Physics Factsheet

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Energy Changes for Vertical Motion

- What energy changes occur when an object falls?
- How is the original height of an object related to the speed before impact?
- What is the effect of air resistance on these energy changes?

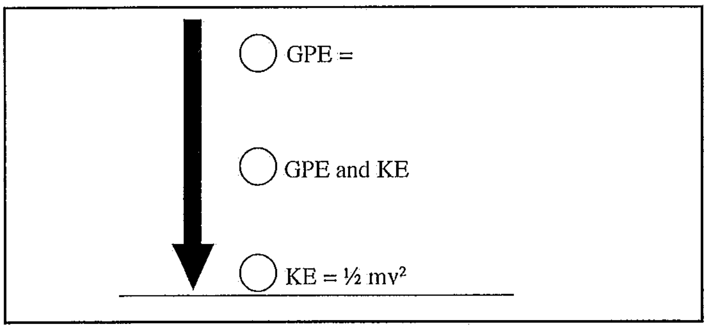
A moving object has kinetic energy, $KE = 1/2mv^2$. When an object changes height, there is a change in gravitational potential energy, $\Delta GPE = mg\Delta h$.

Relate these two expressions for a falling object $1/2mv^2 = mg\Delta h$. Then rearrange for speed.

$1/2v^2 = g\Delta h$ $\quad v^2 = 2g\Delta h$ $\quad v = \sqrt{(2g\Delta h)}$

So, with negligible air resistance, the speed of a falling object is **only** dependent on the change in height, and NOT the mass of the object.

Vertical motion energy changes



The speed of a falling object does NOT depend on the mass of the object (negligible air resistance)

Exam Hint: *Try to rearrange the KE and GPE equations yourself to produce $v = \sqrt{(2g\Delta h)}$*

Worked example 1

(a) Rearrange the kinetic energy and gravitational potential energy equations to show the relationship between the speed and change in height for a falling object assuming negligible air resistance (4 marks).

(b) (i) Determine the speed of a 1kg mass that falls 13m (2 marks)

(ii) State the speed of a 1g mass that also falls 13m (1 mark).

(c) State and explain the energy changes for a falling object that hits the ground (2 marks)

Answers

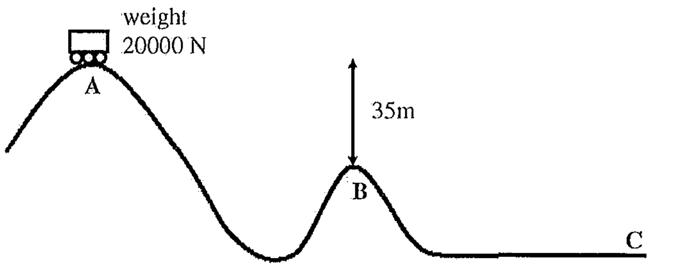
(a) See above for this mathematical proof.

(b)(i) $v = \sqrt{(2g?h)} = \sqrt{(2 \times 9.81Nkg^{-1} \times 13m)} = 16.0ms^{-1}$

(ii) $16.0ms^{-1}$

(c) Before the object is dropped, it has only GPE. This becomes KE as it falls. When the object hits the ground and comes to rest, this KE becomes thermal energy, warming the surroundings.

Worked example 2



A roller coaster moves from A to C.

(i) Determine the change in GPE of the roller coaster from A to B.

(ii) Calculate the maximum speed of the roller coaster at B.

(iii) Explain why the speed of the roller coaster is likely to be less than this maximum.

Answers

(i) $\Delta GPE = mg\Delta h$ Change in gravitational potential energy $= 20{,}000N \times 35m = 7.0\times10^5J$.

(ii) $v = \sqrt{(2g?h)} = \sqrt{(2 \times 9.81N/kg \times 35m)} = 26.2ms^{-1}$

(iii) The maximum speed assumes that there is a 100% transfer of GPE to KE. In reality, some energy would be transferred into other forms, such as heat due to the force of friction between rails and wheels.

Exam Hint: *Take care when dealing with mass or weight. $\Delta GPE = mg\Delta h$ OR $\Delta GPE = weight \times \Delta h$*

Just before an object hits the ground, all of the gravitational potential energy has become kinetic energy. When it hits, this kinetic energy becomes heat energy, the object and surroundings become warmer.

When a falling object comes to rest, all of the original GPE becomes thermal energy, warming the surroundings.

In reality, as objects fall faster, air resistance has a bigger effect. When the air resistance balances the weight of an object, it travels at a steady speed. How does this affect the energy changes? The object still loses gravitational potential energy as it falls. However, it is NOT gaining kinetic energy, as it is not falling more quickly.

Where does this GPE go?

The object is applying a force on the air particles. This causes heating, warming the air and object up as it passes.

If a falling object travels at a steady speed, gravitational potential energy is converted into heat energy.

Exam Hint: *When an object falls at a steady speed due to air resistance, the loss in GPE is EQUAL to the work done on the air particles.*

Worked example 3

(a) A 1kg mass falls 15m at a constant velocity.

(i) Calculate the change in gravitational potential energy for the mass (2 marks).

(ii) State and explain how much work is done on the air particles by the falling mass (3 marks).

(b) Explain why the object is travelling with constant velocity, quoting an appropriate Newton's Law of motion (2 marks).

Answer

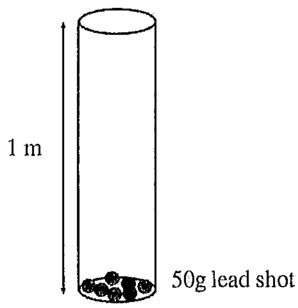
(a) (i) $\Delta GPE = mg\Delta h$ Change in gravitational potential energy $= 1kg \times 9.81N/kg \times 15m = 147.2\ J$

(ii) 147.2 J. The mass is not accelerating so there is no gain in kinetic energy. The gravitational potential energy is transferred into thermal energy in the air. The falling mass does work against the air particles.

(b) The upward force of air resistance balances the downward force of the weight; Newton's first law of motion states that an object will travel at a constant velocity (which could be zero) unless an unbalanced force acts.

Worked example 4

An experiment is carried out with 50g of lead in a 1m sealed tube. The tube is inverted 100 times.



Calculate the temperature change for the lead. The specific heat capacity of lead is $130Jkg^{-1}K^{-1}$. Assume no energy transfer to the surroundings.

Answer

The lead effectively falls 100m.
The corresponding loss in GPE = mgh
$= 0.05kg \times 9.81Nkg^{-1} \times 100m = 49.05J$.
This warms up the lead.

The relationship for specific heat capacity;

Energy change = mass × temperature change × specific heat capacity.

$49J / (0.05kg \times 130Jkg^{-1}K^{-1}) = 7.5K$.

Practice Questions

1. (a) Calculate the change in gravitational potential energy for 1kg of water in a 9m waterfall. (1mark)

   (b) Calculate the temperature change of water due to this waterfall. The specific heat capacity of water is $4200Jkg^{-1}\ K^{-1}$. Assume no energy is transferred to the surroundings. (2 marks)

2. (a) Determine the velocity of a rollercoaster due to a 45m drop. (Assume zero velocity at the top of the drop.) (2 marks)

   (b) Explain why the velocity is likely to be different in reality. (2 marks)

3. (a) A 1.5m tube containing 12g of lead shot is inverted 25 times. Calculate the corresponding temperature change of the lead. The specific heat capacity of lead is $130Jkg^{-1}K^{-1}$ (3 marks)

   (b) State what assumptions you have made in this calculation.

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Answers
1) a) 88.3J b) 2.1×10^{-2} K
2) a) $29.7ms^{-1}$
3) a) 0.11K