

# Ch 5 Work and Energy

Conceptual Question: 5, 6, 9, 14, 18

Problems: 1, 2, 3, 8, 9, 10, 13, 15, 21,  
23, 30, 32, 41, 42, 69, 77

# Work and Energy

Work done on an object by a force is:

$$W = F\Delta x$$

SI units Joule (J) = Newton meter =  $\text{kg m}^2/\text{s}^2$

Work is a scalar

# Work

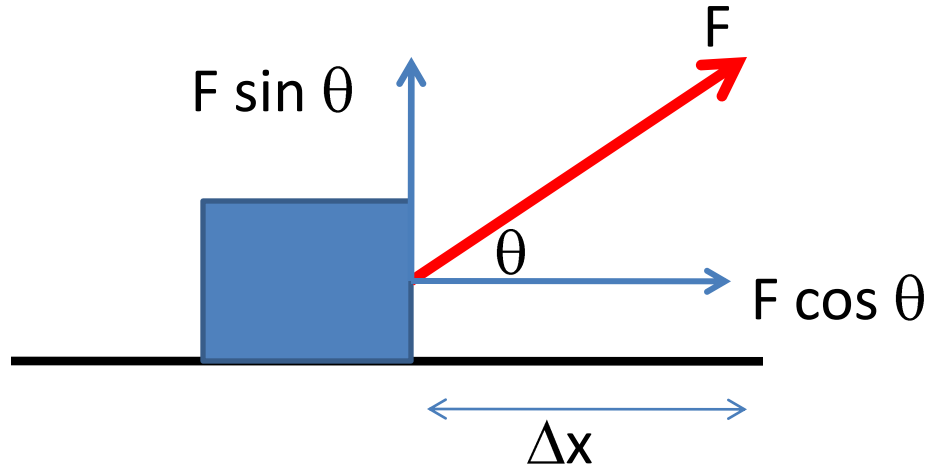
- $W = F\Delta x$

Work depends on displacement

If there is no displacement, there is no work.

- If you are holding a book still in the air, you are doing no work
- If you are sitting in a chair, gravity is doing no work.

Only components of forces parallel to the displacement do work.



$$W = (F \cos \theta) \Delta x$$

The vertical component does no work.

$$W = (F \cos \theta) \Delta x$$

In this definition:

$F$  and  $\Delta x$  are magnitudes, are always positive

The work will be positive or negative based on the  $\cos \theta$ .

# Example

A 500 N force directed 30 degrees above the horizontal is used to pull a 50 kg sled across the ground. The coefficient of friction between the sled and the ground is 0.3. The sled is pulled 5 meters.

- a) What is the work done by the pulling force
- b) work done by friction.
- c) work done by the normal force
- d) work done by gravity

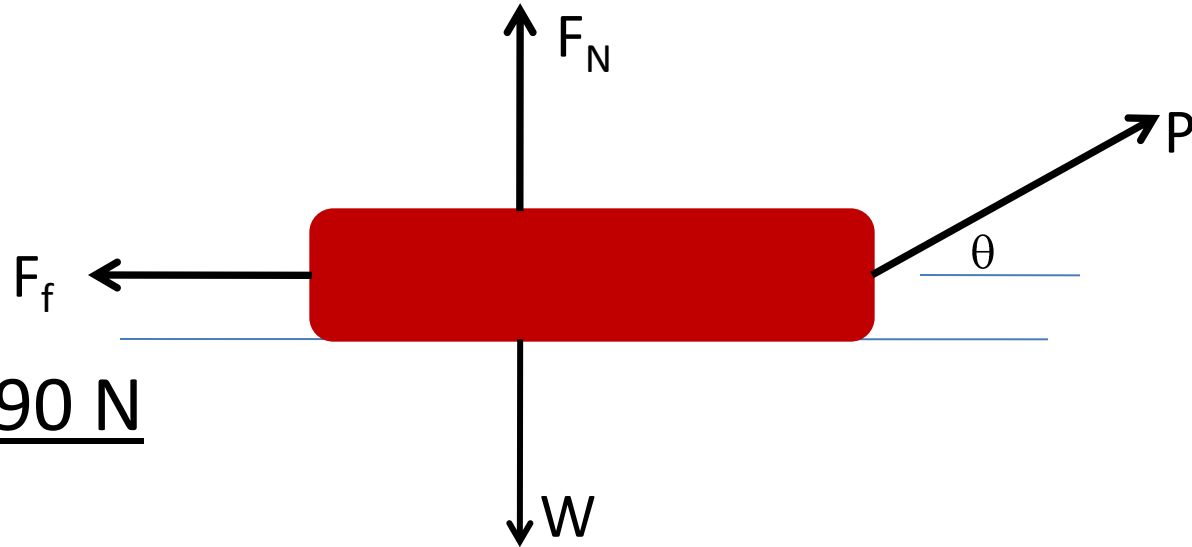
$$P = 500 \text{ N}, \quad \theta = 30^\circ$$

$$m = 50 \text{ kg}$$

$$\mu = 0.3$$

$$\Delta x = 5 \text{ m}$$

$$W = mg = \underline{490 \text{ N}}$$



$$F_N + P_y = W$$

$$F_N = W - P_y = mg - 500 \text{ N} (\sin 30)$$

$$F_N = (50 \text{ kg})g - 250 \text{ N} = \underline{240 \text{ N}}$$

$$F_f = \mu F_N = 0.3 * 240 \text{ N} = \underline{72 \text{ N}}$$

$$W = (F \cos \theta) \Delta x$$

Work by pulling force:

$$W_p = (500 \text{ N} \cos 30) 5 \text{ m} = 2165 \text{ J}$$

Work by friction:

$$W_f = (72 \text{ N} \cos 180) 5 \text{ m} = -360 \text{ J}$$

Work by normal force:

$$W_N = (240 \text{ N} \cos 90) 5 \text{ m} = 0 \text{ J}$$

Work by gravity:

$$W_g = (490 \text{ N} \cos 270) 5 \text{ m} = 0 \text{ J}$$

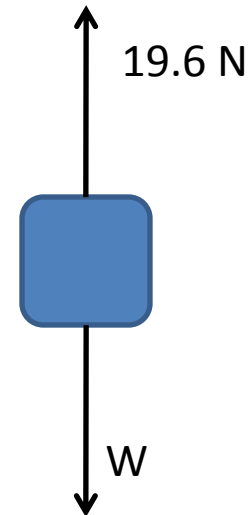
# Example

You lower a bucket down a well, with constant velocity a distance of 8 meters. You exert a constant force of 19.6 N. The bucket has a mass of 2 kg. Find the work done by you, and the work done by gravity.

$$W = mg$$

$$W = (2\text{kg}) g$$

$$W = 19.6 \text{ N}$$



The displacement is down the well.

$$W = (F \cos \theta) \Delta x$$

Your work:  $W_y = (19.6 \text{ N} \cos 180) 8\text{m}$

$$W_y = -156.8 \text{ J}$$

Work by gravity:  $W_g = (19.6 \text{ N} \cos 0) 8\text{m}$

$$W_g = 156.8 \text{ J}$$

Notice that the work done by gravity was  $mgh$ , where  $h$  is the change in height.

# Work-Energy Theorem

- The net work on an object is equal to the object's change in kinetic energy.
- Easy way to find the speed of an object.

# Kinetic Energy

- Kinetic energy is energy an object has due to its motion.
- Units are Joules
- Kinetic energy is always positive.
- $K = \frac{1}{2} mv^2$

Example. A 1 kg ball is thrown with  $v = 20 \text{ m/s}$

$$K = \frac{1}{2} (1\text{kg})(20\text{m/s})^2 = 200 \text{ J}$$

# Work-Energy Theorem

Use:  $W_{\text{net}} = F_{\text{net}}\Delta x = (ma)\Delta x$

Also  $v^2 = v_0^2 + 2a\Delta x$

rewrite as  $a\Delta x = (v^2 - v_0^2)/2$

$$W_{\text{net}} = m (v^2 - v_0^2)/2$$

$$W_{\text{net}} = \frac{1}{2} mv^2 - \frac{1}{2} mv_0^2 \quad \text{or} \quad W_{\text{net}} = \Delta K$$

The net work is equal to the change in kinetic energy.

$$W_{\text{net}} = \frac{1}{2} mv^2 - \frac{1}{2} mv_0^2$$

If the net work is positive, the kinetic energy increases. The speed increases.

If the net work is negative, the kinetic energy decreases. The speed decreases.

# Sled example

A 500 N force directed 30 degrees above the horizontal is used to pull a 50 kg sled across the ground. The coefficient of friction between the sled and the ground is 0.3. The sled is pulled 5 meters.

Find the final velocity of the sled.

Assume the sled starts at rest.

Work by pulling force:

$$W_p = (500 \text{ N} \cos 30) 5 \text{ m} = 2165 \text{ J}$$

Work by friction:

$$W_f = (72 \text{ N} \cos 180) 5 \text{ m} = -360 \text{ J}$$

$$W_{\text{net}} = 2165 - 360 \text{ J} = 1805 \text{ J}$$

$$\Delta K = 1805 \text{ J}$$

$$\Delta K = K_f - K_0$$

Since sled starts at rest,  $K_0 = 0 \text{ J}$

$$K_f = 1805 \text{ J} = \frac{1}{2} (50 \text{ kg}) v^2$$

$$v^2 = 2(1805 \text{ J}) / (50 \text{ kg}) = (72.2 \text{ m/s})^2$$

$$\underline{v = 8.5 \text{ m/s}}$$

# Bucket example

- In this example it was stated that the bucket is lowered at constant velocity.
- So  $\Delta K = 0 \text{ J}$                        $W_{\text{net}} = 0 \text{ J}$
- Your work =  $-156.8 \text{ J}$
- $W_{\text{g}} = 156.8 \text{ J}$
- $W_{\text{net}} = 0 \text{ J}$

# Example: leaving skid marks

- A car with velocity  $v$  skids a distance  $d$  after the brakes lock.
- Estimate how far it skids if the velocity is  $2v$ .

Use work-energy theorem

Assume the braking force is equal for both skids.

$$W = \Delta K = \frac{1}{2} mv^2 - \frac{1}{2} mv_0^2 ,$$

$$-F_f \Delta x = -\frac{1}{2} mv_0^2$$

if  $v_0$  is doubled,  $\Delta x$  is multiplied by 4

# Conservative and Nonconservative forces

- Conservative forces. IF you do work against a conservative force, that work is recoverable. It can be converted into kinetic energy
- Examples: gravity, electric force, spring force.
- If you climb a ladder, you did work against gravity. When you jump off and fall to the ground, that work is converted to kinetic energy.
- Conservative forces are path independent. Only the endpoints are important.

# Nonconservative Forces

- These forces are dissipative.
- Work done by nonconservative forces cannot be recovered.
- Example: friction
- The work is turned into 'waste' energy such as heat or sound.
- They are path dependent

# Potential energy

- Energy that is 'stored up' by doing work against a conservative force.
- Gravitational potential energy.
- Spring potential energy.
- Unit is also the Joule (J)

# Gravitational potential energy

When you raise an object, you are doing work against gravity. That work is then stored as potential energy. If you drop the object, the potential energy is then transferred to kinetic energy.

$$PE = \text{mass} * g * \Delta y \quad \Delta y \text{ is the change in height}$$

## Reference level/zero of potential energy

If an object is above the line of zero potential energy, it has positive potential energy.

If an object is below that height, the object has negative potential energy.

You can set the zero of potential energy wherever you want. Place it in a location that is convenient to the problem.

# Conservation of mechanical energy

Not an equation. This is a rule.

Possibly the most important rule in the universe.

When no dissipative forces are involved, the sum of the kinetic and potential energies is constant.

$$KE_i + PE_i = KE_f + PE_f$$

Energy is passed between the kinetic and potential forms.

# Simple example of cons. of energy.

- A rock is on the edge of a 10 meter high cliff. You can find the speed it hits the ground.

When rock is sitting on cliff it has no kinetic energy, but it has potential energy.

When rock is hitting the ground, that potential energy was transferred to kinetic energy.

$$\Delta y = 10\text{m}$$

$$\text{mass} = 50 \text{ kg}$$

$$KE_i + PE_i = KE_f + PE_f$$

$$0 + PE_i = KE_f + 0$$

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

$$(50\text{kg})g (10\text{m}) = \frac{1}{2} (50\text{kg})v^2$$

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

Notice the mass canceled out. This is why, neglecting air resistance, all falling bodies accelerate the same because of gravity.

A skier is skiing 20 m/s on level ground when the ground begins to slope downward. If the vertical drop is 10 meters, how fast is the skier moving at the bottom of the slope?

$$KE_i + PE_i = KE_f + PE_f$$

$$KE_i + PE_i = KE_f + 0$$

$$\frac{1}{2} m (20\text{m/s})^2 + mg(10\text{m}) = \frac{1}{2} mv^2$$

$$\frac{1}{2} (20\text{m/s})^2 + g(10\text{m}) = \frac{1}{2} v^2$$

$$v = 24.4 \text{ m/s}$$