Chapter 4

Work and Energy
Work

- Work - the product of the magnitude of the force ($F$) and the parallel distance ($d$) through which the object moves
- work = force x parallel distance
- $W = Fd$
- Mechanically, work involves both force and motion
No work is done because there is no movement ($d = 0$)
Work Being Done Applied force ($F$) through a distance ($d$)
Work in horizontal component
No Work in vertical component ($d = 0$)
(even if part of your effort pushes the mower down)
Work - Units

• SI System
  • \( W = Fd \rightarrow \) newton x meter = N-m = joule (J)

• British System
  • \( W = Fd \rightarrow \) pound x foot = foot-pound (ft-lb)
When work is done, we generally feel the other part of Newton’s third-law force acting against us.

Gravity and friction are common agents working against work.

In the case of gravity, we must apply force to overcome the force of gravity (weight = $w = mg$).

Work $= W = Fd = wh = mgh$

(h is the height lifted)
Energy

• The ability to do work. An object or system that possesses energy has the ability to do work.

• When work is done by a system, the amount of energy of the system decreases.

• When work is done on a system, the system gains energy.

• Work is the process by which energy is transferred from one object to another.

• Work and Energy have the same units – joules.
Kinetic Energy

- Kinetic Energy - the energy an object possesses because of its motion, the energy of motion.
- kinetic energy = $\frac{1}{2} \times \text{mass} \times (\text{velocity})^2$
- $E_k = \frac{1}{2} mv^2$
- If an object is already moving
- Work = change in kinetic energy
- $W = \Delta E_k = E_{k2} - E_{k1} = \frac{1}{2}mv_2^2 - \frac{1}{2}mv_1^2$
Change in Kinetic Energy – *an Example*

- A 1.0 kg ball is fired from a cannon. What is the change in the ball’s kinetic energy when it accelerates from 4.0 m/s to 8.0 m/s?

  - **GIVEN:** \( m = 1.0 \text{ kg}; \ v_1 = 4.0 \text{ m/s}; \ v_2 = 8.0 \text{ m/s} \)
  - \( \Delta E_k = E_{k_2} - E_{k_1} = \frac{1}{2}mv_2^2 - \frac{1}{2}mv_1^2 \)
  - \( E_k = \frac{1}{2}(1.0 \text{ kg})(8.0 \text{ m/s})^2 - \frac{1}{2}(1.0 \text{ kg})(4.0 \text{ m/s})^2 \)
  - \( \Delta E_k = 32\text{J} - 8.0\text{J} = 24\text{J} \)
Auto Braking – Work, Force, Distance

- Work to stop auto = braking force x distance \( (W = fd) \)
- \( W = \) kinetic energy auto \( (\frac{1}{2} mv^2) \) therefore \( fd = \frac{1}{2} mv^2 \)
- Since \( f, m, \) and \( \frac{1}{2} \) are all constants, therefore \( d \propto v^2 \)
  - If the velocity is doubled the braking distance is x4.
  - If the velocity is tripled the braking distance is x9
Potential Energy

- Potential Energy - the energy an object has because of its position or location, the energy of position
- Most potential energy is due to gravity
- Remember that:
  - Work = Force x distance (W = Fd)
  - Weight is a force (w = mg)
  - Substitute h (height) for d
- Therefore \( W = mgh \)
  - Grav. potential energy = weight x height
- \( E_p = mgh \)
The gravitational Potential Energy is equal to the work done and this is equal to the weight times the height.

\[ W = E_p = mgh \]

Example: How much work is done lifting a 1.0 kg book to the height of 1m?

\[ \text{Work} = W = (1.0 \text{ kg}) (9.8 \text{ m/s}^2) (1\text{m}) = 9.8 \text{ J} \]

This is also the amount of \( E_p \) that the book has at a height of 1m.
Potential Energy

- Depends only on the initial and final positions (difference in height - $\Delta h$) and is independent of path.
- If we disregard any frictional loss, it takes the same amount of work ($W$) to lift the mass ($m$), no matter the path.

$$E_p = W = mgh$$
Work = change in potential energy

- Work = $W = E_p = mgh = mg\Delta h$
- In the previous examples the $h$ is actually $\Delta h$
- Work is done when there is a change in position
- Therefore the reference point for measuring heights is arbitrary (but must be internally consistent)
Reference Point No matter which scale – $\Delta h$ is the same

$E_p = mgh$

$h = 0$

$E_p = 0$

$E_p = mg(-h) = -mgh$
Other examples of Potential Energy would include:

- Springs (compressed or stretched)
- Bowstring
Conservation of Energy

- Energy can neither be created nor destroyed.
- In changing from one form to another, energy is always conserved.
- The total energy of an isolated system remains constant.
- \((\text{total energy})_{\text{time}1} = (\text{total energy})_{\text{time}2}\)
- The total energy does not change with time.

Audio Link
Conservation of Mechanical Energy

• To simplify we will deal with *ideal systems* – in which energy is only in two forms – kinetic and potential.

• -- Equation Form --

• \((E_k + E_p)_1 = (E_k + E_p)_2\)

• \((\frac{1}{2}mv^2 + mgh)_1 = (\frac{1}{2}mv^2 + mgh)_2\)
A 0.10 kg stone is dropped from a height of 10.0 m. What will be the kinetic and potential energies of the stone at the heights indicated in the figure (neglect air resistance).

$E_T = E_k + E_p$ will be true at all heights.

At the moment the stone is released $E_T = E_p \rightarrow (E_k = 0)$

At the moment the stone hits the ground $E_T = E_k \rightarrow (E_p = 0)$
Solve for $E_p$ and $E_k$ at heights indicated

• At any height, the potential energy $\rightarrow E_p = mgh$
  
• $h = 10\,\text{m}$: $E_p = (0.10\,\text{kg})(9.8\,\text{m/s}^2)(10.0\,\text{m}) = 9.8\,\text{J}$
  
• $h = 7\,\text{m}$: $E_p = (0.10\,\text{kg})(9.8\,\text{m/s}^2)(7.0\,\text{m}) = 6.9\,\text{J}$
  
• $h = 3\,\text{m}$: $E_p = (0.10\,\text{kg})(9.8\,\text{m/s}^2)(3.0\,\text{m}) = 2.9\,\text{J}$
  
• $h = 0\,\text{m}$: $E_p = (0.10\,\text{kg})(9.8\,\text{m/s}^2)(0\,\text{m}) = 0\,\text{J}$
  
• $E_T = E_k + E_p$
  
• $E_k = E_T - E_p$
Solve for $E_p$ and $E_k$ at heights indicated

### Table 4.2 Energy Summary for Example 4.2

<table>
<thead>
<tr>
<th>Height (m)</th>
<th>$E_T$ (J)</th>
<th>$E_p$ (J)</th>
<th>$E_k$ (J)</th>
<th>$v$ (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.0</td>
<td>9.8</td>
<td>9.8</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7.0</td>
<td>9.8</td>
<td>6.9</td>
<td>2.9</td>
<td>7.7</td>
</tr>
<tr>
<td>3.0</td>
<td>9.8</td>
<td>2.9</td>
<td>6.9</td>
<td>12</td>
</tr>
<tr>
<td>0</td>
<td>9.8</td>
<td>0</td>
<td>9.8</td>
<td>14</td>
</tr>
<tr>
<td>(decreases)</td>
<td>(constant)</td>
<td>(decreases)</td>
<td>(increases)</td>
<td>(increases)</td>
</tr>
</tbody>
</table>
Magnitude of Velocity

- Potential Energy \((E_p)\) converted = \(mg\Delta h\)
- Converted into Kinetic Energy \((E_k)\) = \(\frac{1}{2}mv^2\)
- Since all the \(E_p\) is converted into \(E_k\) just before hitting the ground, we can use this to compute the speed or magnitude of velocity
- Therefore:  \(\frac{1}{2}mv^2 = mg\Delta h\)
- \(\frac{1}{2}v^2 = g\Delta h\) (cancel \(m’s\))
- \(v^2 = 2g\Delta h\) (solve for \(v\))
- \(v = \sqrt{2g\Delta h}\)
Power – SI System

• Power - the time rate of doing work

• Power = \( \frac{\text{work}}{\text{time}} = \frac{W}{t} = \frac{Fd}{t} \)

• SI Units \( \rightarrow \) J/s = Watt (1 J/s = 1 W)

• For example a 100W light bulbs uses 100 joules/second of electrical power \( \text{or} \) 100 Watts

• Be careful not to confuse \( W \) (work) with \( W \) (watt)
Force of 1.0 N to raise a mass 1.0 m, the amount of work done is 1.0 J. If this work is done in 1.0 s, then the power is 1.0 W.
A Review of SI Units

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Unit</th>
<th>Symbol</th>
<th>Equivalent Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Force</td>
<td>newton</td>
<td>N</td>
<td>Kg-m/s²</td>
</tr>
<tr>
<td>Work</td>
<td>joule</td>
<td>J</td>
<td>N-m</td>
</tr>
<tr>
<td>Energy</td>
<td>joule</td>
<td>J</td>
<td>N-m</td>
</tr>
<tr>
<td>Power</td>
<td>watt</td>
<td>W</td>
<td>J/s</td>
</tr>
</tbody>
</table>
Power – British System

• Work = foot-pound
• Power = ft-lb/s
• Horsepower – commonly used unit for power in the British system
• 1 hp = 550 ft-lb/s = 746 W
• The greater the power of an engine, the faster it can do work – a 2-hp engine can do twice as much work as a 1-hp engine in the same amount of time
• A constant force of 150 N is used to push a student’s stalled motorcycle 10 m along a flat road in 20 s. Calculate power expended in watts.
Calculating Power

• A constant force of 150 N is used to push a student’s stalled motorcycle 10 m along a flat road in 20 s. Calculate power in watts.
• GIVEN: \( F = 150 \text{ N}; \ d = 10 \text{ m}; \ t = 20 \text{ s} \)
• FIND: \( P \) (power)

\[
P = \frac{W}{t} = \frac{Fd}{t}
\]

\[
P = \frac{(150 \text{ N})(10 \text{ m})}{20 \text{ s}} = 75 \text{ W}
\]
Confidence Exercise

• A student expends 7.5 W of power in lifting a textbook 0.50 m in 1.0 s. How much work is done and how much does the book weigh in N?
Confidence Exercise

• A student expends 7.5 W of power in lifting a textbook 0.50 m in 1.0 s. How much work is done and how much does the book weigh in N?

• GIVEN:  \( P = 7.5 \text{ W}; \ d = 0.50 \text{ m}; \ t = 1.0 \text{ s} \)

• FIND: \( W \) (work) and \( w \) (weight)

• \( W = Pt = (7.5 \text{ W})(1.0 \text{ s}) = (7.5 \text{ J/s})(1.0 \text{s}) = 7.5 \text{ J} \)

• Remember that weight (\( w \)) is a force (\( F \))

• \( W = Fd \rightarrow F = W/d = 7.5 \text{ J}/0.50 \text{ m} = 15 \text{ N} \)

• Work done = 7.5 J: Book weighs = 15 N
Electrical Energy Used

• Power = \textit{energy produced or consumed} \over \textit{time taken} \quad = P = \frac{E}{t}

• \( E = Pt \) (rearranging the equation)

• Power \((P)\) given in \(W\) (watts) \(\Rightarrow\) \(J/s\)

• Therefore: \(Pt\) is \((J/s)(s) = W\cdot s = J\)

• \((J)\) joules are our units of work/energy

• Bigger unit \(\rightarrow\) \textit{kilowatt-hour (kWh)}

• Unit that you pay your electricity in (kWh)
A 1.0 hp electric motor runs for 10 hours. How much energy is consumed in KWh?

Given: \( P = 1.0 \text{ hp} \); \( t = 10 \text{ h} \)

Find: \( E \) (energy in kWh)

Convert power from hp to W to kW

\[
1.0 \text{ hp} = 746 \text{ W} \times \frac{1\text{kW}}{1000\text{W}} = 0.746\text{kW} = 0.75\text{kW}
\]

\[
E = Pt = (0.75\text{kW})(10\text{h}) = 7.5\text{kWh}
\]
Energy

• No matter what type of energy that we speak of – chemical, electrical, mechanical – the main unifying concept is the **conservation of energy**

• We cannot create or destroy energy, but we can change it from one form to another
Forms of Energy

- Thermal (heat) Energy – related to the kinetic and potential energies on a molecular level
- Gravitational potential energy – from an object’s position, stored gravitational energy
- Electrical energy – associated with the motion of electric charges
- Chemical energy – molecular bonds
- Radiant energy – sun – electromagnetic
- Nuclear energy – rearrangement of nuclei
  - Fission – breaking apart of larger nuclei
  - Fusion - smaller nuclei are put together

Audio Link
Fossil Fuels

- **Fossil Fuels** – oil, gas, coal - from once living organisms; basically stored solar and chemical energy
- **Oil** – from marine organisms (U.S. imports more than 50% of our needs)
- **Gas** – from marine organisms (most is produced domestically)
- **Coal** – from terrestrial (land) plants (the U.S. has large reserves, but environmental problems in coal mining)
- **Methane hydrate** – crystalline form of natural gas and water (research on possible usage)
Approximate Relative Fuel Consumption in the U.S.

- Oil: 37%
- Natural gas: 24%
- Coal: 23%
- Nuclear: 8.5%
- Renewables*: 7.5%
Fuels for Electrical Generation

- Coal: 49%
- Natural gas: 21%
- Nuclear: 20%
- Hydroelectric: 6%
- Petroleum Oil: 1%
- Other Renewables: 3%
Energy Consumption by Sector

- Industry: 41%
- Transportation: 24%
- Commercial and residential: 32%
Alternate and Renewable Energy Sources

- **Alternate energy sources** – energy sources not based on fossil fuels or nuclear processes.
- **Renewable energy sources** – energy sources that cannot be exhausted.
- In large part these types of energies overlap.
Hydropower

• Uses the gravitational potential energy of water flowing downhill due to gravity
• Best dam sites (where large amounts of water can be stored in narrow deep canyons) have been taken
• Environmental/ecological damage
• Loss of agricultural land
Flaming Gorge Dam, Utah
Wind Power

• Not particularly aesthetic
• Must be located where the wind is sufficiently constant and fast enough
• Minor environmental effects
• Has been used for thousands of years to grind grains and pump water
Wind Farm near Mojave, California
Solar Power

• Very promising future source of reliable and economic energy.

• Although some solar power is in use now, many more applications are possible.
Geothermal Energy

• Very site specific
• Depends on a large natural change in temperature being present and accessible
• Extensively used in Iceland
• Tidal energy is steady, reliable, and predictable
  • Must be designed to handle bidirectional tidal currents
• Tidal currents have been generating electricity along the Rance River in France since the 1960’s.
Biofuels

• Corn, sugarcane, and other plants can be used to make ethanol (an alcohol).
• Ethanol can be mixed with gasoline and used as fuel for cars (gasohol).
• Depending on the plant processed, more energy may be used in the production of ethanol than will be supplied by burning the ethanol itself.
Biomass

- Any organic matter available on a renewable basis is considered biomass.
- Biomass includes agricultural crops, wood, animal wastes, municipal wastes, aquatic plants, etc.
- Biomass is capable of being burned and therefore can generate energy.
Chapter 4 - Important Equations

- \( W = Fd \) (Work)
- \( E_k = \frac{1}{2}mv^2 \) (Kinetic Energy)
- \( W = \Delta E_k = E_{k2} - E_{k1} = \frac{1}{2}mv_2^2 - \frac{1}{2}mv_1^2 \)
  - (Work = change in kinetic energy)
- \( E_p = mgh \) (Potential Energy)
- \( (E_k + E_p)_1 = (E_k + E_p)_2 \)
  - (Conservation of Mechanical Energy)
- \( P = \frac{W}{t} = \frac{E}{t} = Fd/t \) (Power)
- \( v = \sqrt{2g\Delta h} \)