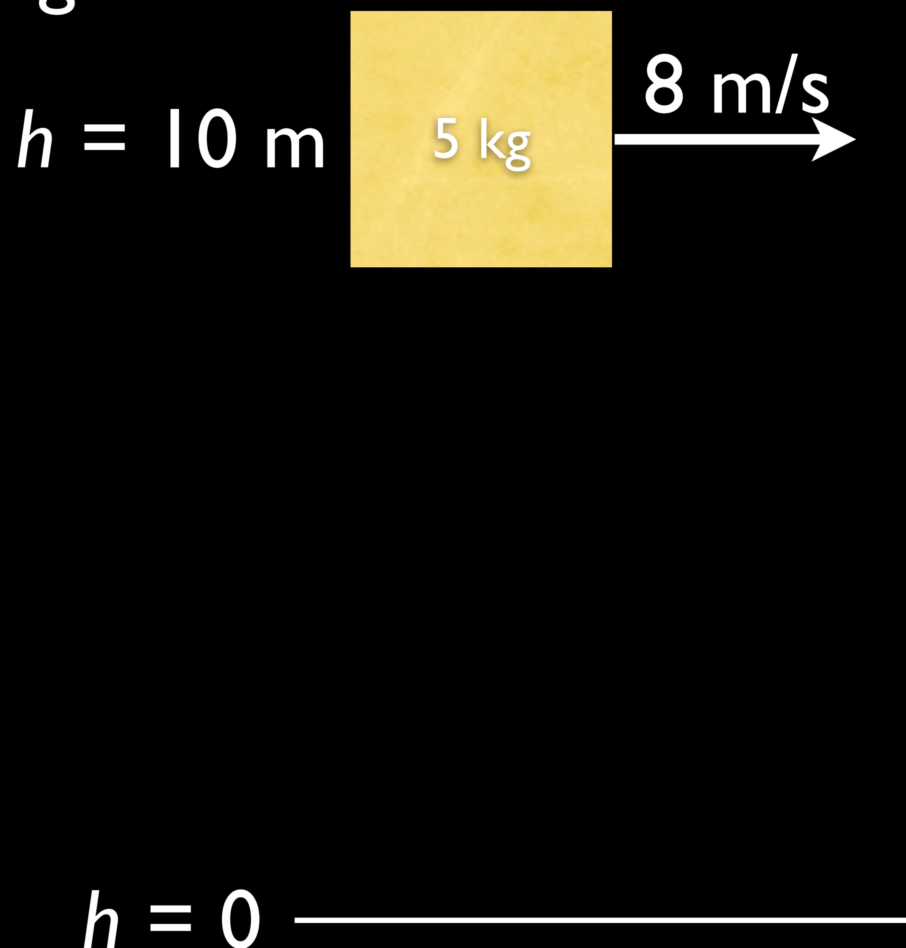
$$(mgh)_i = \left(\frac{1}{2}mv^2\right)_f$$

$$490\text{ J} = \left(\frac{1}{2}mv^2\right)_f$$

$$14\text{ m/s} = v_f$$

Using Conservation of Energy

- A 5-kg block is thrown horizontally from a height of 10 m. Its initial speed is 8 m/s. How fast is it going right before hitting the ground?



Energy before = Energy after

$$KE_i + PE_i = KE_f + \cancel{PE_f}$$

$$(\frac{1}{2}mv^2)_i + (mgh)_i = (\frac{1}{2}mv^2)_f$$

$$160\text{ J} + 490\text{ J} = (\frac{1}{2}mv^2)_f$$

$$16.1\text{ m/s} = v_f$$

Using Conservation of Energy

- A 5-kg block starts at rest at the top of a frictionless inclined plane. The plane has a length of 10 m and is inclined at 30 degrees. How fast is the block moving when it reaches the bottom of the ramp?

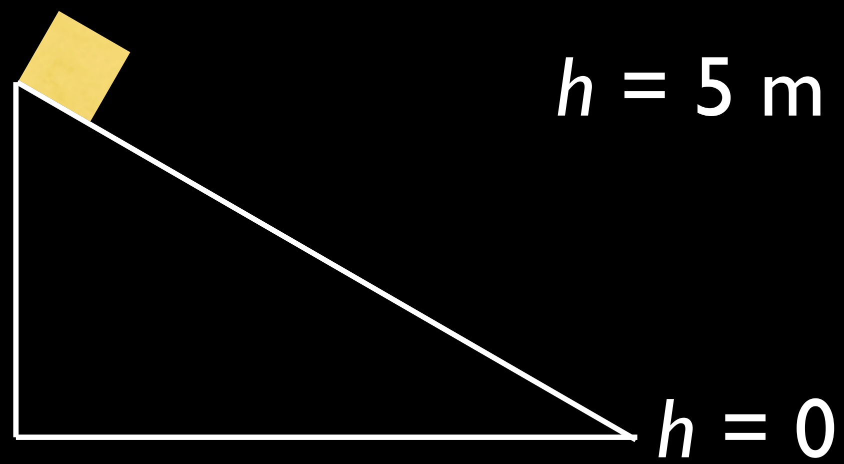
Energy before = Energy after

$$\cancel{KE_i} + PE_i = KE_f + \cancel{PE_f}$$

$$(mgh)_i = (\frac{1}{2}mv^2)_f$$

$$245\text{ J} = (\frac{1}{2}mv^2)_f$$

$$9.90\text{ m/s} = v_f$$



Using Conservation of Energy

- A certain pendulum consists of a 20-kg mass on the end of a 1.5-m long string. The mass is pulled back until it is 0.4 m above its lowest position, and is then released. What is the mass's speed at the lowest position in its swing?

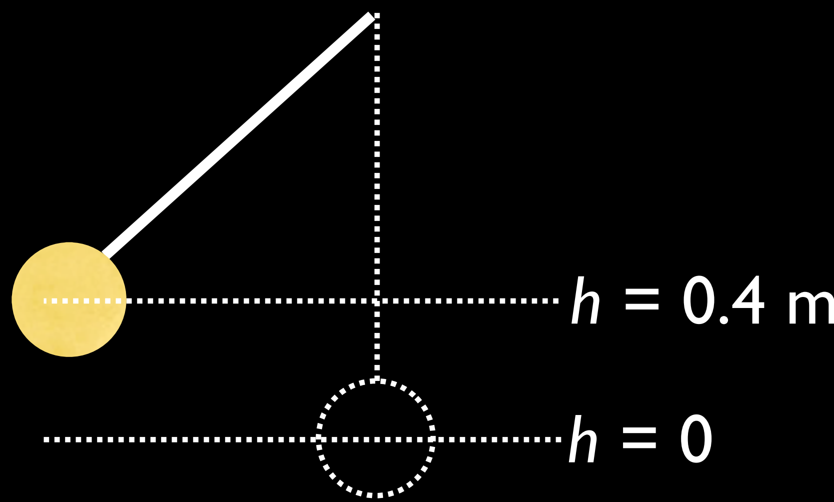
Energy before = Energy after

$$\cancel{KE_i} + PE_i = KE_f + \cancel{PE_f}$$

$$(mgh)_i = (\frac{1}{2}mv^2)_f$$

$$78.4\text{ J} = (\frac{1}{2}mv^2)_f$$

$$2.80\text{ m/s} = v_f$$



- One of the tallest and fastest roller coasters in the world is the Steel Dragon in Mie, Japan. The ride includes a vertical drop of 93.5 m. The coaster has a speed of 3.0 m/s at the top of the drop. Assume friction is negligible and find the speed of the riders at the bottom.

Energy before = Energy after

$$KE_i + PE_i = KE_f + PE_f$$

$$(\frac{1}{2}mv^2)_i + (mgh)_i = (\frac{1}{2}mv^2)_f$$

Mass cancels out!

$$\sqrt{(v_i^2 + 2gh_i)} = v_f$$

$$42.9 \text{ m/s} = v_f$$