PHYSICAL SCIENCE

WORK ENERGY AND POWER

GRADE 12

basic education
Department:
Basic Education
REPUBLIC OF SOUTH AFRICA

Read to Lead
A Reading Nation is a Leading Nation

2030 NDP

Foreword

In order to improve learning outcomes the Department of Basic Education conducted research to determine the specific areas that learners struggle with in Grade 12 examinations. The research included a trend analysis by subject experts of learner performance over a period of five years as well as learner examination scripts in order to diagnose deficiencies or misconceptions in particular content areas. In addition, expert teachers were interviewed to determine the best practicesto ensure mastery of thetopic by learners and improve outcomes in terms of quality and quantity.

The results of the research formed the foundation and guiding principles for the development of the booklets. In each identified subject, key content areas were identified for the development of material that will significantly improve learner's conceptual understanding whilst leading to improved performance in the subject.

The booklets are developed as part of a series of booklets, with each bookletfocussing onlyon one specific challenging topic. The selected content is explained in detail and include relevant concepts from Grades 10 - 12 to ensure conceptual understanding.

The main purpose of these booklets is to assist learners to master the content starting from a basic conceptual level of understanding to the more advanced level. The content in each booklets is presented in an easy to understand manner including the use of mind maps, summaries and exercises to support understanding and conceptual progression. These booklets should ideally be used as part of a focussed revision or enrichment program by learners after the topics have been taught in class. The booklets encourage learners to take ownership of their own learning and focus on developing and mastery critical content and skills such as reading and higher order thinking skills.

Teachers are also encouraged to infuse the content into existing lesson preparation to ensure in-depth curriculum coverage of a particular topic. Due to the nature of the booklets covering only one topic, teachers are encouraged to ensure learners access to the booklets in either print or digital form if a particular topic is taught.

Table of Contents

2. HOW TO USE THIS BOOKLET

- This book in intended to assist and guide you through the topics. It is complementary to your textbooks, worksheets and other learning materials that you might have. Your efforts to practise and master the concepts outlined will assist you to become confident about the learning and assessments you will do.
- Ensure that you understand all the relevant concepts, formulae, etc.
- Do extra research on your own to get more information on the topics in this booklet. It is important that you discuss your understanding of your findings with fellow learners.
- Work through the examples given in each topic, master them and try to develop more examples yourself. You must work through the examples in your textbooks. There are exercises for you to do at the end of Unit 5 of this study guide. Work through them on your own and compare them with the answers provided in Unit 6.
- When you are doing calculations, take note of all the information given. It is intended to help you. Read the given information with the intention of understanding what you must do with it. Always look for action verbs, in order to answer correctly, *e.g. determine, explain, discuss, calculate, list, compare, etc.*
- If you are given measurements in millimetres (mm), convert it into metres.
- Familiarise yourself with the scientific notations used, e.g. kilo, mega, giga, and write them as 10^x.
- It is important to show SI units in the final answer. This will earn you marks.
- An extract from the examination guidelines is included at the beginning of each topic. You must use these to check what you are expected to master. Revise what you have not yet mastered and do more exercises.

3. STUDY AND EXAMINATION TIPS

General guidelines

Here are some general guidelines to help you to succeed:

Prepare well in advance

You cannot ensure success if you only study the week or a few days before an exam. Plan your way to success six months before the exam (or even from the beginning of the year).

Study timetable

- Set up a study timetable, so that you systematically revise all the material on which you will be examined on. For the Physical Sciences (and Mathematics) papers, this includes aspects of your Grade 10 and Grade 11 work. Study for 3 or 4 hours every day during school days, and for 5-7 hours per day over weekends and during school holidays. Study in 50-minute blocks, with a 10-minute break in between. Breaks are important.
- **Above all, stick to your timetable.**
- Don't wait until tomorrow, or next week, or next month – learning and understanding doesn't take place magically.
- Do whatever homework is required; then study.
- Read your notes / textbook, write summaries, calculate answers, and memorise definitions every day.

Eat, sleep and exercise

Eat properly and healthily. Get enough sleep – not too little and not too much. Studying through the night doesn't help. The brain requires sleep to fix learning into long-term memory. And sleeping more than your body requires just tires you out. Exercise daily – even if it is only for 20 minutes. A fast walk, a short jog, or some conditioning exercise all help to keep the mind fresh, active and capable of learning. Exercise that totally exhausts you is counter-productive.

Study skills to accelerate your learning

1) **Ask 'Why?' – 'Why, Why, Why?'**
   Asking "why" questions works by encouraging you to integrate a new fact with things that you already know. Doing so improves your memory for the new fact by giving you more "hooks" to retrieve it. Don't just accept it – ask yourself why you should accept it.

2) **Explain to yourself**

After answering a problem, or reading some text, ask yourself what this means to you. What inferences can you draw? Can you connect this with some other part of the work you have studied? How would you explain this to a friend?

3) **Practise testing**

Actively test your memory. It improves learning by exercising memory retrieval. It helps you to store the information in your long-term memory. Do on-line tests, answer questions from your textbook, etc. This works best when you can check your answers (but don't just read the answers).

Memorisation tips

- Surely you can memorise the 30 definitions you must know as part of a particular subject?
- Definitions, terms, laws, etc. form the **vocabulary** of a subject such as Physical Science and therefore it is very important **to know them.**
- Knowing involves two things: **understanding** and **remembering.** Of these two, understanding is far more important. You must try to understand what the various concepts and terms mean.
- Nevertheless, some things have to be **committed to memory.** Use these tips / tricks to help you.
- **Repetition:** You can't memorise anything without repetition – be it verbal or in writing. As you repeat a definition by saying it aloud or writing it down, think of context and meaning to focus your remembering.
- **Mnemonic devices** are word-tools to help you remember:
- **Acronyms:** such as ROYGBIV (What Physical Science learner has not heard of dear old Roy?) or BODMAS (in Mathematics).
- **Acrostics:** these are sentences that use the first letter of words or a list, etc., e.g. Please Excuse My Dear Aunt Susie (**P**arentheses, **E**xponents, **M**ultiplication, **D**ivision, **A**ddition, **S**ubtraction). Develop your own.
- **Chunking / grouping:** Group information together and memorise it as a set. If each set has three entries, this will prod your memory if you can only remember two.
- **Associations / linking:** Link the material being memorised with images, smells, touch, personal circumstances, etc. The more senses that are involved, the better the remembering.
- **Mindmaps:** Draw a mindmap of a concept / idea / subject. Then explore the connections between concepts.
- **Key words:** Write out definitions, etc. Then highlight and memorise the key words in a definition.

- **Erase to remember:** Write out what you need to recall for an exam completely in pencil. Progressively erase words as you commit them to memory.
- **Be selective -** you cannot memorise everything.
- **Work with a friend (or small group):** Take turns to define a concept or term or explain a method orally. Give clues when your friend has difficulty remembering.
- **A good night's sleep.** Research shows that sleep is crucial in establishing long-term memory.

Past Papers

- Practise questions from previous examination papers.
- *Instructions.* Take careful note of all instructions – for the paper as a whole, and for each question.
- *Don't cheat.* Try to answer the questions without looking at your notes or at the solutions.
- *Time yourself.* Divide the time allocated (in minutes) by the total number of marks for a paper. This gives you the time per mark. In your Physical Sciences exams, you need to work at a rate of about 1 mark per minute. Practise this again and again.
- *Memo.* Check your working against the memo. If the answer is wrong, try it again. Note that understanding the question and answering is more important than getting the answer right.
- *Why?* Work with your friends and challenge each other by asking *Why?* Why this? Why that? Help each other to understand the question and the answer. Understanding the subject gives you the best chance of passing the exam.

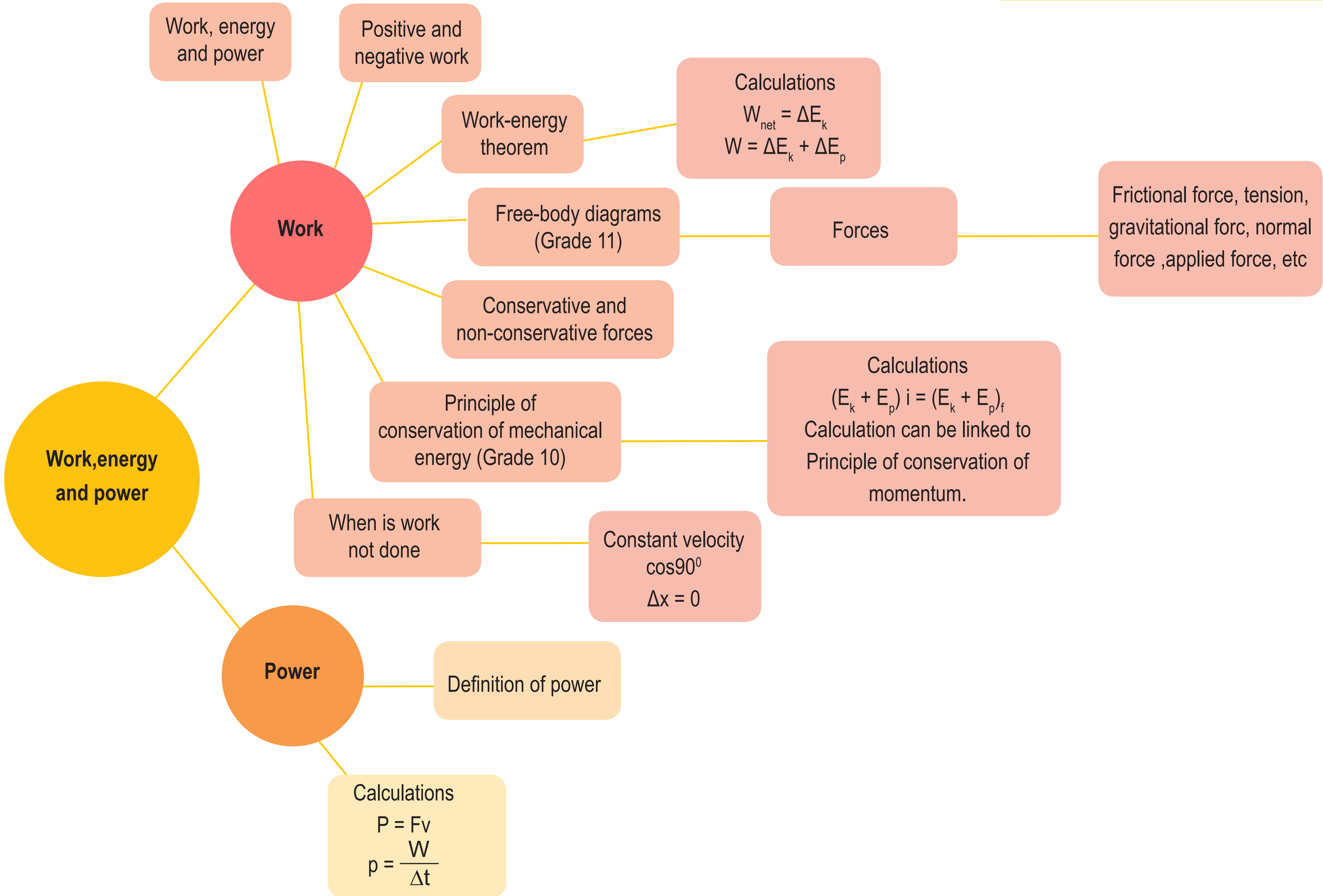
In the exam venue

- When you receive the exam paper, *calmly read* through all the instructions at the beginning of the paper. This is very important, as you don't want to answer questions you may skip and so waste time and lose marks.
- Write all your details on the answer sheet.
- Read through *each question carefully* before you rush to answer it. Underline key words, and note instructions and CAPITALIZED words. Are you given any choices between questions and within questions?
- Note the *mark allocation* – don't spend 20 minutes on a 10-mark question.
- Number your answers correctly, beginning each new question on a new page.
- Set out your answers clearly and legibly. Leave plenty of space between questions and sections.

4. OVERVIEW OF WORK ENERGY POWER

This section must be read in conjunction with the CAPS document p. 117-120.

MINDMAP: WORK ENERGY POWER



Work

- Define the work done on an object by a constant force F as $F \Delta x \cos \theta$ where: F is the magnitude of the force; Δx is the magnitude of the displacement; and θ is the angle between the force and the displacement. (Work is done by a force. The use of the phrase 'work is done against a force', e.g. work done against friction, must be avoided).
- Draw a force diagram and free-body diagrams.
- Calculate the net work done on an object.
- Distinguish between positive net work done and negative net work done on a system.

Work-Energy Theorem

- State the work-energy theorem: The net work done on an object is equal to the change in the object's kinetic energy. OR The work done on an object by a net force is equal to the change in the object's kinetic energy.
    - o In symbols: $W_{net} = K = K_f - K_i$.
- Apply the work-energy theorem to objects on horizontal, vertical and inclined planes (for both frictionless and rough surfaces).

Conservation of energy with non-conservative forces present

- Define a conservative force as a force for which the work done in moving an object between two points is independent of the path taken. Examples are gravitational force, the elastic force in a spring and electrostatic forces (coulomb forces).
- Define a non-conservative force as a force for which the work done in moving an object between two points depends on the path taken. Examples are frictional force, air resistance, tension in a chord, etc.
- State the principle of conservation of mechanical energy: The total mechanical energy (sum of gravitational potential energy and kinetic energy) in an isolated system remains constant.
    - o A system is isolated when the net external force acting on the system is zero.
- Solve conservation of energy problems using the equation: $W_{nc} = \Delta E_k + \Delta E_p$
- Use the relationship above to show that, in the absence of non-conservative forces, mechanical energy is conserved.

Power

- Define power as the rate at which work is done or energy is expended.
  In symbols: $P = \frac{W}{\Delta t}$
- Calculate the power involved when work is done.
- Perform calculations using $P_{ave} = Fv_{ave}$ when an object moves at a constant speed along a rough horizontal surface or a rough inclined plane.
- Calculate the power output for a pump lifting a mass, e.g. lifting water through a height at constant speed.

Work, energy and power definitions

GRADE 10 - ENERGY	
Gravitational potential energy (EP): $E_p = mgh$	The energy that an object has owing to its position in the Earth's gravitational field relative to a reference point.
Isolated system (Closed system)	A system on which no external forces act (e.g. friction).
Kinetic energy (EK): $E_k = \frac{1}{2} mv^2$	The energy of an object owing to its motion.
Law of conservation of energy	Energy cannot be created or destroyed – it can only be transferred from one form to another.
Mechanical energy (Em): $E_m = E_k + U$	The sum of the gravitational potential energy and the kinetic energy of an object.
Principle of conservation of mechanical energy: $(E_K + U)_{top} = (EK + U)_{bottom}$	The total mechanical energy in an isolated system remains constant.
GRADE 12 - WORK, ENERGY AND POWER	
The work done on an object by a constant force F: $W = F\Delta x cos\theta$	The work done on an object by a constant force, F, where: $F \Delta x \cos \theta$ F is the magnitude of the force; Δx is the magnitude of the displacement; θ is the angle between the force and the displacement
The work-energy theorem: $W_{net} = \Delta E_K$	The net/ total work done on an object is equal to the change in the object's kinetic energy. OR The work done on an object by a resultant/ net force is equal to the change in the object's kinetic energy.
Conservative force:	A force for which the work done in moving an object between two points is independent of the path taken.
Non-conservative force: $W_{net} = \Delta E_K + \Delta U$	A force for which the work done in moving an object between two points depends on the path taken.
The principle of conservation of mechanical energy: $(E_K + U)_{top} = (E_K + U)_{bottom}$	The total mechanical energy (sum of gravitational potential energy and kinetic energy) in an isolated system remains constant.
Power: $P = \frac{W}{\Delta t}$	The rate at which work is done or energy is expended.

5. WORK, ENERGY AND POWER

5.1 Key concepts

Make sure that you are able to do the following:

- Draw force and free-body diagrams and solve problems for different situations. For example:
  - A stationery object on a horizontal surface, on an incline or hanging from a rope.
  - An object moving vertically upwards or downwards, with or without an applied force.
  - An object moving on a horizontal surface:
    - ✓ with or without a force applied to it.
    - ✓ with a force applied horizontally or at an angle to the horizontal plane.
    - ✓ with a force applied in a direction opposite to the direction of motion.
    - ✓ In the presence or in the absence of friction.
  - An object moving on an inclined surface:
    - ✓ with or without a force applied to it.
    - ✓ with a force applied in a direction opposite to the direction of motion.
    - ✓ in the presence or in the absence of friction.
  - Know and understand the following:
    - ✓ What is work?
    - ✓ Positive work?
    - ✓ Negative work?
  - The difference between F and F_{net} and between W and Wnet.
  - Work energy theorem
  - Conservation of energy with non-conservative forces present.
  - Power

5.2 Drawing free body diagrams

Avoid doing the following:

- Drawing a force diagram instead of a free-body diagram.
- Drawing a free-body diagram for an object on an incline, when the object is on a horizontal surface and vice versa.
- Resolving a force (the weight of an object on an incline and a force acting at an angle) into its components and then including the force and the components in one diagram.

- Including a frictional force when friction should be ignored or omitting the frictional force when there is friction.
- Incorrect representation of the normal force when the object is on an inclined plane.
- Incorrect labeling of forces.
- Drawing straight lines without arrow-heads.
- Including the normal force for an object that is hanging.

5.3 Calculations / solving problems

- Identify the correct initial and final velocities and do not swap these two velocities.
- Understand the meaning of F and F_{net} and W and W_{net}. F_{net} is the sum of all the forces acting on an object. W_{net} is the sum of the work done by all the forces. F is a single force acting on an object, while W is the work done by ONE force.
- Do not leave out the subscripts in the formulae, i.e. writing F or W instead of F_{net} or W_{net}.
- Do not include a frictional force where friction should be ignored or leave out the frictional force where there is friction.
- Remember that friction always acts in the opposite direction to the motion of an object.
- Make sure you understand the concept of negative work. Note that an object can be moving in one direction whilst a force is acting in the opposite direction and this force may not necessarily be frictional force.
- When a force does negative work on an object, energy is removed from the object and converted to other forms of energy such as heat. (The object becomes warmer.)

5.4 Work

DEFINITION OF WORK

Use the definition from the exam guidelines, which should have been given to you. Define the work done on an object by a constant force F as $F \Delta x \cos \theta$, where: F is the magnitude of the force; Δx is the magnitude of the displacement; θ is the angle between the force and the displacement. (Work is done by a force. The use of the phrase 'work is done against a force', e.g. work done against friction, must be avoided).

5.5 Calculating the net work done on an object

In the past, the following formulae were acceptable.

$W = F\,x\,s$ and $W = F\Delta x$. Both formulae are **not acceptable,** so please do not use them.

ACCEPTABLE FORMULAE:

- $W = F\Delta x\cos\theta$ for work done by a single force.
- $W_{net} = F_{net}\Delta x\cos\theta$ for work done by a net force (total work done by all the forces acting on an object).

Where F_{net} is the magnitude of the net force / the magnitude of the sum of all the forces acting on the object.

W_{net} is the net work / the sum of all the work done by each of the forces acting on the object.

$F\Delta x$ = the magnitude of the displacement.

θ= the angle between the force and the displacement.

5.6 Summary of two methods of determining the net work done.

Use any one of the methods given below.

5.6.1 METHOD ONE:

- Draw a force / free-body diagram of all the forces acting on the object.
- Determine the angle θ between each force and the direction of motion / displacement.
- Use $W = F\Delta x\cos\theta$ to determine the work done by each force.
- Calculate the sum of the work done by all the forces, i.e.: $W_{net} = W_1 + W_2 + W_3 +$

5.6.1 METHOD TWO:

- Draw a force / free-body diagram of all the forces acting along the plane of motion of the object.
- Ignore the forces that act perpendicular to the plane, because they do zero work on the object.
- Calculate the net force / the sum of the forces acting parallel to the plane, i.e.: $Fnet = F_1 + F_2 + F_3 +$

- Calculate the work done on the object using (F_{net}) i.e.:

  $W_{net} = F_{net} \Delta x cos\theta$

  Positive work

  – Positive work is done on an object by a force when the angle between the force and the displacement is less than 90^0.

  – When positive work is done on an object, the energy of the object increases.

  Negative work

  – Negative work is done on an object by a force when the angle between the force and the displacement is greater than 90^0 and less than or equal to180^0, i.e. $cos90^0 = 0$ and $cos180^0 = -1$.

  – When negative work is done on an object, the energy of the object decreases.

  Zero work

  – Zero work is done on an object when the angle between the force and the displacement is 90^0.

  The difference between F and F_{net} and between W and W_{net}:

  – F represents a single force, whilst F_{net} represents the sum of forces acting on an object.

    W represents work done by a single force whilst W_{net} represents the sum of the work done by all the forces acting on an object.

5.7 Work-energy theorem

The net work done on an object is equal to the change in the object's kinetic energy.

$$\begin{aligned} W_{net} &= \Delta E_k \\ &= E_{kf} - E_{ki} \end{aligned}$$

5.8 Conservation of energy with non-conservative forces present

What is a conservative force?

- A force is a conservative force if the net work done by the force is zero while moving the object around a closed path, starting and ending at the same point.

OR

- A force is conservative if the net work done by the force in moving an object does not depend on the path taken.
- If a conservative force is the only force acting on an object during its motion, the mechanical energy of the object is conserved.
- Examples of conservative forces are the gravitational force and electrostatic force.

What is a non-conservative force?

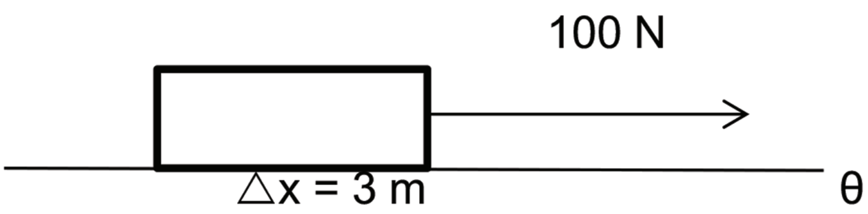
- A force is a non-conservative force if the work done by the force causes a change in the sum of the gravitational potential energy and the kinetic energy, and thus, to the mechanical energy of the object. OR
- A force is non-conservative if the net work done by the force in moving an object depends on the path taken.
- If a non-conservative force acts on an object, the mechanical energy of the object will not be conserved.
- Examples of non-conservative forces are frictional force, air resistance, an applied pulling or pushing force or tension in a rope.
- Work done by all non-conservative forces is equal to the change in the total mechanical energy of the object.

$$
\begin{aligned}
W_{nc} &= \Delta E_p + \Delta E_k \\
&= (E_{pf} - E_{pi}) + (E_{kf} - E_{ki}) \\
&= (E_{kf} + E_{pf}) - (E_{ki} + E_{pi}) \\
&= E_{mf} - E_{mi}
\end{aligned}
$$

5.9 Examples

EXAMPLE 1

A box lying on a horizontal frictionless surface is pulled by a horizontal force of 100 N. The box is displaced 3m to the right, as shown in the sketch below. Calculate the work done by the force on the box.



= 0^0

Solution:

There is one force acting on the object; therefore, we use the formula:

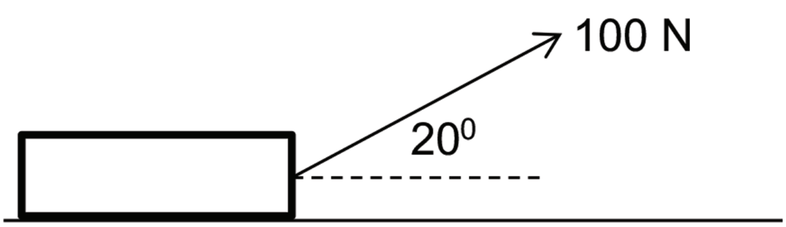
W = F**Δx**cosθ

= $100(3)\cos 0^0$ (substitute the formula from data sheet)

= 300J

EXAMPLE 2

Calculate the work done on a box lying on a horizontal frictionless surface, by a 100 N force, which acts at an angle of 20^0 to the horizontal. The force displaces the box 3m, as shown in the diagram below.



Δx = 3m

Solution:

Again, there is one force acting on the object.

W = F**Δx**cosθ

= $100(3)\cos 20^0$

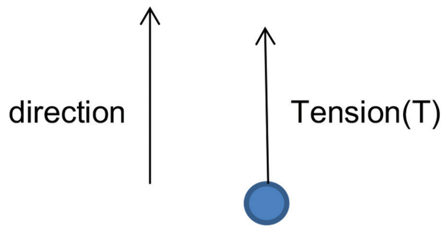
= 289,91 J (Round off the answer to 2 decimals and insert the correct unit for the answer.)

EXAMPLE 3

An electric motor is used to lift a load of bricks through a vertical height of 20m. The tension in the cable attached to the lift is 2000 N. Calculate the work done by the electric motor on the bricks.

Solution:

Draw a free-body diagram showing all the forces acting on the bricks and label the forces. There is one acting on the bricks, which is the tension (T) in the cable. Note that there is no normal force in this example.



Here, the force is parallel to the displacement (Δx). The angle between T and Δx is 0^0.

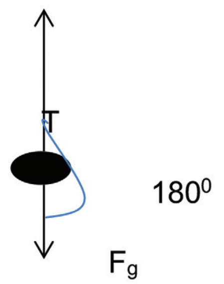
$W = F\boldsymbol{\Delta x}\cos\theta$

$= 2000(20)\cos 0^0$

$= 40000$ J

N.B. We can change the above example to include the total mass of the bricks. Suppose the bricks have a total mass of 50kg. Now there is another force, which is the weight of the bricks, so that there are two forces acting on the bricks.

Again, draw a free-body diagram:



The angle between Fg and Δx is 180^0. There are two forces and we use Wnet and F_{net}

$W_{net} = F_{net}\,\Delta x\cos\theta$

$WT = 2000(20)\cos 0^0$

$= 40000$ J

$W_{weight} = (50 \times 9{,}8)(20)\cos 180^0$ (Remember to multiply mass by 9,8.)

$= -9800$ J

$W_{net} = WT + W_{weight}$

$= 40000 + (-9800)$

$=30200$ J

EXAMPLE 4

A car with a mass of 500kg accelerates from 10 $m \cdot s^{-1}$ to 50 $m \cdot s^{-1}$ in 25 s on a horizontal frictionless surface. Calculate the car's power.

Solution:

This example involves the use of the equations of motion and Newton's second law.

First calculate the acceleration of the car:

$v_f = v_i + a\Delta t$

$50 = 10 + a(25)$

$a = 1{,}6\ ms^{-2}$ in the direction of motion (a is a vector).

Then calculate the displacement:

$v_f^2 = v_i^2 + 2a\Delta x$

$(50)^2 = (10)^2 + 2(1{,}6)\Delta x$

$\Delta x = 750$ m in the direction of motion.

Then calculate the net force:

$F_{net} = ma$

$= 500(1{,}6)$

$= 800$ N in the direction of motion.

Calculate the net work:

$W_{net} = F_{net}\,\Delta x\cos\theta$

$= 800(750)\cos 0^0$

$= 600000$ J

Finally, calculate the power:

$P = \dfrac{W}{\Delta t}$

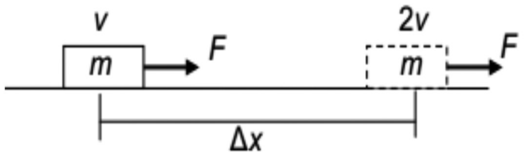
$= \dfrac{600000}{25}$

$= 24000$ W

5.10Practice Questions on Work, Energy and Power

QUESTION1: MULTIPLE CHOICE QUESTIONS

1.1 An applied force F accelerates an object of mass m on a horizontal frictionless surface, from velocity v to velocity $2v$.



The net work done on the object is equal to:

A. ½mv² B. 1½ mv² C. mv² D. 2mv²

1.2 If air resistance is negligible, the total mechanical energy of a free-falling body…

A. remains constant. B. increases. C. becomes zero. D. decreases.

1.3 The engine of a car does work, W, to increase the velocity of the car from 0 to **v.** The work done by the engine to increase the velocity from v to **2v** is…

A. W B. 2W C. 3W D. 4W

1.4 Power is defined as the rate …

A. of change of velocity. B. of change of momentum.
C. at which work is done. D. of change of displacement.

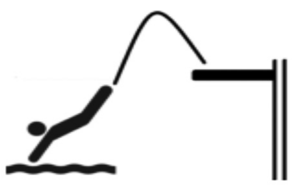
1.5 A car moves up a hill at **constant** speed. Which **one** of the following represents the work done by the weight of the car as it moves up the hill?

A. ΔE_k B. $-\Delta E_k$ C. ΔE_p D. $-\Delta E_p$

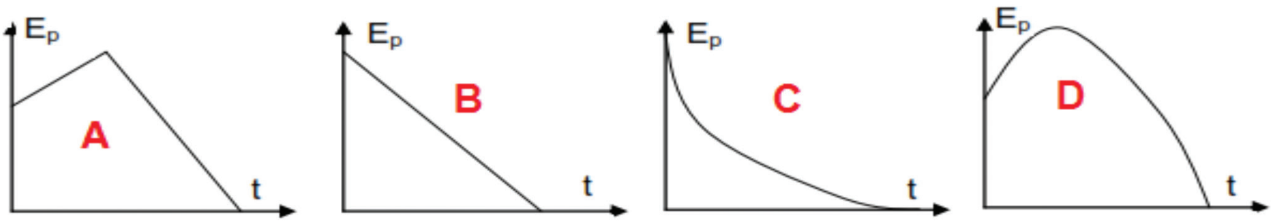
1.6 An object moves in a straight line on a **rough** horizontal surface. If the net work done on the object is zero, then…

A. the object has zero kinetic energy. B. the object moves at constant speed.
C. the object moves at constant acceleration. D. there is no frictional force acting on the object.

1.7 A diver dives from a diving board into a swimming pool.



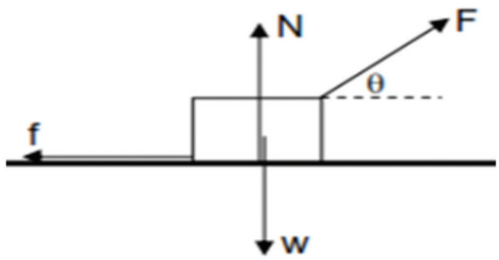
Which one of the following graphs represents his gravitational potential energy versus the time from the moment the diver leaves the diving board until just before he enters the water? Ignore the effects of friction.



1.8 Which one of the following is incorrect? W_{nc} is…

A. equal to ΔE_k.
B. equal to the change in mechanical energy of an object.
C. the total work done by a sum of non-conservative forces.
D. a sum of works.

1.9 An object is pulled along a straight horizontal road to the right without being lifted. The force diagram shows all the forces acting on the object. Which one of the above forces does **positive work** on the object?



A. W
B. N
C. F
D. f

1.10 The kinetic energy of object X is E. Object Y has double the mass and moves with twice the velocity of X. The kinetic energy of Y is …

A. 2E
B. 4E
C. 6E
D. 8E

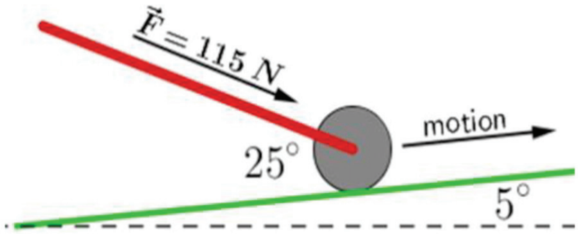
1.11 Two objects with a mass of 1 x 10^{-3}kg and 4 x 10^{-3}kg have equal momentum. What is the ratio of their kinetic energy?

A. 4 : 1
B. 2 : 1
C. 16 : 1
D. √2 : 1

1.12 A girl carries a heavy suitcase up a flight of stairs. A boy of the same weight carries the same suitcase slowly up the flight of stairs. Which statement is **true?**

A. The girl did less work and had less power than the boy.
B. The girl had less power than the boy.
C. The girl did more work and had more power than the boy.
D. The girl had more power than the boy.

1.13 A push lawnmower is rolled across a tilted lawn by a force of 115 N along the direction of the handle. The handle makes an angle of 25° in relation to the surface of the lawn. The lawn is at an angle of 5° to the horizontal, as shown in the graphic below. If the person pushing the lawnmower expends 75 W of power over 90 seconds, what is the distance the lawnmower travels?



A. 21,4m B. 64,8m C. 36,7m D. 71,0m

1.14 Consider these statements:

(i) Work is done on an object when a force displaces the object in the direction of the force.

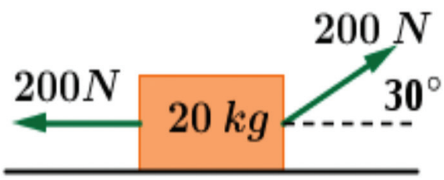
(ii) The mechanical energy of a system is conserved when an external force does no work on the system.

(iii) The work done on an object by a net force is equal to the kinetic energy of the object.

Which of the above statements is / are **true?**

A. only (i) B. (i) and (ii) C. (ii) and (iii) D. (i), (ii) and (iii)

1.15 Work will be done on the crate shown in the diagram below because the crate will …



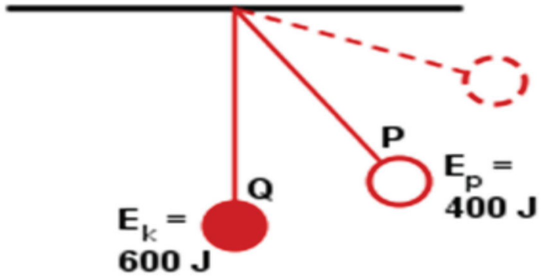
A. be lifted off the surface.

B. accelerate to the right.

C. accelerate to the left.

D. remain at rest.

1.16 A steel ball is suspended from the ceiling, and then released from a certain height. At point P in the swing, the ball has a gravitational potential energy of 400 J with respect to the lowest point at Q. At Q, the ball has a kinetic energy of 600 J. The total mechanical energy of the system is …



A. 200 J B. 600 J C. 400 J D. 1000

1.17 A force **F** directed at an angle **θ** above the horizontal, is used to pull a crate a distance **D** across a level floor. The work done by the force F is …

A. FD B. mgsin θ C. FDcos θ D. mgDcos θ E. FD sin θ

1.18 A car of mass **m** slides across a patch of ice at a speed **v** with its brakes locked. It hits a dry pavement and skids to a stop in a distance **d**. The coefficient of kinetic friction between the tyres and the dry pavement is **μ**. If the car has a mass of **2m**, it would have skidded a distance of …

A. 0,5 d B. 2 d C. d D. 4 d E. 1,41 d

1.19 If the car mentioned in the previous question had a speed of **2v** (mass **m**), it would have skidded a distance of …

A. 0,5 d B. 2 d C. d D. 4 d E. 1,41 d

1.20 A fan blows the air and gives it kinetic energy. An hour after the fan has been turned off, what has happened to the kinetic energy of the air?

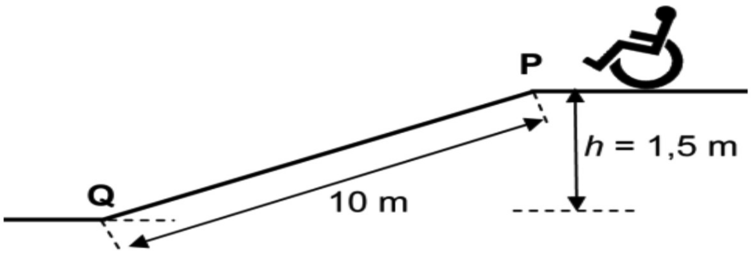
A. It disappears.
B. It turns into thermal energy.
C. It turns into electrical energy.
D. It turns into potential energy.
E. It turns into sound energy.

5.11 Structured Questions

QUESTION 1

A healthcare worker pushes a patient in a wheelchair and approaches an inclined plane with a length of $10m$ and a height of $1,5\ m$.

The combined mass of the patient and the wheelchair is $120kg$. A constant frictional force of $50N$ acts on the wheelchair as it moves down the incline. The rotational effects of the wheels of the wheelchair may be ignored. The worker exerts a force on the wheelchair. This force is parallel to the incline plane. The wheelchair moves down the incline at a constant speed of $1,25\ m{\cdot}s^{-1}$.



1.1 Is the mechanical energy of the wheelchair conserved while it moves down the incline?

1.2 What is meant by a conservative force?

1.3 Draw a labelled free-body diagram showing the forces that act on the wheelchair as it moves down the incline. Indicate the following forces on your diagram:

- Normal force. Label this force A.
- Frictional force. Label this force B.
- The component of weight that acts parallel to the incline. Label this force C.
- The component of weight that acts perpendicular to the incline. Label this force D.
- The force exerted by the healthcare worker on the wheelchair parallel to the incline. Label this force E.

1.4 Calculate the magnitude of the force C.

1.5 Write down the amount of work done on the wheelchair by force D, without doing a calculation. Give a reason for your answer.

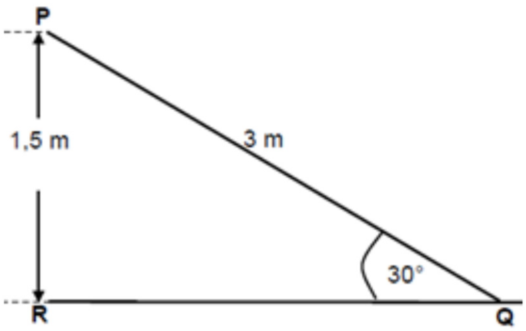
1.6 State the work-energy theorem in words.

1.7 Calculate the work done on the wheelchair as it moves down the incline by the force labelled:

1.7.1. B 1.7.2. C

QUESTION 2

PQ is a slide at a playground. The slide is 3m long and 1,5m high. A boy with a mass of 40kg and a girl of mass 22 kg stand at the top of the slide at P. The girl accelerates uniformly from rest down the slide. She experiences a constant frictional force of 1,9 N. The boy falls vertically down from the top of the slide through the height PR of 1,5 m. Ignore the effects of air friction.



2.1 Write down the **principle of conservation of mechanical energy** in words.

2.2 Draw a labelled free-body diagram to show ALL the forces acting on the:

2.2.1 boy while he is falling vertically downwards.

2.2.2 girl as she slides down the slide.

2.3 Use the principle of **conservation of mechanical energy** to calculate the speed of the boy when he reaches the ground at R.

2.4 Use the **work-energy theorem** to calculate the speed of the girl when she reaches the end of the slide at Q.

2.5 How would the velocity of the girl at Q compare to that of the boy at R if the slide exerts no frictional force on the girl? Write down only **greater than, less than or equa**l to **equal to.**

QUESTION 3

A cable car has a mass of 3 000kg when fully laden. An electrical motor is used to pull the cable car up from the lower base station (at 366m above sea level) to the top of the mountain, which is 1 066m above sea level. The motor can deliver a maximum of 88kW. It takes 7 minutes for the cable car to move from the lower base station to the top of the mountain.

3.1 Define power.

3.2 If the motor operates at maximum power output, calculate the electrical energy used by the motor to pull the cable car.

3.3 Calculate the gain in gravitational potential energy of the fully laden car when it moves from the bottom station to the top station. Compare your answer with the value calculated in the previous question and explain the difference.

3.4 Should the braking mechanism of the fully laden car fail while it is at rest at the top of the station, at what speed will the car strike the bottom station, if during the descent, the car loses 6×10^6 J of mechanical energy in doing work against friction?

QUESTION 4

Hikers climb to the top of a waterfall that is 948m high. 6×10^4kg of water falls from the top of the waterfall each minute. (Ignore air resistance and any other frictional forces).

4.1 Define gravitational potential energy.

4.2 Calculate the gravitational potential energy of 6×10^4kg of water at the top of the waterfall, relative to the bottom of the waterfall.

4.3 The gravitational potential energy stored in this water could be used to turn a turbine connected to an electrical generator at the bottom of the falls.

4.3.1 Describe the energy conversion that takes place in a generator.

4.3.2 80% of the power that the water has owing to its gravitational potential energy is converted into electrical power. Calculate the output power of the generator.

4.3.3 What would be the average kinetic energy of a kilogram of water when it reaches the bottom of the waterfall?

QUESTION 5

5.1 A winch designed to be mounted on a truck is advertised as being able to exert a 6,8 x 10^3N force and to develop a power of 0,30 kW. How long would it take the truck and the winch to pull an object 15m?

5.2 Your car has stalled and you need to push it. You notice that, as the car gets going, you need less and less force to keep it going. Suppose that, for the first 15m, your force decreased at a constant rate from 210,0N to 40,0N. How much work did you do on the car? Draw a force-displacement graph to represent the work done during this period.

5.3 Does the work required to lift a book to a high shelf depend on how fast you lift it? Does the power required to lift the book depend on how fast you lift it? Explain.

5.4 An elevator lifts a total mass of 1,1 x 10^3kg a distance of 40,0m in 12,5s. How much power does the elevator generate?

5.5 Haloke does 176 J of work lifting himself 0,300m. What is Haloke's mass?

5.6 To keep a car traveling at a constant velocity, a 551N force is needed to balance frictional forces. How much work is done against friction by the car as it travels a distance of 161km?

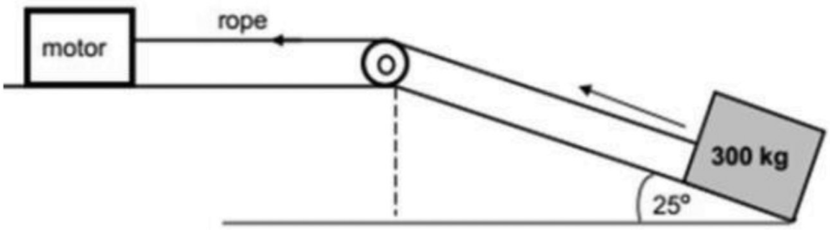
5.7 John pushes a crate across the floor of a factory with a horizontal force. The roughness of the floor changes, and John must exert a force of 20N for 5m, then 35 N for 12m, and then 10N for 8m.

5.7.1 Draw a graph of force as a function of distance.

5.7.2 Find the work John does pushing the crate.

QUESTION 6

A motor pulls a crate with a mass of 300kg with a constant force by means of a light inextensible rope running over a light frictionless pulley, as shown below. The coefficient of kinetic friction between the crate and the surface of the inclined plane is 0,19.

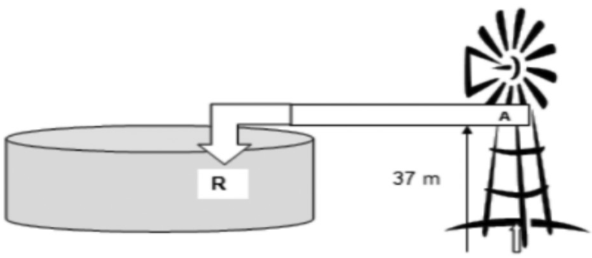


6.1 Calculate the magnitude of the frictional force acting between the crate and the surface of the inclined plane.

6.2 The crate moves up the incline at a constant 0,5 $m \cdot s^{-1}$.Calculate the average power delivered by the motor while pulling the crate up the incline.

QUESTION 7

A windmill is used on a farm to pump water out of a well. The water flows past point A, 37m above the well water level, to the dam, with a constant velocity of 2 $m \cdot s^{-1}$.



7.1 Calculate how much energy is necessary to pump 90kg of water out of the well to point **A**.

7.2 It is necessary to pump 90kg of water per minute. What is the maximum power that the windmill must produce?

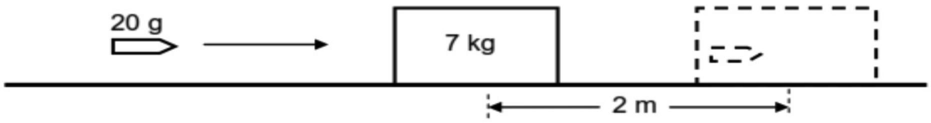
7.3 The farmer wants to modernise the farm. The farmer decides to buy a 0,5 kW petrol water pump.

7.3.1 Will the petrol water pump be able to produce the required power? (YES or NO)

7.3.2 Why would you advise the farmer to rather use a windmill instead of a petrol water pump?

QUESTION 8

The diagram below shows a bullet with a mass of 20g that is travelling horizontally. The bullet strikes a stationary 7kg block and becomes embedded in it. The bullet and block together travel on a rough horizontal surface for a distance of 2m before coming to a stop.



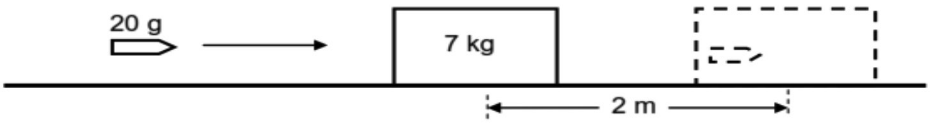
8.1 Use the work-energy theorem to calculate the magnitude of the velocity of the bullet-block system immediately after the bullet strikes the block, given that the frictional force between the block and surface is 10N.

8.2 State the **principle of conservation of linear momentum** in words.

8.3 Calculate the magnitude of the velocity with which the bullet hits the block.

QUESTION 9

A 5kg block is released from rest from a height of 5m and slides down a frictionless incline to point P, as shown in the diagram below. It then moves along a frictionless horizontal portion (PQ) and finally moves up a second rough inclined plane. It comes to a stop at point R, which is 3m above the horizontal. The frictional force, which is a non-conservative force, between the surface and the block is 18N.



9.1 Using **energy principles** only, calculate the speed of the block at point P.

9.2 Explain why the kinetic energy at point P is the same as that at point Q.

9.3 Explain the term **non-conservative force.**

9.4 Calculate the angle (θ) of the slope QR.

QUESTION 10

During a fire-extinguishing operation, a helicopter remains stationary (hovers) above a dam while filling a bucket with water. The bucket, with a mass of 80kg, is filled with 1 600kg of water. It is lifted vertically upwards through a height of 20m by a cable, at a **constant speed** of 2 $m \cdot s^{-1}$. The tension in the cable is 17 000N. Assume that there is no sideways motion during the lift. Air friction is NOT ignored.

10.1 Draw a labelled free-body diagram showing ALL the forces acting on the bucket of water, while it is being lifted upwards.

10.2 Use the **work-energy theorem** to calculate the work done by air friction on the bucket of water after moving through the height of 20m.

6. CHECK YOUR ANSWERS

6.1 Solutions on work, energy and power practice questions

QUESTION 1

1.1 B – $W_{net} = \Delta Ek = ½m(2v)^2 - ½mv^2 = 3(½mv^2) = 1½\ mv^2$

1.2 A – the law of the conservation of mechanical energy.

1.3 C - work done initially: $W_{net} = \Delta Ek = ½mv^2 - 0 = ½mv^2 = W$

work done in second part: $W_{net} = \Delta Ek = ½m(2v)^2 - ½mv2 = 3(½mv^2) = 3W$

1.4 This work is done by the force of friction = μN = μmg, and since W = F·d, $– ½\ mv^2 = – \mu mg \cdot d$; thus $d = mv^2/2m\mu g$, and m cancels above and below the line; therefore, the distance d skidded is independent of the mass of the car – a car with a mass of 2m will skid as far as the car with mass m.

1.5 D – the weight of the car pulls the car down, working in the direction opposite to motion, i.e. negative work is done by the weight of the car. Since it moves up the hill at constant speed, there is no change in the kinetic energy of the car. It is the potential energy that changes. The car's motor must do positive work to overcome the negative work of the car's weight.

1.6 B – $W_{net} = \Delta Ek$, so if the net work is zero, there cannot be a change in kinetic energy. Thus, the object moves with constant speed.

1.7 D

1.8 B – $W_{nc} = \Delta Ek + \Delta Ep$ – which is equal to the change in mechanical energy of an object.

1.9 C – the force acting in the direction of the motion does positive work.

1.10 D – 8E. Ek (of Y) = ½ (2m)(2v)2 = ½ ·2·4 mv2 = 8E.

1.11 A – equal momentum: $m_1v_1 = m_2v_2$, but m2 = 4m1; therefore $v_2 = v_1/4$.

$Ek_1 = ½\ m_1v_1^2$; $Ek_2 = ½\ m_2v_2^2 = ½\ (4m_1)(v_1/4)^2 = (4/16) \times ½\ m_1v_1^2 = Ek_1/4$ – the ratio is 4:1

1.12 D – the girl does the same amount of work as the boy, but in less time. She has more power (work per unit time).

1.13 B – 64,8 m. A person expends 75 W of power of 90 seconds, and since P = W/t, the person does 75 × 90 = 6750 J of work. This work is done by the force (or component of the force) in the direction of motion.

The component of F in the direction of motion = Fcos 25° = 104,23 N.

Since W = FΔx, we know that Δx = W/F = 6750 / 104,23 = 64,76 m.

1.14 B – statements (i) and (ii) are true. (iii) is not true – the work done is equal to the change in kinetic energy.

1.15 C – there is a resultant force to the left and thus acceleration to the left.

1.16 B – 600 J. At the lowest point, all the potential energy has been converted into kinetic energy. This is then the total energy that the system has.

1.17 C – W = F·Δx = F·(cos θ)·D = Fdcosθ

1.18 C – the work done to bring the car to rest = W_{net} = ΔEk = 0 – ½ mv^2 = – ½ mv2.

1.19 D – it will now travel four times as far. From the previous question: d = $v^2/2\mu g$, thus if v is doubled: d_{new} = $(2v)^2/2\mu g$ = $4v^2/2\mu g$ = 4d C – power is the rate at which work is done (or energy is used): P = W/t

1.20 B – it turns into thermal energy and is then dissipated (spread into the environment).

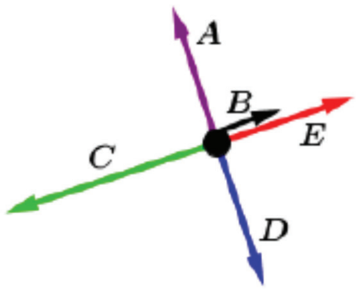
6.2 Solutions to Structured Questions

QUESTION 1

1.1 Given that friction (a dissipative force) is involved in moving down the incline, the total mechanical energy is not conserved.

1.2 Conservative force: one for which work done by or against it depends only on the start and end points of the motion, and not on the path taken.

1.3 Note: the vertical downward force due to gravity is replaced by its two components (C – parallel to the incline and D – perpendicular to the incline).



1.4 C is the component of F_g parallel to incline:

$Fg_{//}$ =mg.Sinθ = (120)(9,8)(1,5/10) = 176,4 N

1.5 0 J. Force D acts perpendicular (at right angles) to the direction of motion; thus, no work is done by force D.

1.6 The work done on an object by a net force equals the change in kinetic energy of the object – $W_{net} = \Delta Ek$.

1.6.1 B is the frictional force. Note that it acts to oppose motion (in the opposite direction to motion).

$W_f = F_f.\Delta x.\cos\theta$ = (50)(10)cos 180o = -500J.

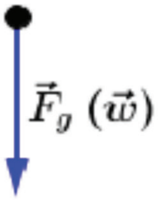
1.6.2 C is the parallel component of the weight pulling the wheelchair down the incline:

$W_f = F_f.\Delta x \cdot \cos\theta = (176,4)(10)\cos 0^o = 1764J$

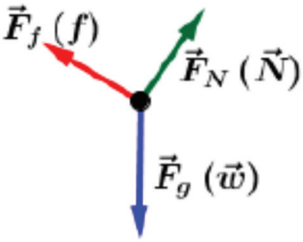
QUESTION 2

2.1 In a closed system, and in the absence of dissipative forces, the total amount of mechanical energy remains constant.

2.2.1



2.2.2



2.3 Total mechanical energy (U + K) at P is equal to total mechanical energy at R, therefore:

$(K + U)_P = (K + U)_R$

$0 + (40)(9,8)(1,5) = ½(40)v^2 + 0$

$\therefore v = 5,422 \text{ m.s}^{-1}$

2.4 There are two forces acting on the girl – gravity (use parallel comp.) and friction:

$W_{net} = \Delta K$

$F_{g//}.\Delta x.\cos\theta + F_f.\ \Delta x.\cos\theta = ½mv_f2 – ½mv_i2$

$(22)(9,8)(\sin 30^o)(3)(\cos 0^o) + (1,9)(3)(\cos 180^o) = ½(22)(v_f^2 – 0)$

$\therefore v_f = 5,374 \text{ m.s}^{-1}$

2.5 With no friction acting, the girl would have the same final velocity as the boy. Just leave out the frictional force in the previous calculation to confirm this.

Question 3

3.1 Power is the rate at which work is done.

3.2 Power = W/Δt (and since work = energy) = ΔE/Δt, then ΔE = 88 000 × (7 × 60) = $3,696 \times 10^7$ J.

3.3 Ep = mgh = (3000) (9,8)(1066 – 366) = $2,058 \times 10^7$ J. This value is lower than that calculated in 3.2 because some energy is lost in overcoming friction. Energy is also required to accelerate the cable car initially.

3.4 Assume an isolated system. The total mechanical energy at the top (potential energy only since the car is at rest), minus the energy lost due to friction = total mechanical energy at bottom (kinetic energy).

$E_{Mtop} + E_{friction} = E_{Mbottom}$

$mgh - E_f = \frac{1}{2}mv^2$

$(3000)(9,8)(1066 - 366) - 6 \times 10^6 = \frac{1}{2}(3000)vf^2$

$\therefore v_f = 98,59\ m.s^{-1}$

QUESTION 4

4.1 Gravitational potential energy is the energy a body possesses owing to its position above a particular reference point (particularly the earth's surface).

4.2 E*p* = mgh = $6 \times 10^4 \times 9,8 \times 948 = 5,574 \times 10^8$ J

4.3.1 Kinetic energy is converted into mechanical and then electrical energy.

4.3.2 P = W/t = ΔEp / t = $5,574 \times 10^8 / 60 = 9,29 \times 10^6$ W (convert minutes into seconds); however, there is only an 80% conversion,
hence power output = $0,8 \times 9,29 \times 10^6 = 7,432 \times 10^6$ W.

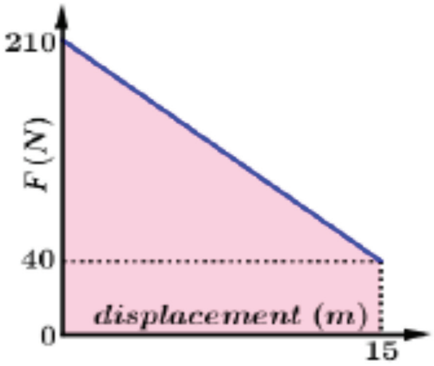
4.3.3 Assuming the conservation of mechanical energy, the potential energy of 1kg of water at the top will be converted into kinetic energy at the bottom; therefore:
Ep = mgh = (1)(9,8)(948) = 9290,4 J
The average kinetic energy is then = 9290,4 J

QUESTION 5

5.1 P = F·v, therefore 300 = 6,8×10^3 v, ∴ v = 0,04412 m·s^{-1}. Time = distance/ velocity = 15 / 0,04412 = 339,98s or 5,67min *(or W = Fd = 102 000J; t = W/p= 102000/300 = 340s)*.

5.2 See graph below:

Work = force × distance = area under the graph = ½(15)(210 – 40) + (15 × 40) = 1875 J.



5.3 No, work is purely a function of force and distance; thus, how fast you lift the book makes no difference to the amount of work done. Power is the rate at which work is done, so clearly the faster your raise the book, the more power is delivered.

5.4 Assume that the elevator lifts the mass at constant velocity – to do so, it must counter the force of gravity on the

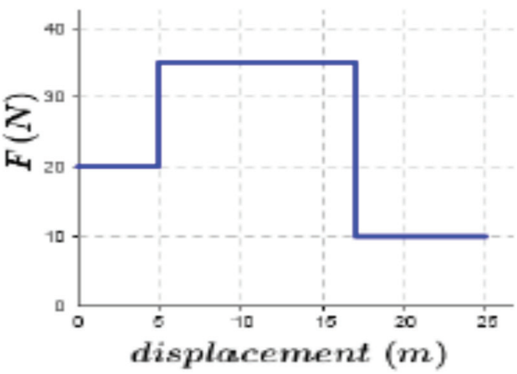
mass = mg.

Now P = W/Δt = (F·Δy)/Δt = mgΔy/Δt = (1,1 × 10^3)(9,8)(40) / 12,5 = 34496 or 3,4 × 10^4 W.

5.5 W = F·Δx = mgΔx, therefore 176 = m(9,8)(0,3), therefore m = 59,864 or 59,9 kg.

5.6 W = F·Δx = (551)(161 × 10^3) = 8,87 × 10^7 J.

5.7.1



5.7.2 W = $F_1d_1 + F_2d_2 + F_3d_3$ = (20)(5) + (35)(12) + (10)(8) = 600 J

Question 6

6.1 To calculate the magnitude of the frictional force, first calculate the normal force:

$F_N = mgCos\ 25^o$

$= (300)(9,8)(Cos\ 25^o)$

$= 2664,545\ N$

$F_f = \mu_k F_N$

$= (0,19)(2664,545)$

$= 506,26\ N$

6.2 There are three forces to consider: the motor's force applied (F_{app}), the force of friction (F_f) and the component of the force of gravity parallel to the incline ($F_{g||}$) – the last two in the opposite direction to the first.

Since the crate moves up the incline at constant speed, the resultant force is zero.

$F_{res} = F_{app} + F_f + F_{g//} = 0$

$F_{app} + (-506,26) + (-300)(9,8)(Sin25^o) = 0$

$\therefore F_{app} = 1748,76\ N$

$P_{ave} = Fv_{ave} = 1748,76 \times 0,5 = 874,38\ W$

Question 7

7.1 **Note:** the depth of the well is measured from point A.

When pumping the water out, it is given potential energy and kinetic energy. Work is done by the pump.

$Ep = mgh = (90)(9,8)(37) = 32634\ J$ $Ek = ½\ mv^2 = ½\ (90)(22 – 0^2) = 180\ J.$

The pump must thus supply 32634 + 180 = 32814 J of energy.

7.2 P = W/t = 32814 / 60 = 546,9 W

7.3.1 0,5 kW = 500 W, which is less than the required 546,9 W; thus, the petrol pump will not be able to pump the water out at the same rate.

7.3.2 A windmill has some advantages: It is environmentally friendly and, except for maintenance costs, is cost-free. However, it will not work when there is no or very little wind. A petrol pump (stronger than 0,5 kW) would be more efficient and would work as long as petrol is available. However, petrol has a price, and the price of petrol is constantly increasing.

Question 8

8.1 Assume that all the kinetic energy of the bullet is transferred to the bullet-block system, with no energy lost due to the deformation of the block. Immediately after collision, the only force acting on the system is the frictional force of 10 N.

$W_{net} = \Delta K$

$F_f \cdot \Delta x \cdot \cos 180^o = ½(mv_f^2 – mv_i^2)$

$(10)(2)(-1) = ½(7{,}02)(0 – v^2)$

$\therefore$ v = 2,39 $m.s^{-1}$

8.2 The total momentum of an isolated system is conserved; alternatively, in an isolated system, the total linear momentum before a collision is equal to the total linear momentum after the collision.

8.3 Total momentum before = total momentum afterwards:

$m_b v_b + m_{block} v_{block} = m_{bullet\text{ - }block} v$

$(0{,}02)v_b + 0 = (7{,}02)(2{,}39)$

$\therefore v_b = 838{,}89\ m.s^{-1}$

The bullet travels at 838,89 $m \cdot s^{-1}$ towards the block.

Question 9

9.1 $Em_{top} = Em_P$

mgh = ½mv^2

$(5)(9{,}8)(5) = ½(5)v^2$

$\therefore$ v = 9,90 $m.s^{-1}$

9.2 PQ is a horizontal, frictionless surface; therefore, no energy is lost to friction and none is gained or lost as potential energy. Consequently, the kinetic energy will be the same at P and Q.

9.3 A non-conservative force is any force for which the work done is path-dependent.

9.4 To calculate θ, calculate the length of QR. Use the work-energy theorem for this.

$W_{nc} = K + U$

$F_f \cdot \Delta x \cdot \cos 180^o = ½m(v_f^2 – v_i^2) + mg(h_f – h_i)$

$(-18)(\Delta x) = ½(5)(-9{,}90^2) + (5)(9{,}8)(3)$

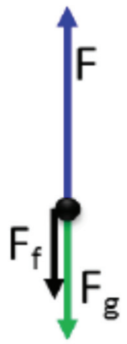
$\therefore \Delta x = 5{,}4458$ m

Now Sin θ = 3/5,44

$\therefore \theta = 33{,}43^o$

Question 10

10.1



10.2 $W_{net} = \Delta K$

$W_F + W_g + W_f = \Delta K$

$(1700)(20)\text{Cos } 0^o) + (1600 + 80)(9{,}8)(20)\text{Cos } 180^o) + W_f = 0$ ($\Delta K = 0$, since velocity is constant).

$\therefore W_f = -10720$ J

7. MESSAGE TO GRADE 12 LEARNERS FROM THE WRITERS

This booklet is intended to assist you with revision and prepare you for the examination. Please use it effectively.

I wish you everything of the best in the examination and hope that you will achieve your ultimate goal and fulfil your dream.

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PHYSICAL SCIENCE

WORK ENERGY AND POWER

GRADE 12

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