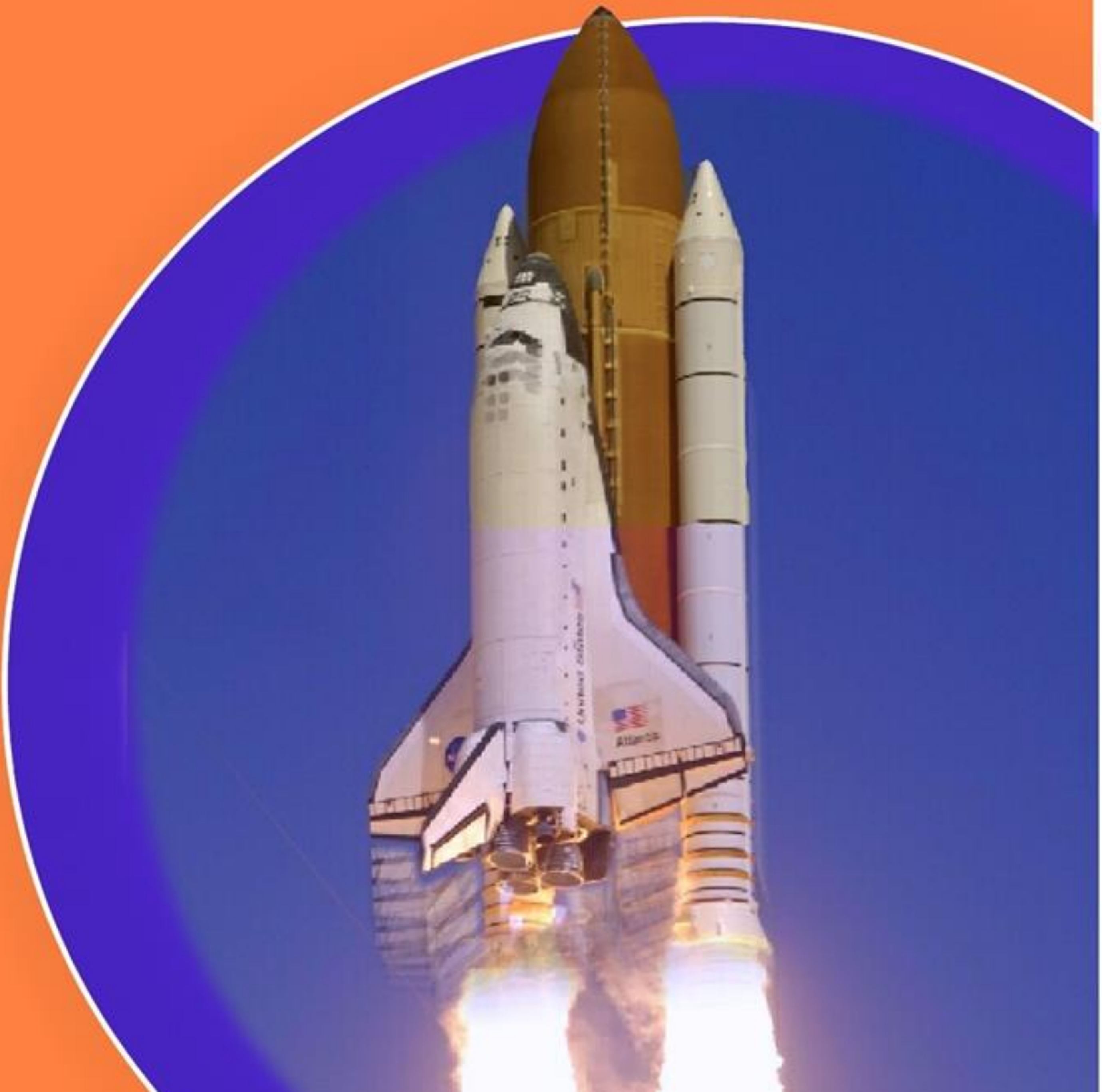
Mechanics

Work & Energy



Work & Energy – Specific Learning Objectives

(mark each specific learning objective as you finish it)

- [ ] I know the definition of work
- [ ] I know SI unit for work, and energy.
- [ ] I am able to use the formulae W = Fd to calculate work, distance and force.
- [ ] I know the definition of energy, kinetic energy, and potential energy.
- [ ] I am able to describe different forms of energy.
- [ ] I am able to identify energy transformations.
- [ ] I am able to use the formula $E_k = \frac{1}{2}mv^2$.
- [ ] I am able to use the formula $E_p = mgh$.

Key Terms

Energy, Gravitational Potential Energy, Joule, Kinetic Energy, Work

Write the key word next to its definition

	The energy of motion
	The energy stored within an object when it is raised to a height
	The ability to do work
	A force acting over a distance
	The S.I. unit for work and energy

Work – Notes

Work is done when an object is moved in the direction of a force.
The S.I. unit for work is the Joule (J)

Formula

$$W = F \times d$$

W = Work (J)

F = force (N)

d = distance (m)

Example:
How much work is done by a cyclist pedaling a tricycle with a force of 200 N over a distance of 300 m?

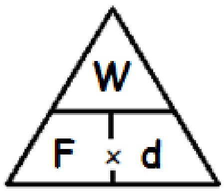
W = ?
F = 200 N
d = 300 m

$W = F \times d$
$W = 200\ N \times 300 m$
$W = 60\ 000$ Joules

Magic Triangle

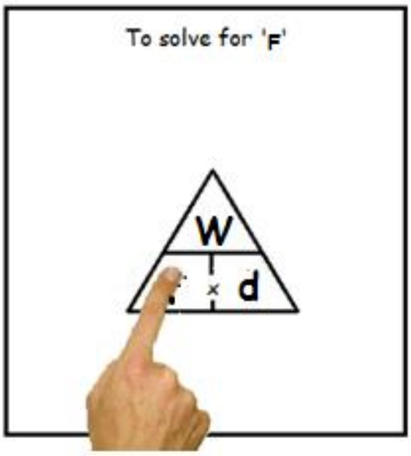
You need to be able to manipulate a formula to solve different variables within the formula. For example, what do you do when you want to solve for distance? Algebra comes in handy here, but if your algebra skills are a bit below par, you may wish to use a magic triangle.

The formula, **W = F × d** can be converted to the magic triangle

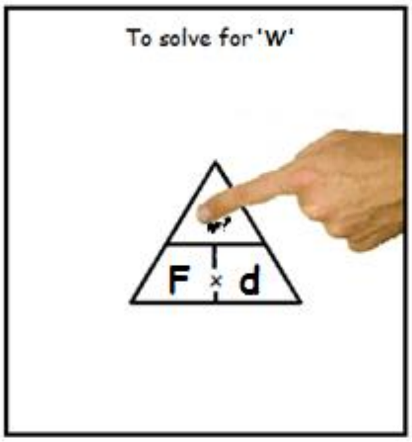


Notice that the formula has **F** × **d**; the same must happen in the triangle, so **F** & **d** must be at the bottom of the triangle.

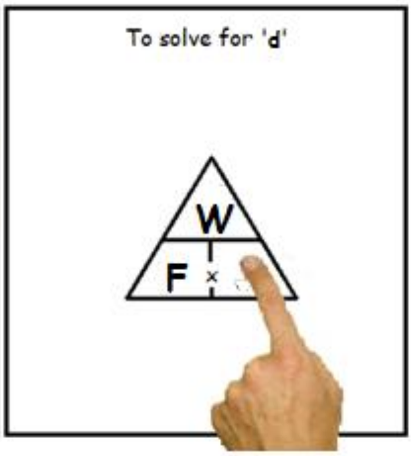
To use the triangle simply use your finger to cover the variable you wish to solve for. The remaining symbols tell you what to do.



If you wish to solve for force:
F = W/d



If you wish to solve for work:
W = F x d

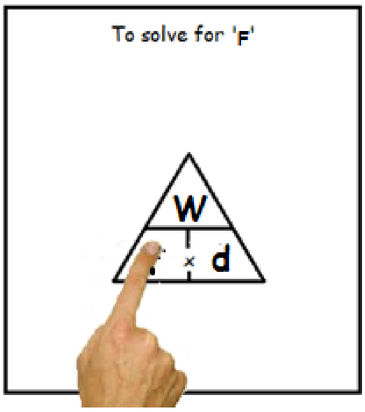


If you wish to solve for distance:
d = W/f

Example: A cow pushes a lawnmower for 100m and does 2000 Joules of work. What force was used to push the lawnmower forward?

W = 2000J
F = ?
d = 100m

F = W / d
F = 2000J/100m
F = 20 N



Complete the table below:

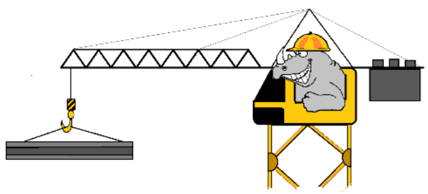
Force	Distance	Work
200 N	20 m	
500 N		100 000 J
	3 m	6000 J
	25 km	125 000 000 J
150 N		30 000 J
	6 m	1200 J

Work Problems

1. A wizard lifts a 8.0 kg book up 90 cm onto a table. What work has he done?

2. A weight lifter did 6300 J of work when he lifted a 300 kg up over his head. How high did he raise the bar?

3. A crane does 1000 kJ of work setting a steel beam into place 50 m above the ground. What is the mass of the beam?



4. A gardener has a wheel barrow filled with 15 kg of soil, seeds and tools. He pushes it forward with a force of 20 N for 40 m. How much work has he done?

Energy –Notes

Energy has the ability to do work.
S.I. unit of energy is the Joule (J)
Energy comes in many forms: kinetic, light, sound, electrical, gravitational potential, elastic potential, and nuclear.

Forms of Energy

Match the different forms of energy below with the best description

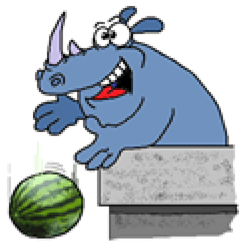
gravitational potential, electrical, sound, heat, kinetic, light, chemical, elastic potential

	Energy stored in an object when it is raised to a height.
	Energy stored when an object is stretched or squashed
	Energy caused by vibrating objects
	Energy stored in the bonds between atoms
	Energy caused by the movement of particles
	Energy due to moving electrons in a wire
	Energy of electromagnetic waves

Law of Conservation of Energy

Energy can neither be created nor destroyed it can only be transformed from one form to another.

For Example: *If watermelon has 200 Joules of gravitational potential energy when it is raised to 10 m and then dropped, it will have 200 Joules of kinetic energy just before it hits the ground.*



Gravitational potential energy → kinetic energy

1. Give an example or situation that could be responsible for the following energy transformations

   a. electrical energy → light energy ________________________
   b. electrical energy → heat energy ________________________
   c. electrical energy → sound energy ________________________
   d. chemical energy → electrical energy ________________________
   e. chemical energy → heat energy ________________________
   f. kinetic energy → elastic potential energy ________________________
   g. elastic potential energy → kinetic energy ________________________
   h. sound energy → electrical energy ________________________
   i. electrical energy → sound energy ________________________
   j. light energy → electrical energy ________________________

<u>Most technological devices will produce more than one form of energy.</u>

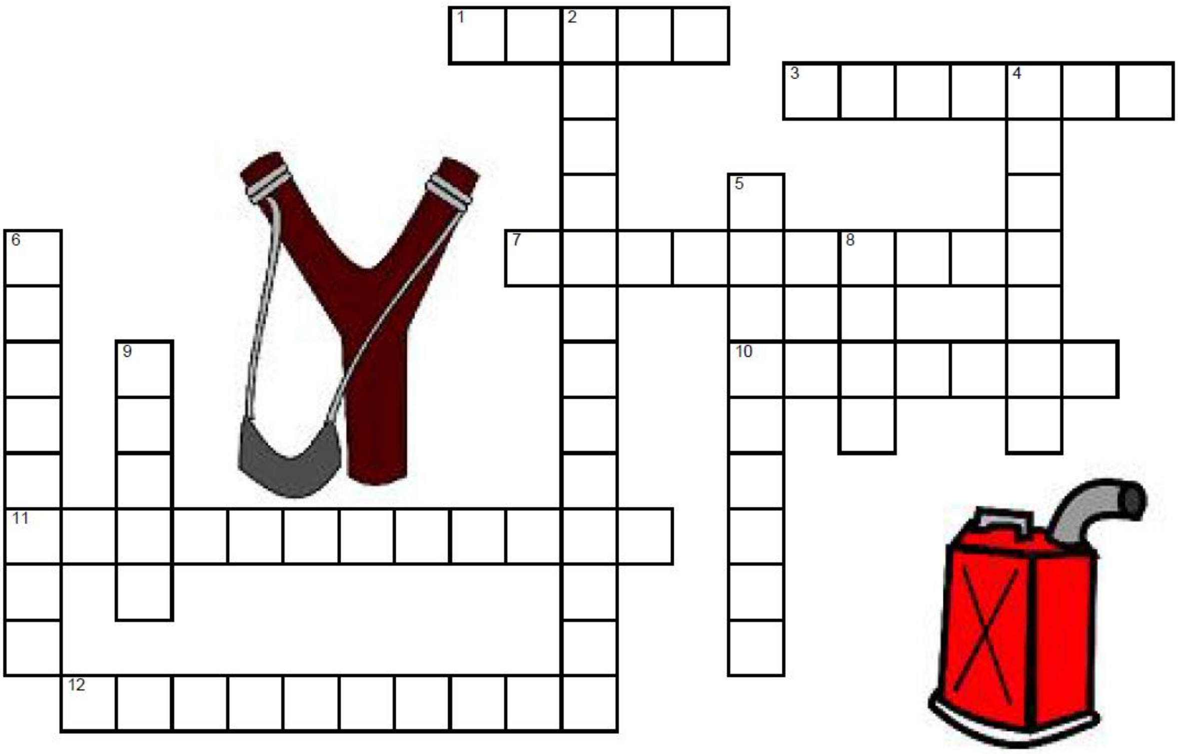
If we look at a mobile phone, we can see that it uses chemical energy to produce electrical energy. The electrical energy is transformed into the light coming from the screen and the sound coming from the speaker. There is one more form energy produced that is 'wasted' energy and it is heat. All mobile phones produce some heat energy.

The Energy Chain for a Mobile Phone is:

Chemical energy → electrical energy → Light + Sound + Heat

2. Write the Energy Chains for the following technologies. Underline any energies you would consider 'wasted' energy.
   a. Light bulb ____
   b. Hair Dryer ____
   c. Motor Cycle ____
   d. Fireworks ____
   e. Shot gun ____

3. Energy Crossword



Across

1. This is a type of electromagnetic energy.
3. This device changes electrical energy into sound energy
7. This device converts sound energy into electrical energy.
10. A stretched rubber band is an example of this type of potential energy.
11. The Law of __________ of Energy.
12. A solar cell transforms light energy into _____________ energy

Down

2. A book on a bookshelf 1 m above the ground has this type of potential energy.
4. A moving object has this type of energy.
5. Stored energy is also known as _______________ energy.
6. 1 Litre of gasoline has this type of potential energy.
8. A lighter transforms chemical potential energy into _______ energy
9. Vibrating objects produce this type of energy.

Gravitational Potential Energy - Notes

Gravitational potential energy (E_p) is the energy stored in an object as it is raised to a height.
The S.I. unit for Gravitational Potential Energy is the Joule (J)

Formula

$$\Delta E_p = mg\Delta h$$

ΔE_p = change in gravitational potential energy (J)
m = mass (kg)
g = acceleration due to gravity (10 ms^{-2})
Δh = change in height (m)

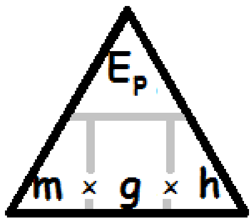
Example:
A forklift lifts a 500 kg crate to a height of 2.5 m. How much gravitational potential energy does the crate now have?

ΔE_p = ?
m = 500kg
g = 10 ms^{-2}
Δh = 2.5 m

$\Delta Ep = mg\Delta h$
$\Delta Ep = 500kg \times 10\ ms^{-2} \times 2.5\ m$
$\Delta Ep = 12\ 500\ J$

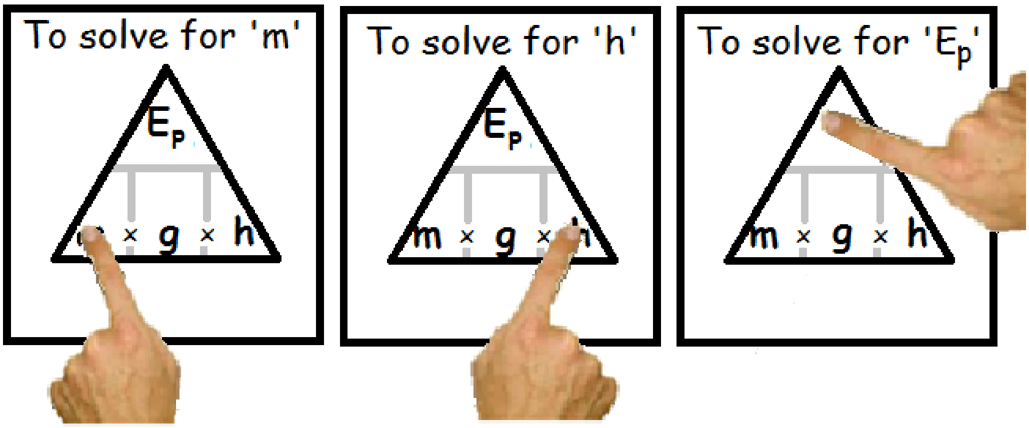
Magic Triangle
Although the gravitational potential energy formula has 4 variables, you can place it into a magic triangle to help you manipulate the formula to solve for any variable.

The formula, $\Delta \mathbf{E_p = mg\Delta h}$ can be converted to the magic triangle



Notice that the formula has **m** × **g** × **h**; the same must happen in the triangle, so **m**, **g** & **h** must be at the bottom of the triangle.

To use the triangle simply use your finger to cover the variable you wish to solve for. The remaining symbols tell you what to do.



If you wish to solve for mass:	If you wish to solve for height:	If you wish to solve for potential energy:
$m = E_p/gh$	$h = E_p/mg$	$E_p = mgh$

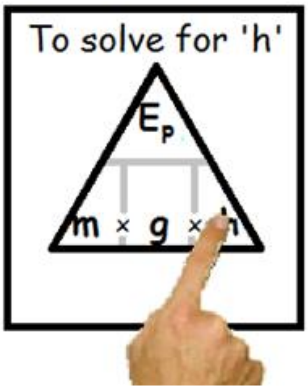
note - students often make a mistake on the calculator when dividing by two variables. You must divide both numbers. For example: $m = \frac{8J}{10ms^{-2} \times 2m}$

Many students will punch 8 ÷ 10 x 2 into their calculator; this is incorrect. You must divide by 10 and 2. The correct way to input this into the calculator is 8 ÷ 10 ÷ 2 or 8 ÷ (10 x 2).

Example: A giraffe in a zoo steals a woman's 10.0kg bag and lifts it to its full height. The raised bag now has 500 J of potential energy. How high did the giraffe lift the bag?

$E_p = 500J$
$m = 10.0kg$
$g = 10\ ms^{-2}$
$h = ?$

$\Delta h = \Delta E_p / mg$
$\Delta h = 500J/(10kg \times 10ms^{-2})$
$\Delta h = 500J/100\ kgms^{-2}$
$\Delta h = 5\ m$



Complete the table below:

Gravitational Potential Energy	Mass	Acceleration due to gravity	Height
200 J	10 kg	10 ms^{-2}	
500 J		10 ms^{-2}	5 m
6000 J	3 kg	10 ms^{-2}	
	25 kg	10 ms^{-2}	150 m
	1500 kg	10 ms^{-2}	2 m
9000 J	600kg		3 m

Gravitational Potential Energy Problems

1. A 1.5 kg cannon ball is shot 120 m straight into the air by a not too smart hyena. Calculate the ball's potential energy at this height.

2. A moose in a canoe is at the top of a 6.0 m waterfall. If the canoeist and canoe have a combined potential energy of36 kJ in relation to the bottom of the waterfall, what is the mass of the canoeist and his canoe?

3. A monkey has done 108 J of work to climb to the top of a high tree.
   a. How much gravitational potential energy has the monkey gained in climbing the tree?
   b. If the monkey has a mass of 600 g, how high up the tree is he?

4. A 1500 kg hippopotamus on a pogo stick is able to gain 4500 kJ of gravitational potential energy at the top of its bounce. What is the maximum height that the hippo reaches?

5. A monkey hanging on a vine in the jungle is 1.5 m from the ground.
   a. If the monkey's mass is 600g, what is his gravitational potential energy at this height?

   b. The monkey now climbs up the vine. He does 39 Joules of work to reach a new height on the vine. How high is the monkey above the ground at this new position?

6. A weightlifter lifts a 120 kg barbell up doing 2160 J of work.
   a. What is the gravitational potential energy of the barbell?
   b. How high was the barbell lifted?

Kinetic Energy - Notes

- Kinetic energy (E_k) is the energy of motion.
- Kinetic energy depends upon two quantities: Mass and Speed.
- The more massive a moving object is the more kinetic energy it has.
- The faster an object is moving the greater the kinetic energy. Objects that are not moving have no kinetic energy.
- The S.I. unit for Kinetic Energy is the Joule (J)

Formula

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

E_k = kinetic energy (J)

m = mass (kg)

v = speed (ms^{-1})

Example:

A 12 000 kg asteroid is hurtling toward Earth at 20 000 ms^{-1}. What is the kinetic energy of the asteroid?

E_k = ?

m = 12 000kg

v = 20 000 ms^{-1}

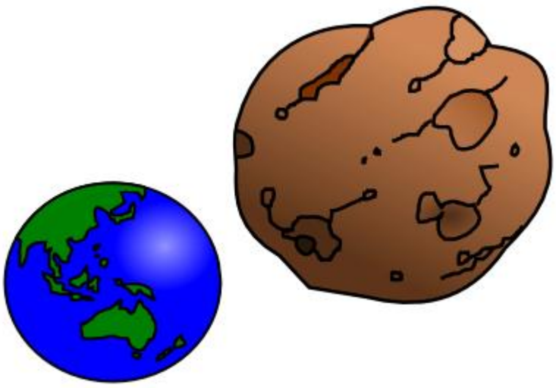
$E_k = \frac{1}{2}mv^2$

$E_k = \frac{1}{2} \times 12{,}000kg \times (20\ 000)^2$

E_k = 2400,000,000,000 J

E_k = 2400,000,000kJ

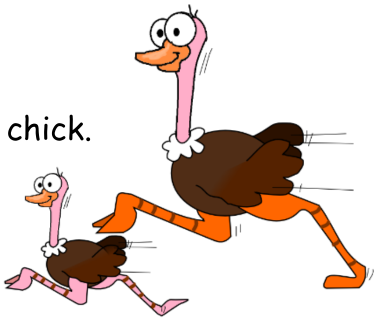
$E_k = 2.4 \times 10^9$ kJ



Kinetic Energy Problems

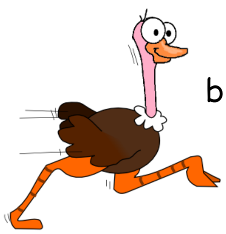
1. An 1800 kg speed boat is travelling across the water at a speed of 25.0 ms^{-1}. How much kinetic energy does the speed boat have?

2. An ostrich and her chick are running across the African Savannah, both at a speed of 10 ms^{-1}.
    a. Calculate the kinetic energy of the 80 kg mother bird.
    b. Calculate the kinetic energy of the 40 kg ostrich chick.



    c. Using the ostrich example, what effect does doubling the mass have on the kinetic energy?

3. Now two adult ostriches of an equal mass of 80 kg are racing across the savannah. One is much faster than the other.
    a. Calculate the kinetic energy of the ostrich travelling at 10 ms^{-1}.



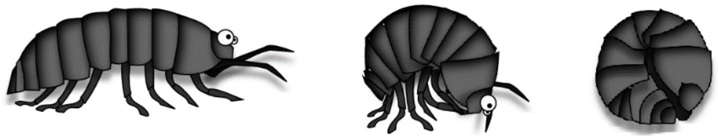
    b. Calculate the kinetic energy of the ostrich travelling at 20 ms^{-1}.

    c. Using the ostrich example, what effect does doubling the speed have on the kinetic energy?

Another Energy Problem

The previous questions dealt with energy transformations that were 100% efficient. In real life this is rarely the case. Energy is often lost as heat and sound.

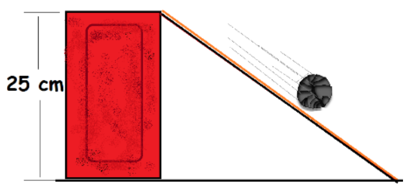
Pill-bugs can be considered pests of homes and gardens. They are closely related to the slaters (wood lice) that you will find in your gardens at home. Sometimes, children enjoy keeping them as pets. When these creatures are frightened they curl into tiny balls to protect themselves.



1. A 50 g pill-bug climbs to the top of a brick. Convert 50 g into kilograms.

2. The brick is 25 cm high. How much gravitational potential energy does the pill-bug have when it reaches the top of the brick?

3. The pill-bug becomes frightened and rolls into a ball and then rolls down a board that was leaning against the brick. At the bottom of the ramp, it is rolling at $2.0ms^{-1}$. How much kinetic energy does the rolling pill-bug have?



4. How does this compare to the gravitational potential energy of the bug at the top of the brick? Why are these two values different?

Answers

Key Terms

Energy, Gravitational Potential Energy, Joule, Kinetic Energy, Work

Write the key word next to its definition

Kinetic Energy	The energy of motion
GPE	The energy stored within an object when it is raised to a height
Energy	The ability to do work
work	A force acting over a distance
Joule	The S.I. unit for work and energy

Page 3

Complete the table below:

Force	Distance	Work
200 N	20 m	**4 000 J**
500 N	**200 m**	100 000 J
2 000 N	3 m	6000 J
5 000 N	25 km	125 000 000 J
150 N	**200 m**	30 000 J
200 N	6 m	1200 J

Work Problems

1. A wizard lifts a 8.0 kg book up 90 cm onto a table. What work has he done?

Step 1

$F = mg$

$F = 8kg \times 10\ ms^{-2}$

$F = 80\ N$

Step 2

$W = F \times d$

$W = 80N \times 0.9\ m$

$W = 72\ J$

2. A weight lifter did 6300 J of work when he lifted a 300 kg up over his head. How high did he raise the bar?

$W = Fxd$

$d = W/F$

$d = 6300J\ /\ 3000N$

$d = 2.1\ m$

3. A crane does 1000 kJ of work setting a steel beam into place 50 m above the ground. What is the mass of the beam?

$W = Fxd$

$F = W\ /\ d$

$F = 1\ 000\ 000J\ /\ 50m$

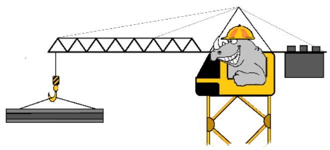
$F = 20\ 000N$

$F = mg$

$m = F\ /\ g$

$m = 20\ 000N/10ms^{-2}$

$m = 2000kg$



4. A gardener has a wheel barrow filled with 15 kg of soil, seeds and tools. He pushes it forward with a force of 20 N for 40 m. How much work has he done?

$W = F \times d$

$W = 20N \times 40m$

$W = 800J$

Forms of Energy

Match the different forms of energy below with the best description

gravitational potential, electrical, sound, heat, kinetic, light, chemical, elastic potential

Gravitational Potential Energy	Energy stored in an object when it is raised to a height.
Elastic potential energy	Energy stored when an object is stretched or squashed
sound	Energy caused by vibrating objects
chemical	Energy stored in the bonds between atoms
heat	Energy caused by the movement of particles
electrical	Energy due to moving electrons in a wire
light	Energy of electromagnetic waves

page 6

1. Give an example or situation that could be responsible for the following energy transformations

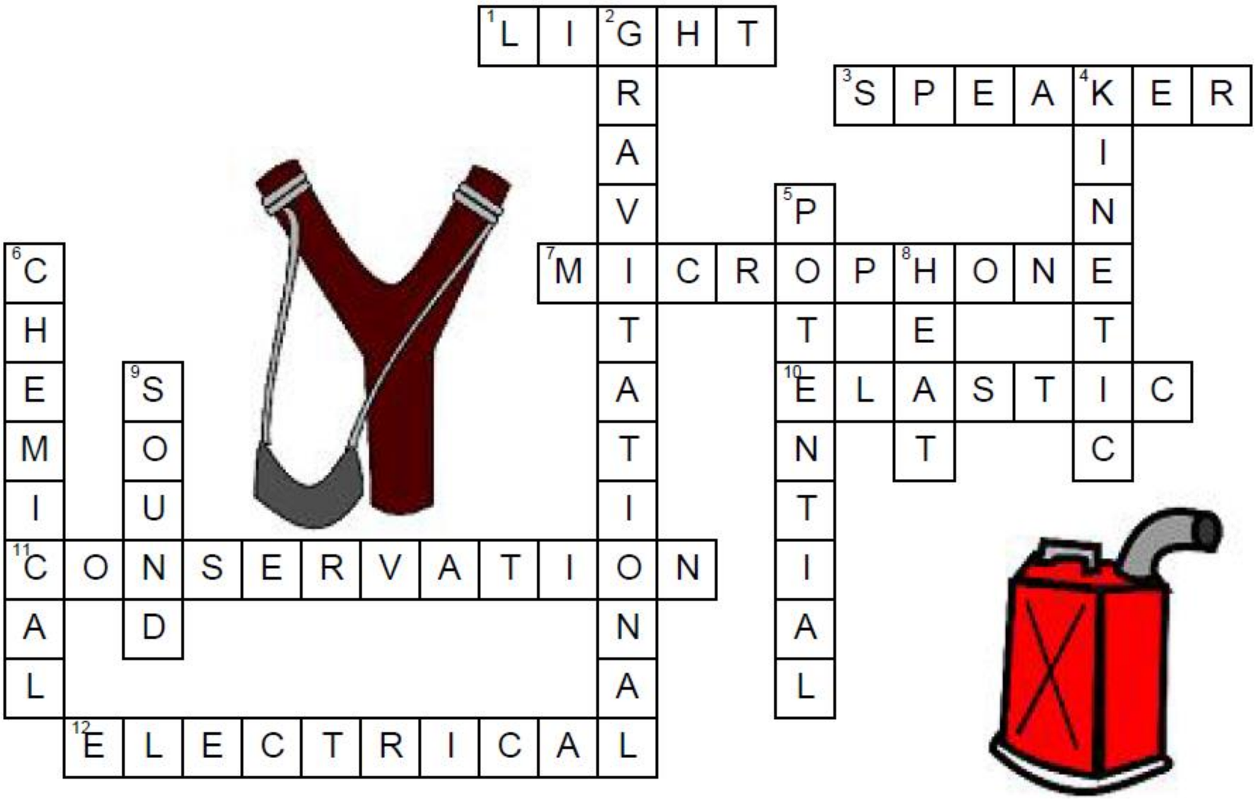
    a. electrical energy → light energy — light bulb
    b. electrical energy → heat energy — electric heater
    c. electrical energy → sound energy — speaker
    d. chemical energy → electrical energy — battery
    e. chemical energy → heat energy — camp fire
    f. kinetic energy → elastic potential energy — wind-up toy
    g. elastic potential energy → kinetic energy — bow & arrow
    h. sound energy → electrical energy — microphone
    i. electrical energy → sound energy — school bell
    j. light energy → electrical energy — photovoltaic cell

page 7

2. Write the Energy Chains for the following technologies. Underline any energies you would consider 'wasted' energy.

    a. Light bulb — electrical energy → light + <u>heat</u>
    b. Hair Dryer — electrical energy → kinetic + heat + <u>sound</u>
    c. Motor Cycle — chemical energy → kinetic + <u>heat</u> + <u>sound</u>
    d. Fireworks — chemical energy → kinetic + light + sound + heat
    e. Shot gun — chemical energy → kinetic + <u>sound</u> + <u>light</u> + <u>heat</u>

3. Energy Crossword



Complete the table below:

Gravitational Potential Energy	Mass	Acceleration due to gravity	Height
200 J	10 kg	10 ms^{-2}	**2m**
500 J	**10 kg**	10 ms^{-2}	5 m
6000 J	3 kg	10 ms^{-2}	**200 m**
37500 J	25 kg	10 ms^{-2}	150 m
30 000 J	1500 kg	10 ms^{-2}	2 m
9000 J	600kg	**5 ms^{-2}**	3 m

Gravitational Potential Energy Problems

1. A 1.5 kg cannon ball is shot 120 m straight into the air by a not too smart hyena. Calculate the ball's potential energy at this height.

E_p = mgh

E_p = 1.5kg x 10ms^{-2} x 120m

E_p = 1800 J = 1.8 kJ

2. A moose in a canoe is at the top of a 6.0 m waterfall. If the canoeist and canoe have a combined potential energy of36 kJ in relation to the bottom of the waterfall, what is the mass of the canoeist and his canoe?

$$m = \frac{E_p}{g \times h}$$

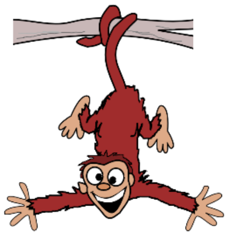
$m = 36\ 000J \div (10 \times 6.0m)$

$m = 600\ kg$

3. A monkey has done 108 J of work to climb to the top of a high tree.
   a. How much gravitational potential energy has the monkey gained in climbing the tree?

      $Ep = work$

      $Ep = 108\ J$



   b. If the monkey has a mass of 600 g, how high up the tree is he?

$$h = \frac{E_p}{m \times g}$$

$h = 108J \div (0.600kg \times 10ms^{-2})$

$h = 18\ m$

page 11

4. A 1500 kg hippopotamus on a pogo stick is able to gain 4500 kJ of gravitational potential energy at the top of its bounce. What is the maximum height that the hippo reaches?

$$h = \frac{E_p}{m \times g}$$

$h = 4500J \div (1500\ kg \times 10ms^{-2})$

$h = 0.30\ m$ (30cm)

5. A monkey hanging on a vine in the jungle is 1.5 m from the ground.

   a. If the monkey's mass is 600g, what is his gravitational potential energy at this height?

$E_p = 1.5m \times 10ms^{-2} \times 0.60kg$

$E_p = 9.0\ J$

   b. The monkey now climbs up the vine. He does 39 Joules of work to reach a new height on the vine. How high is the monkey above the ground at this new position?

$$h = \frac{E_p}{m \times g}$$

$h = 39J \div (0.600kg \times 10ms^{-2})$

$h = 39J \div (0.600kg \times 10ms^{-2})$

$h = 6.5\ m$

new height = 1.5m + 6.5m = <u>8.0 m</u>

6. A weightlifter lifts a 120 kg barbell up doing 2160 J of work.

   a. What is the gravitational potential energy of the barbell?

   Ep = work

   Ep = 2160 J

   b. How high was the barbell lifted?

$$h = \frac{E_p}{m \times g}$$

$h = 2160J \div (120kg \times 10ms^{-2})$

$h = 1.8\ m$

Kinetic Energy Problems

1. An 1800 kg speed boat is travelling across the water at a speed of 25.0 ms^{-1}. How much kinetic energy does the speed boat have?

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

$E_k = \frac{1}{2}$ 1800kg x $(25.0ms^{-1})^2$

E_k = 562500 J

E_k = 563 kJ

2. An ostrich and her chick are running across the African Savannah, both at a speed of 10 ms^{-1}.
   a. Calculate the kinetic energy of the 80 kg mother bird.

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

   $E_k = \frac{1}{2}$ 80kg x $(10ms^{-1})^2$

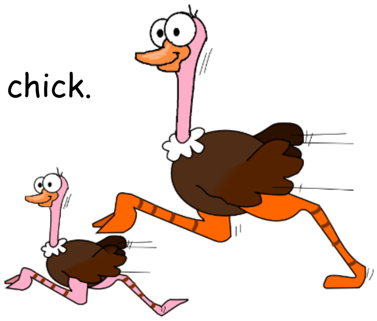
   E_k = 4000 J

   b. Calculate the kinetic energy of the 40 kg ostrich chick.

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

   $E_k = \frac{1}{2}$ 40kg x $(10ms^{-1})^2$

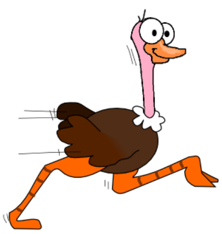
   E_k = 2000 J



   c. Using the ostrich example, what effect does doubling the mass have on the kinetic energy?

   If you double the mass you double the kinetic energy

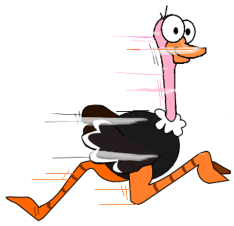
3. Now two adult ostriches of an equal mass of 80 kg are racing across the savannah. One is much faster than the other.
   a. Calculate the kinetic energy of the ostrich travelling at 10 ms^{-1}.



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

   $E_k = \frac{1}{2}$ 80kg x $(10ms^{-1})^2$

   E_k = 4000 J



b. Calculate the kinetic energy of the ostrich travelling at 20 ms^{-1}.

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

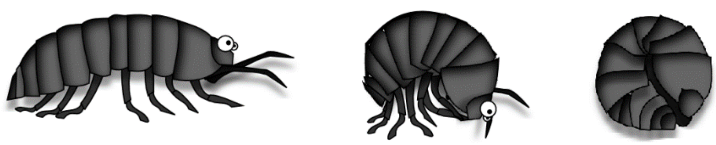
$E_k = \frac{1}{2}\ 80kg \times (20ms^{-1})^{2}$

$E_k = 16\ 000\ J$

c. Using the ostrich example, what effect does doubling the speed have on the kinetic energy?

Doubling the speed quadruples the kinetic energy

Another Energy Problem



Page 14

1. A 50 g pill-bug climbs to the top of a brick. Convert 50 g into kilograms.

$50\ g \div 1000 = 0.050\ kg$

2. The brick is 25 cm high. How much gravitational potential energy does the pill bug have when it reaches the top of the brick?

$E_p = mgh$

$E_p = 0.050kg \times 10\ ms^{-2} \times 0.25m$

$E_p = 0.125$ Joules

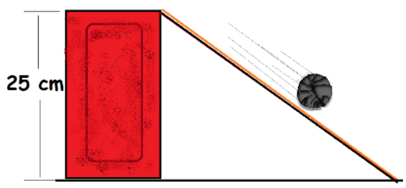
$E_p = 0.13$ Joules (2 s.f.)

3. The pill-bug becomes frightened and rolls down a board that was leaning against the brick. At the bottom of the ramp it is rolling at $2.0ms^{-1}$. How much kinetic energy does the rolling pill bug have?

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

$E_k = \frac{1}{2}\ 0.05kg \times (2.0ms^{-1})^2$

$E_k = 0.10$ Joules



4. How does this compare to the gravitational potential energy of the bug at the top of the brick? Why is it different?

The pill-bug has 0.13 Joules of energy at the top of the ramp in the form of gravitational potential energy. At the bottom of the ramp there is only 0.10 Joules of kinetic energy. This means that approximately 0.03 Joules of energy have been lost as heat and sound as the little crustacean rolls down the ramp.

**note* in actual fact most of the 'lost' energy is rotational kinetic energy, but this type of kinetic energy is beyond the scope of this level of physics.*