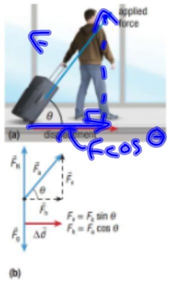
# SPH3U 5.1 Work

## 1. Work done by a constant force

| | |
|---|---|
| Mechanical work: | a force applied over a distance. |
| equation | $W = F\Delta d\cos\theta$<br>Units: $N\cdot m = kg\cdot m^2/s^2 = J$ (Joule). |
| theta | $\theta$, angle between $F$ and $\Delta d$ |
| special case | when $\theta = 0$, $F$ and $\Delta d$ point in the same direction. $W = F\Delta d$. |




How much mechanical work does a person do on a shopping cart if they apply a force of 25 N in the forward direction, and displace the cart 3.5 m in the same direction?


$W = F\Delta d$
$= (25\,N)(3.5\,m)$
$= 87.5\,J \approx \underline{88\,J}$

A curler applies a force of 15.0 N on a curling stone and accelerates the stone from rest to a speed of 8.00 m/s in 3.50 s. Assuming that the ice surface is level and frictionless, how much mechanical work does the curler do on the stone?

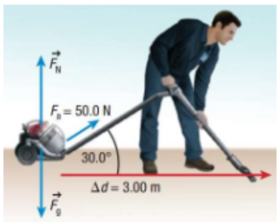
$W = F\Delta d$ $\quad F = 15.0\,N$. $\Delta d = ?$, $v_i = 0$, $v_f = 8\,m/s$, $\Delta t = 3.5\,s$.

$\Delta d = \left(\frac{v_f + v_i}{2}\right)\Delta t = \left(\frac{8+0}{2}\right)3.5 = 14.0\,m$.

$W = F\Delta d = (15)(14) = 210\,J = \underline{2.10\times10^2\,J}$.

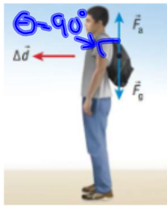
## 2. Work done when force and displacement are in different directions

Calculate the mechanical work done by a custodian on a vacuum cleaner if the custodian exerts an applied force of 50.0 N on the vacuum hose and the hose makes a 30.0° angle with the floor. The vacuum cleaner moves 3.00 m to the right on a level, flat surface.




$W = F\Delta d\cos\theta$
$= (50)(3)\cos 30^\circ$
$= \underline{1.30\times10^2\,J}$.

### 3. Special cases



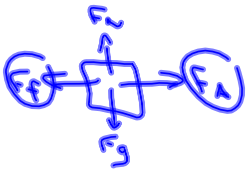

Ranbir wears his backpack as he walks forward in a straight hallway. He walks at a constant velocity of 0.8 m/s for a distance of 12 m. How much mechanical work does Ranbir do on his backpack?

$\underline{W = 0\,J.}$ ( $\theta = 90°$ $W = F\Delta d\cos\theta$ $\underline{\cos 90° = 0.}$ )

How much mechanical work is done on a stationary car if a student pushing with a 300 N force fails to displace the car?

$W = 0\,J$ (needs to be movement!)
($W = F\Delta d\cos\theta$, $\Delta d = 0$, $\therefore W = 0$).

A shopper pushes a shopping cart on a horizontal surface with a horizontal applied force of 41.0 N for 11.0 m. The cart experiences a force of friction of 35.0 N. Calculate the total mechanical work done on the shopping cart.

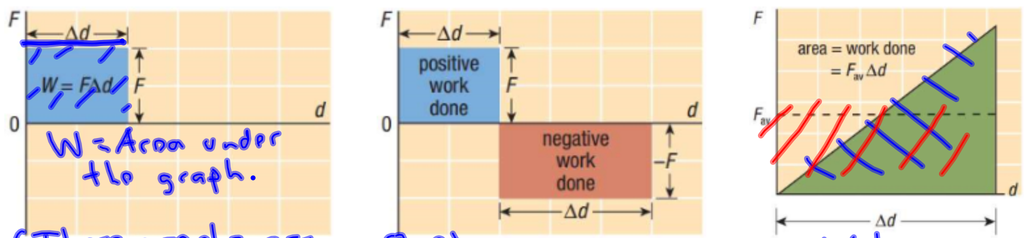



Applied:
$W_A = F_A\Delta d\cos\theta$
$= 41(11)\cos 0°$
$= \underline{451\,J.}$

Friction:
$W_f = F_f\Delta d\cos\theta$
$= 35(11)\cos 180°$
$= \underline{-385\,J}$
Negative work = slowing down!

Total:
$W_{Net} = W_A + W_f$
$= 451 - 385$
$= \underline{66\,J.}$

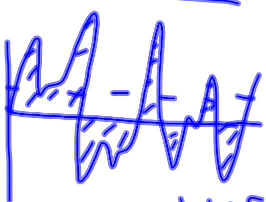
### 4. Graphing work done (F-d graphs)




W = Area under the graph.

(These graphs assume $\theta = 0$).

$A = \frac{1}{2}bh$
$W = \frac{1}{2}(\Delta d)(F_{max})$
$\boxed{\text{or } W = F_{av}\Delta d = \left(\frac{F_f + F_i}{2}\right)\Delta d}$



$\underline{W = F_{av}\Delta d}$

**Homework:** page 229: #1-3, 5-6, 9

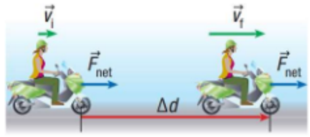
## SPH3U 5.2 Energy

### 1. Kinetic energy

| | |
|---|---|
| Energy: | The ability to do work. |
| kinetic energy | Energy possessed by moving objects. |
| equation | $E_k = \frac{1}{2}mv^2$ Units: $kg(\frac{m}{s})^2 = kg\,m^2/s^2 = J$. |

Where does this value come from? Consider the amount of work it takes to change speeds.

Imagine a motorcycle moving at a constant speed, which then accelerates to a new speed. To accelerate, it must have a force acting on it. What is the work done by this force? Assume that all you know is the mass of the motorcycle, its initial speed, and its final speed.




$W = F\Delta d \qquad F = ma \rightarrow \underline{W = ma\Delta d}$.

$v_f^2 = v_i^2 + 2a\Delta d \qquad a = \frac{v_f^2 - v_i^2}{2\Delta d} \rightarrow W = m\left(\frac{v_f^2 - v_i^2}{2\cancel{\Delta d}}\right)\cancel{\Delta d}$

$W = m\left(\frac{v_f^2 - v_i^2}{2}\right) = \boxed{\frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2}$

$\underline{W = E_{kf} - E_{ki}}$

How much work is done to accelerate from rest to some final speed ($v_i = 0$)?

$W = \frac{1}{2}mv^2 = \underline{E_k}$.

Calculate the kinetic energy of a 150 g baseball that is traveling toward home plate at a constant speed of 35 m/s.

$E_k = \frac{1}{2}mv^2 = \frac{1}{2}(0.15)(35)^2$

$= \underline{92\,J}.$

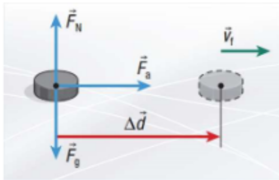
### 2. The relationship between mechanical work and kinetic energy

What is the work done to change from one speed to another?

$\boxed{W = \Delta E_k} = E_{kf} - E_{ki}$

This is called the **work-energy principle**.

A 165 g hockey puck initially at rest is pushed by a hockey stick on a slippery horizontal ice surface by a constant horizontal force of magnitude 5.0 N (assume that the ice is frictionless). What is the puck's speed after it has moved 0.50 m?




$W = F\Delta d = (5)(0.5) = \underline{2.5\ J}$

$W = \Delta E_k = E_{kf} - \cancel{E_{ki}}$

$E_{kf} = W = \underline{2.5\ J.} = \frac{1}{2}mv^2 \qquad v = \sqrt{\frac{2E_k}{m}} = \sqrt{\frac{2(2.5)}{0.165}} = \underline{\underline{5.5\ m/s.}}$

## 3. Gravitational potential energy: A stored type of energy

| | |
|---|---|
| Potential energy: | A stored form of energy |
| gravitational potential energy | Energy due to gravitational Force and object's height. |
| equation | $E_g = mgh$ Units: J. |
| reference level | The zero point that you measure height from. |

Where does this value come from? Consider the amount of work it takes to lift something.

Imagine lifting a textbook off your desk at a constant speed (not accelerating). Remember, this means that forces are balanced ($F_{net} = 0$). How much work is done by the applied force?

$h$: $F_a = F_g = mg$ $\qquad W = F\Delta d$

$F_g$ $\qquad \underline{W = mgh} = E_g.$

What is the gravitational potential energy of a 48 kg student at the top of a 110 m high drop tower ride relative to the ground?

$E_g = mgh$

$= 48(9.8)(110\ m)$

$= \underline{5.2 \times 10^4\ J.}$

## 4. Mechanical energy

| | |
|---|---|
| Mechanical energy: | Total kinetic and gravitational potential energy of an object. $E_m = E_k + E_g$. |

**Homework:** page 235: #1-3, 5

# SPH3U 5.3 Types of Energy and the Law of Conservation of Energy

**1. Types of energy**

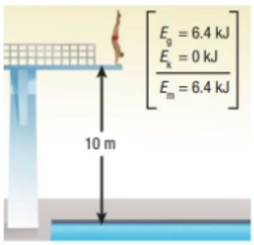
| Form of Energy | Type of Energy | Description |
|---|---|---|
| Potential and Kinetic | mechanical. | Gravity + kinetic |
| | radiant (light). | Electromagnetic fields |
| | electrical (current). | Flowing charges |
| | thermal (heat). | Randomly moving molecules |
| | sound. | Oscillating molecules |
| Potential | gravitational. | Gravity |
| | electrical (static). | Static charges |
| | nuclear | Protons and neutrons |
| | elastic. | Stretched materials |
| | chemical. | Molecular bonds |

| | |
|---|---|
| Energy transformation: | change energy from one type to another. |
| example | photosynthesis (radiant → chemical). |

**2. The law of conservation of energy**

| | |
|---|---|
| Law of conservation of energy: | the total amount of energy in the universe is conserved. Energy is not created or destroyed, it can only change forms. |

A 65.0 kg diver dives from a 10.0 m high platform into the water below. What is his mechanical energy when he is on the platform (before diving)?

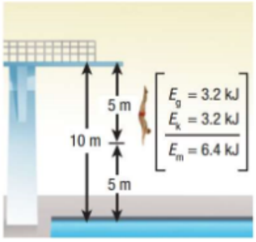



$E_g = mgh = (65)(9.8)(10)$

$= 6370\,J = \underline{6.37\,kJ}$

$E_k = 0.$ $\quad E_m = E_g + E_k = \underline{6.37\,kJ}.$

What is his mechanical energy when he is halfway to the water?




$E_g = mgh = (65)(9.8)(5) = \underline{3185 J.}$

$E_k = \frac{1}{2}mv^2$ $\quad v_f^2 = \cancel{v_i^2}^{\,0} + 2a\Delta d$

$v_f = \sqrt{2a\Delta d} = \sqrt{2(-9.8)(-5)} = \underline{9.9 m/s.}$

$E_k = \frac{1}{2}(65)(9.9)^2 = \underline{3185 J.}$ $\quad E_m = E_k + E_g = 2(3185) = \underline{6.37 kJ.}$

What is his mechanical energy when he reaches the surface of the water?

$E_m = \underline{6.37 kJ.}$

**3. Applying the law of conservation of energy**

A 1.1 kg camera slips out of a photographer's hands while he is taking a photograph. The camera falls 1.4 m to the ground below.

a. What is the camera's gravitational potential energy relative to the ground when it is in the photographer's hands?

$E_g = mgh = (1.1)(9.8)(1.4)$

$= \underline{15 J.}$

b. Using the law of conservation of energy, determine the camera's kinetic energy at the instant it hits the ground.

$E_g = 0 J.$ $\quad$ ($E_m = E_g + E_k$, $E_m$ is conserved).

$\therefore E_k = \underline{15 J.}$

c. Use the camera's kinetic energy to determine its speed when it hits the ground.

$E_k = 15 J = \frac{1}{2}mv^2$

$v = \sqrt{\frac{2E_k}{m}} = \sqrt{\frac{2(15)}{1.1}} = \underline{\underline{5.2 m/s.}}$

**Homework:** page 241: #1-4

# SPH3U 5.4 Efficiency, Energy Sources, and Energy Conservation

## 1. Efficiency

| | |
|---|---|
| Efficiency: | Ratio of useful energy out to energy in. |
| equation | $Eff = \frac{E_{out}}{E_{in}} \times 100\%$ No units. |

A firefly's body transforms chemical energy in food into radiant energy to glow. What is a firefly's efficiency if its body transforms 4.13 J of chemical energy into 3.63 J of radiant energy?

$$Eff = \frac{E_{out}}{E_{in}} \times 100\%$$

$$= \frac{3.63}{4.13} \times 100\% = \underline{88\%.}$$

What is the efficiency of a rope-and-pulley system if a painter uses 1.93 kJ of mechanical energy to pull on the rope and lift a 20.0 kg paint barrel at constant speed to a height of 7.5 m above the ground?


$$E_{out} = E_g = mgh$$
$$= (20)(9.8)(7.5)$$
$$= 1470\ J = \underline{1.47\ kJ.}$$

$$Eff = \frac{E_{out}}{E_{in}} \times 100\%$$
$$= \frac{1.47}{1.93} \times 100\% = \underline{76.2\%.}$$

## 2. Improving the efficiency of energy transformations

| Device or Process | Transformation | Waste Energy | Efficiency |
|---|---|---|---|
| gas-powered vehicle | Chem → Kinetic. | Thermal | 8-15%. |
| electric vehicle | Electrical → Kinetic | Thermal | 24-45%. |
| bicycle | Kinetic → Kinetic | Thermal | 90%. |
| speakers | Elec → Sound. | Thermal. | 1%. |
| electric heater | Elec → Thermal | Radiant. | 98%. |

| Device or Process | Transformation | Waste Energy | Efficiency |
|---|---|---|---|
| hydroelectric power plant | Kinetic → Elec. | Thermal | 80%. |
| nuclear power plant | Nuclear → Elec. | Thermal. | 30-40%. |
| solar cell | Radiant → Elec. | Thermal. | 20-40%. |
| photosynthesis | Radiant → Chemical | Thermal. | 5%. |
| animal muscles (including human) | Chemical → Kinetic. | Thermal. | 20%. |

3. **Sources of energy**

| Type | Resources | Pros | Cons |
|---|---|---|---|
| **Renewable** | Solar<br>Hydro<br>Geothermal<br>Wind<br>Tidal<br>Biofuels. | -renewable (don't run out).<br>-Usually better for the environment.<br>-use energy that is otherwise unused. | -not very efficient<br>-expensive to build.<br>-disrupt nature/wildlife. |
| **Non-Renewable** | Fossil fuels. (Gasoline, oil). | -have lots of energy.<br>-easy to convert. | -limited.<br>-very bad for environment. |
| | Nuclear. | -even more energy than fossil fuels<br>-relatively clean (not much waste). | -safety (CANDU reactors are very safe).<br>-radioactive waste. |

**Homework:** page 249: #1-4

# SPH3U 5.5 Power

## 1. Power

| | |
|---|---|
| Power: | the rate at which energy is transferred. |
| equation | $P = \frac{W_{net}}{\Delta t} = \frac{\Delta E}{\Delta t}$ Units: $\frac{J}{s} = W$ (Watt). |

How much power does a swimmer produce if she transforms 2.4 kJ of chemical energy (in food) into kinetic energy and thermal energy in 12.5 s?

$\Delta E = 2.4 kJ$. $P = \frac{\Delta E}{\Delta t}$

$\Delta t = 12.5 s$.

$P = \frac{2.4 kJ}{12.5 s} = \frac{2400 J}{12.5 s} = \underline{190 W}$

A 64 kg student climbs from the ground floor to the second floor of his school in 5.5 s. The second floor is 3.7 m above the ground floor. What is the student's power?

$P = \frac{\Delta E}{\Delta t}$ $\Delta E = E_{gf} - E_{gi}$ $P = \frac{\Delta E}{\Delta t} = \frac{2320}{5.5}$

$\Delta t = 5.5 s$. $= mgh = (64)(9.8)(3.7)$ $= \underline{420 W}$.

$= \underline{2320 J}$.

The student runs back down the stairs in 2.25 s. What is the student's power?

$P = \frac{\Delta E}{\Delta t}$. $P = \frac{-2320}{2.25}$

$\Delta E = -2320 J$. $= -1031 W$

$\Delta t = 2.25 s$. $= -1.0 \times 10^3 W = \underline{-1.0 kW}$.

## 2. Electrical power

| | |
|---|---|
| Power rating: | Maximum power of an electric device. |
| energy transformed | $\Delta E = P \Delta t$ |

What is the power of an electric elevator motor if it uses 2.9 x $10^5$ J of electrical energy to lift an elevator car 12 m in 16 s?

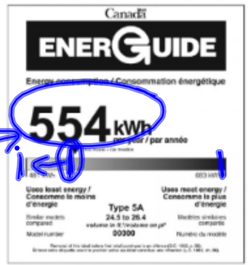
$P = \frac{\Delta E}{\Delta t}$ $\Delta E = 2.9 \times 10^5 J$. $\Delta t = 16 s$.

$P = \frac{2.9 \times 10^5}{16} = 18125 W$

$= \underline{18 kW}$.

| Appliance | Power Rating (W) | Appliance | Power Rating (W) | Appliance | Power Rating (W) |
|---|---|---|---|---|---|
| laptop | 20-75 | microwave | 600-1500 | fridge | 100-500 |
| vacuum | 200-700 | dishwasher | 1200-1500 | stove | 6000-10 000. |

| | |
|---|---|
| Electricity metres: | Measures your house's energy usage in kWh. (energy... J). |
| EnerGuide: | labels on appliances in Canada that tell you their efficiency. |




What is the cost of operating a 25 W light bulb 4.0 h a day for 6.0 days if the price of electrical energy is 5¢/kWh?

$\Delta E = P\Delta t$ $\Delta t = (4h)(6\ days) = 24h.$

$= (25)(24)$

$= 600\ Wh$

$= 0.6\ kWh.$

Cost = Price × Energy.

$= (\$0.05)(0.6)$

$= \$0.03$

Twenty incandescent light bulbs are turned on for 12 h a day for an entire year to light up a store. Each bulb has a power rating of 100.0 W. The average cost of electricity is 6.0¢/kWh.

Calculate the cost of lighting the store for a year.

$\Delta E = P\Delta t$

$P = (100\ W)(20) = 2\ kW.$

$\Delta t = (12)(365)$

$= 4380\ h.$

$\Delta E = (2\ kW)(4380\ h)$

$= 8760\ kWh.$

Cost = ΔE × price.

$= (8760)(\$0.06)$

$= \$525.60.$

How much money could be saved by using CFLs, if they have a power rating of 23 W?

$\frac{\$525.60}{100\ W} \times 23\ W = \$120.89.$

Savings: $\$525.60 - 120.89$

$= \$404.71.$

**Homework:** page 254: #1-2, 4-5