Physics Chapter 5

Work and Energy
Work

- Work - (if force is constant) - is the product of the force exerted on an object and the distance the object moves in the direction of the force.

\[ W = F_{\parallel}d \]
✓ Work is a scalar quantity and can be positive or negative, but you don’t have to indicate direction/angle in your answer.
✓ Unit is Joule (N•m)
✓ The object must **MOVE** in the **DIRECTION** (positive or negative) that the force is exerted on **THE OBJECT**.
  ➢ *Holding a flag in the air (no work on the flag)*
  ➢ *Walking forward while holding the flag in the air (no work on flag)*
Work and Direction of Force

✓ If force is applied at an angle, then the work must be computed using the component of force in the direction of the motion.

➢ Ex: you are pushing a lawnmower...
Work and Direction of Force

Force (parallel to ground) doing work is $F \cos \theta$

- Work ($W$) = $F \cos \theta d = F d \cos \theta$
- Work that the grass/lawn is doing on the mower = $F_{\text{friction}} d$
Example

How much work is done on a vacuum cleaner pulled 4.0 meters by a force of 45 N at an angle of 30.0 degrees above horizontal?

Here’s the equation: \( W = F \parallel d = F \cos \theta d = F d \cos \theta \)

\[ W = F \parallel d = F \cos \theta d = 45N \cos 30 \times 4.0 \text{ m} = 156 \text{ Joules} \]
\[ W_{\text{grav}} = mg \sin \theta d \]

Or \[ W_{\text{grav}} = mgd \]
if lifted vertically
Gravity Example

✓ How heavy is a barrel that is lifted 45 meters vertically using 670 joules of work?
✓ Formula for work done against gravity.
✓ $W_{\text{against grav}} = -W_{\text{by grav}} = -mgd$
✓ $670J = -mgd$
✓ $m = -670J/(gd) = -670/(-9.81\text{m/s}^2\times45\text{m}) = 1.5 \text{ kg}$
Practice 5A page 170
Energy - an object has energy if it can produce a change in itself or its surroundings.

Kinetic Energy - energy due to the motion of an object.

KE = 1/2mv^2
Doing Work to Change Kinetic Energy

✓ Kinetic Energy is related to the amount of work done on the object.

➢ Work done equals the KE gained by the object.
A 7.0 kg bowling ball moves at 3.00 m/s. How much kinetic energy does the bowling ball have? How fast must a 2.45 g ping pong ball move in order to have the same kinetic energy as the bowling ball?
Known, unknowns and formulas

✓ \( m_{bb} = 7.0 \text{kg} \)
✓ \( V_{bb} = 3.00 \text{m/s} \)
✓ \( m_{ppb} = 2.45 \text{g} = 0.00245 \text{kg} \)
✓ \( KE_{bb} = \frac{1}{2}m_{bb}v_{bb}^2 = KE_{ppb} = \frac{1}{2}m_{ppb}v_{ppb}^2 \)
Solve for Kinetic Energy of Bowling Ball

\[ KE_{bb} = \frac{1}{2} m_{bb} v_{bb}^2 = \frac{1}{2} (7.0\, \text{kg})(3.00\, \text{m/s})^2 = 31.5\, J = 32\, J \]
Solve for \( v_{ppb} \) with KE of Bowling Ball

\[ KE_{bb} = 32J = KE_{ppb} = \frac{1}{2}m_{ppb}v_{ppb}^2 \]

\[ v_{ppb} = \sqrt{\frac{32J}{\frac{1}{2}m_{ppb}}} \]

\[ v_{ppb} = \sqrt{\frac{32J}{\frac{1}{2}(0.00245\text{kg})}} \]

\[ v_{ppb} = 160\text{m/s} \]
Example 2

What is the speed of a 0.20 kg baseball that has a Kinetic Energy of 390 Joules?

\[ KE = \frac{1}{2} mv^2 \]

\[ v = \sqrt{\frac{2KE}{m}} \]

\[ v = \sqrt{2 \left( \frac{390 \text{ J}}{0.20 \text{ kg}} \right)} = 62 \text{ m/s} \]
Example 3

What is the mass of a satellite traveling at 92 km/h with a kinetic energy of 240,000 J

KE = 240,000, v=92km/h

92km/h X 1000 / 3600 = 26m/s

KE=1/2mv^2, m=2KE/v^2

m=2(240,000J)/(26m/s)^2 = 710kg
5B page 174

✓ Also, pg. 171 4–6 only
The Work-Energy Theorem

✓ As positive work is done on an object (lifting a box), energy is transferred to that object (it can now fall and crush something).

✓ As negative work is done on an object (lowering a box), energy is transferred from the object to the one lowering the box.
The Work-Energy Theorem

✓ The net work done on an object is equal to its change in kinetic energy.

\[ W_{\text{net}} = KE_f - KE_i = \Delta KE \]

✓ If the net work is positive, the kinetic energy increases.

✓ If the net work is negative, the kinetic energy decreases.
Example pg. 175

✓ On a frozen pond, a person kicks a 10.0 kg sled, giving it an initial speed of 2.20 m/s. How far does the sled move if the coefficient of kinetic friction between the sled and the ice is 0.10?
Known, unknowns and formulas

✓ $m_s = 10.0\, \text{kg}$
✓ $V_s = 2.20\, \text{m/s}$
✓ $\mu_k = 0.100$
✓ $K_{E_f} = 0$
✓ $F_{\text{net}} = F_k$...the only force working once the sled is kicked, but it is NEGATIVE in direction!!

✓ $F_{\text{net}} = -F_k = -\mu_k \, F_n = -\mu_k \, mg$
✓ $W_{\text{net}} = -F_k \, d = K_{E_f} - K_{E_i}$
✓ $-\mu_k \, mg \, d = -K_{E_i} = -1/2m_s v_s^2$
Solve for $d$

✓ $\mu_k \ mg \ d = -\frac{1}{2}m_s v_s^2$

✓ $d = -\frac{1}{2}m_s v_s^2 / - (\mu_k \ mg) = -\frac{1}{2}(10.0 \text{kg})(2.20 \text{m/s})^2 / - (0.10)(10.0 \text{kg})(9.81 \text{m/s}^2)$

$= 2.46 \text{m}$

It still travels a positive distance, but it slows down as it is traveling so its change in kinetic energy, friction and acceleration are negative.
Example 2

A 910kg crate starting from rest is pulled with a 560 N force at an angle of 23° above horizontal. If the force of friction is 290N, how far must the crate be pulled to reach a speed of 78m/s?
\[ F_{\text{net}} = F_{\text{ax}} - F_k \]

\[ F_k = 290 \text{N} \]

\[ 560 \text{N} \]

\[ F_{\cos \theta} \]

\[ 23 \]

\[ d \]
\[ \sqrt{F_{net}} = F_{ax} - F_k \]

\( F_k = 290 \text{N} \)

\[ \sqrt{F_{net}} = 560 \text{N} \cos 23 - 290 \text{N} = 225 \text{N} \]

\[ W = F_{net}d = \Delta KE = KE_f - KE_i = KE_f - 0 \]

\[ \sqrt{F_{net}}d = KE_f \]

\[ d = KE_f / F_{net} = \left[ \frac{1}{2}(910 \text{kg})(78 \text{m/s})^2 \right] / 225 \text{N} \]

\[ = 12,303 \text{m} = 12,000 \text{m} \]
Practice 5C, pg. 176
Potential Energy

Potential Energy - energy stored in an object because of its state or position.
Gravitational potential energy depends on an object's position above a zero level.

\[ PE_g = mgh \]

\[ \Delta PE_g = mgh_f - mgh_i = \text{Work done} \]

Potential energy can be stored in bent or stretched objects = Elastic Potential Energy

\[ PE_{\text{elastic}} = \frac{1}{2}kx^2 \]

- \( x = \text{distance compressed or stretched} \)
- \( k = \text{spring constant} \)

\( g \) is positive for potential energy!
What is the Potential Energy of a 24.0 kg mass 7.5 m above the ground?

\[ \text{PE}_g = mgh = (24.0 \text{ kg})(9.81 \text{ m/s}^2)(7.5 \text{ m}) = 1.8 \times 10^3 \text{ J} \]
What is the Potential Energy of a spring stretched 5.0 cm that has a spring constant of 79 N/m?

\[ PE = \frac{1}{2} kx^2 = \frac{1}{2} (79 \text{N/m})(0.05 \text{m})^2 = 0.099 \text{J} \]
\( \text{Total Potential energy} = \text{Elastic Potential Energy} + \text{Gravitational Potential Energy} \)

\( PE_{\text{Total}} = \frac{1}{2}kx^2 + mgh \)
Example 179

A 70.0 kg stuntman is attached to a bungee cord with an unstretched length of 15.0 m. He jumps off a bridge spanning a river from a height of 50.0 m. When he finally stops, the cord has a stretched length of 44.0 m. Treat the stuntman as a point mass, and disregard the weight of the bungee cord. Assuming the spring constant of the bungee cord is 71.8 N/m, what is the total potential energy relative to the water when the man stops falling?
Known, unknowns and formulas

✓ $m_s = 70.0\text{kg}$
✓ $h_i = 50.0\text{m}$, $h_f =$?
✓ $h_f = 50\text{m} - 44\text{m} = 6.0\text{m}$
✓ $L_i = 15.0\text{m}$
✓ $L_f = 44.0\text{m}$
✓ $\Delta L = 29.0\text{m} = x$
✓ $k = 71.8\text{N/m}$
✓ $PE_{Total} = \frac{1}{2}kx^2 + mgh_f$
✓ $PE_{Total} = \frac{1}{2}(71.8\text{N/m})(29\text{m})^2 + (70.0\text{kg})(9.81\text{m/s}^2)(6.0\text{m}) = 3.43 \times 10^4 \text{J}$
✓ Swing problem...

\[(\text{hyp}) \cos \theta = \text{adj}\]

Height above zero point = hyp-adj
Problems 5D, page 180
Swing problem...

\[(\text{hyp}) \cos \theta = \text{adj}\]

Height above zero point = hyp-adj
Mechanical Energy

Mechanical Energy (ME) is the sum of KE and ALL forms of PE associated with an object or group of objects.
Mechanical Energy

✓ When a ball is thrown into the air, the kinetic energy you give the ball is transferred to potential energy and then back into the same amount of kinetic energy - Total Mechanical Energy is constant.

\[ ME_{TOTAL} = \Sigma KE + \Sigma PE \]
Law of Conservation of Energy

States that within a closed, isolated system, energy can change form, but the total amount of energy is constant.

(Energy can be neither created nor destroyed).
✓ \text{ME}_i = \text{ME}_f

\Rightarrow KE_i + PE_{g,i} + PE_{E,i} = KE_f + PE_{g,f} + PE_{E,f}

\frac{1}{2} \text{mv}_i^2 + mgh_i + \frac{1}{2} kx_i^2 = \frac{1}{2} \text{mv}_f^2 + mgh_f + \frac{1}{2} kx_f^2
Example 1

✓ Starting from rest, a child slides down a frictionless slide from an initial height of 3.00 m. What is his speed at the bottom of the slide? Assume he has a mass of 25 kg.
\[ h_i = 3.00\text{m}, \quad h_f = 0.00\text{m} \]
\[ V_i = 0 \]
\[ m = 25.0\text{kg} \]
\[ g = 9.81\text{m/s}^2 \]
\[ V_f = ? \]
Use the Conservation of Mechanical Energy Formula (no PE<sub>E</sub>)

- \( KE_i + PE_{g,i} = KE_f + PE_{g,f} \)

- \( mgh_i = \frac{1}{2} mv_f^2 \)

- \( v_f = \sqrt{\frac{gh_i}{\frac{1}{2}}} \)

\[ v_f = \sqrt{\frac{(9.81)(3.00m)}{(1/2)}} = 7.67 \text{m/s} \]
Example 2. A brick with a mass of 2.1 kg falls from a height of 2.0 m and lands on a relaxed spring with a constant of 3.5 N/m. How far will the spring be compressed? Assume final position is 0.0 m and final KE is 0.

No KE initial or final

Given: \( m = 2.1 \text{ kg} \) \( h_i = 2.0 \text{ m} \) \( g = 9.81 \text{ m/s}^2 \) \( k = 3.5 \text{ N/m} \)

Find: \( x \)

Formula: \( PE_{g,i} + PE_{E,i} = PE_{g,f} + PE_{E,f} \)

Solution:
\[
x = \sqrt{\frac{2 m g h_i}{k}} = \sqrt{\frac{2(2.1 \text{ kg})(9.81 \text{ m/s}^2)(2.0 \text{ m})}{3.5 \text{ N/m}}} = 4.9 \text{ m}
\]
Practice 5E pg. 185
Power

✓ **Work** is not affected by the time it takes to perform it.

✓ **Power** is the rate of doing work.

\[ P = \frac{W_{\text{net}}}{\Delta t} = F_{\text{net}} \parallel \Delta \frac{d}{\Delta t} \quad \text{OR} \quad P = F_{\text{net}} \parallel v \]

• Remember... \( W_{\text{net}} = \Delta \text{KE} \)
• \( F_{\text{net}} = ma \)
• Friction/Resistance is a force that needs to be included in \( F_{\text{net}} \) calculations

➢ **Units are in watts (W)**

• One Watt = 1 Joule/second
• Kilowatt = 1000 watts
Example 1. How long does it take for a 1.70 kW steam engine to do $5.6 \times 10^6$ J of work? (assume 100% efficiency.)

Given: $P = 1.70 \times 10^3$ W  \hspace{1cm} W = 5.6 \times 10^6$ J

Find: $\Delta t$

Formula: $P = \frac{W}{\Delta t}$

Solution: $\Delta t = \frac{W}{P} = \frac{5.6 \times 10^6 \text{ J}}{1.70 \times 10^3 \text{ W}} = 3.3 \times 10^3$ s
Example 2. How much power must a crane’s motor deliver to lift a 350 kg crate to a height of 12.0 m in 4.5 s?

Given: \( m = 350 \text{ kg} \quad h = 12.0 \text{ m} \quad \Delta t = 4.5 \text{ s} \quad g = 9.81 \text{ m/s}^2 \)

Find: \( P \)

Formula: \( P = \frac{F_{\text{net}}d}{\Delta t} = \frac{mgh}{\Delta t} \)

Solution:

\[
P = \frac{mgh}{\Delta t} = \frac{(350 \text{ kg})(9.81 \text{ m/s}^2)(12.0 \text{ m})}{4.5 \text{ s}} = 9200 \text{ W}
\]
Example 3

A 1450 kg car accelerates from rest to 5.60 m/s in 5.00 sec. If \( F_k \) is 560.0 N, what is the power developed by the engine?

- **Given:** \( m = 1450 \text{ kg}, \; v_i = 0, \; v_f = 5.60 \text{ m/s}, \; \Delta t = 5.00 \text{ s}, \; F_k = 560.0 \text{ N} \)

- **Need:** acceleration to determine net force \( (F = ma) \)! Then you need \( \Delta x \) (this is \( \Delta s \)) to find Work. Then you can calculate Power.
\( a = \Delta v / \Delta t = 5.60 \text{m/s} / (5.00 \text{s}) = 1.12 \text{m/s}^2 \)

**engine has to overcome friction (\( F_k \)) and cause acceleration (\( F = ma \))

\[
F_{\text{net}} = F_k + ma = 560.0 \text{N} + (1450 \text{kg}) \times (1.12 \text{m/s}^2) = 2184 \text{N}
\]

**use an old formula to find \( \Delta x \)

\[
\Delta x = \frac{1}{2} (v_i + v_f) \times \Delta t = \frac{1}{2} (0 + 5.60 \text{m/s}) \times 5 \text{s} = 14 \text{m}
\]

**Now find power

\[
P = W / \Delta t = F_{\text{net}} d / \Delta t = 2184 \text{N} \times 14 \text{m} / 5.00 \text{s}
\]

\[P = 6115 \text{Watts} = 6.115 \text{kW}\]
Practice 5F on page 189
Example 3. A $1.2 \times 10^3$ kg elevator carries a maximum load of 900.0 kg. A constant frictional force of $5.0 \times 10^3$ N retards the elevator’s upward motion. What minimum power must the motor deliver to lift the fully loaded elevator at a constant speed of 3.00 m/s?

Hint: The key to this problem is to find the required net force required in the vertical
\[ F_{\text{net}} = F_{w \text{ elevator}} + F_{w \text{ load}} + F_{\text{friction}} = g(m_e + m_l) + F_f \]

\[ F_{\text{net}} = 9.81 \text{ m/s}^2(1.2 \times 10^3 \text{ kg} + 900.0 \text{ kg}) + 5.0 \times 10^3 \text{ N} \]

\[ F_{\text{net}} = 25601 \text{ N (without rounding)} \]
Given: \( F_{\text{net}} = 25,601 \, \text{N} \) \( \nu = 3.00 \, \text{m/s} \)

Find: \( P \)

Formula: \( P = F_{\text{net}} \nu \)

Solution: \( P = F_{\text{net}} \nu = (25,601 \, \text{N})(3.00 \, \text{m/s}) = 77,000 \, \text{W} \)
Review problems in class

1, 7, 10, 19, 23, 33, 35, 36, 37, 39, 41, 43, 45, 53 and 57 on page 193-197