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Karin Kelder, Derick Govender and Jagathesan Govender
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MODULE 1 Mechanics

Learner's Book pages 1-56

Although aspects of mechanics are introduced to learners early in their study of science, its abstractness and rigour is only dealt with from Grade 10 onwards. Learners are expected to internalise and engage with concepts beyond both their understanding and common experiences. As a branch of physics, mechanics is explained mainly in mathematical terms using relationships and equations. However, this mathematical description is not the purpose of study in science, but a means to understanding motion, forces and associated quantities. The learning outcomes require educators to contextualise mechanical concepts and to make sense of them in the real world. When teaching this module, keep sight of this goal.

UNIT 1 Motion in two dimensions

Learner's Book pages 2-39

Unit 1 requires learners to start with revision of basic concepts covered in Grade 10, from horizontal motion in a straight line to vertical motion in a straight line. It is important to revise these concepts, particularly as they relate to direction and sign conventions. These concepts are then extended to two-dimensional motion. Ensure that the learners understand the mathematics required for the solution of triangles using trigonometry ratios. Refer to the Learner's Book, page x.

Activity 1: Appreciating the contribution of Newton

GROUP — Learner's Book page 5

LO3: AS1; LO2: AS3

1. People have always taken for granted that objects will fall downwards. Some people have not considered this in a scientific context, whilst others may have thought of it as God's will.
2. Earth and the apple are considered as two objects; by Newton's Law of Universal Gravitation, these two objects attract each other with equal but opposite forces. Since the force is too small to overcome the inertia of Earth with its much larger mass, this force does not change the motion of Earth. The apple, on the other hand, has a much smaller mass, and the force is sufficient to change its state of motion, causing it to accelerate downwards.
3. Try to get learners to appreciate the impact of Newton's explanation and how it changed the taken-for-granted assumptions of life in general and the power of science.

Activity 2: Investigating the theoretical value for *g*

INDIVIDUAL — Learner's Book page 6

LO2: AS1, AS2

1. For an object of mass m near the surface of Earth, the attractive force between the object and Earth is given by:

   $F = \frac{GmM}{r^2}$ where M is the mass of Earth and r is the radius of Earth.

But F is the same as the weight ($W = mg$) of the object on Earth.

Therefore, $mg = Gm\frac{M}{r^2}$

$\Rightarrow g = G\frac{M}{r^2}$ …….. (equation 1)

2. No. Since Earth is not a perfect sphere, the radius is different at different points on its surface; the radius is longer at the equator than at the poles. From equation 1, a longer radius will result in a smaller value of g.
3. The value of g does not change, since g is independent of the mass of the object (from equation 1).

$$g = G\frac{M}{r^2}$$
$$= 6{,}67 \times 10^{-11}\ \text{N·m}^2\text{·kg}^{-2}\frac{6 \times 10^{24}\ \text{kg}}{(6{,}4 \times 10^6\ \text{m})^2}$$
$$= 9{,}77\ \text{m·s}^{-2}$$

LO1: AS1, AS2, AS4

Activity 3: Determining the value of g experimentally and showing that g is independent of mass

GROUP

Learner's Book page 7

Learners have been exposed to this experiment in Grade 10. Refer to the Learner's Book for a possible method of finding g experimentally. The idea is not to provide a method or procedure to conduct this experiment, but for learners to come up with their own designs. Learners' reports should be assessed according to the following assessment rubric. It is advisable to provide learners with this rubric so that they can be clear about the assessment of the task.

Assessment criteria	Levels of performance
1. Aims	
Both aims correctly stated.	2
Only one aim correctly stated.	1
Aims not correctly stated.	0
2. Method	
Design of experiment systematically presented and clearly allows for practical determination of g.	5
Design of experiment not systematically presented, but clearly allows for practical determination of g.	4
Design of experiment systematically presented, but does not allow for practical determination of g.	3
Design of experiment clear, but does not allow for determination of g.	2
Design of experiment presented, but not clear.	1
Design of experiment not presented.	0

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3. Apparatus	
Apparatus identified is *both* sufficient and necessary to conduct the experiment as per design.	4
Apparatus identified is *either* sufficient *or* necessary to conduct the experiment as per design.	3
Apparatus identified is *neither* sufficient *nor* necessary to conduct the experiment as per design.	2 1
Apparatus not identified.	0
4. Collection of data	
Relevant data identified and obtained from the experiment conducted.	4
Some essential data not collected from the experiment conducted.	3
Data presented, but not obtained from experiment conducted.	2
Data presented, but irrelevant for the determination of g.	1
No data collected.	0
5. Analysis of data	
Data correctly analysed to obtain correct value(s) of g.	4
Most aspects of data *correctly* analysed.	3
Most aspects of data *incorrectly* analysed.	2
Data incorrectly analysed.	1
Data not analysed.	0
6. Conclusion	
Both conclusions correctly stated as per results obtained.	2
One conclusion correctly stated as per results obtained.	1
No conclusions stated.	0

Activity 4: Solving problems on vertical projectile motion

LO1: AS2, AS4; LO2: AS1, AS2, AS3; LO3: AS1

INDIVIDUAL

Learner's Book page 13

1. a) Acceleration due to gravity for the falling crate.
Gradient = $+9{,}8\ \text{m}\cdot\text{s}^{-2}$

b) Consider the motion of the crate from when the cable snapped to when the crate reached its maximum height:

$a = 9{,}8\ \text{m}\cdot\text{s}^{-2}$; $v = 0\ \text{m}\cdot\text{s}^{-1}$; $t = 0{,}2\ \text{s}$; $u = ?$

$$v = u + at$$
$$0\ \text{m}\cdot\text{s}^{-1} = u + 9{,}8\ \text{m}\cdot\text{s}^{-2}\,(0{,}2\ \text{s})$$
$$u = -1{,}96\ \text{m}\cdot\text{s}^{-1}$$
$$u = 1{,}96\ \text{m}\cdot\text{s}^{-1}\ \text{upwards}$$

c) Again, consider the motion of the crate from when the cable snapped to when the crate reached its maximum height:

$u = -1{,}96\ \text{m}\cdot\text{s}^{-1}$; $v = 0\ \text{m}\cdot\text{s}^{-1}$; $a = 9{,}8\ \text{m}\cdot\text{s}^{-2}$; $\Delta x = ?$

$$v^2 = u^2 + 2a\Delta x$$
$$(0\ \text{m}\cdot\text{s}^{-1})^2 = (-1{,}96\ \text{m}\cdot\text{s}^{-1})^2 + 2(9{,}8\ \text{m}\cdot\text{s}^{-2})\Delta x$$
$$\Delta x = -0{,}196\ \text{m}$$
$\Delta x = 0{,}196$ m above the position where the cable snapped.

d) Consider the motion of the crate from when the cable snapped to when the crate strikes the water:

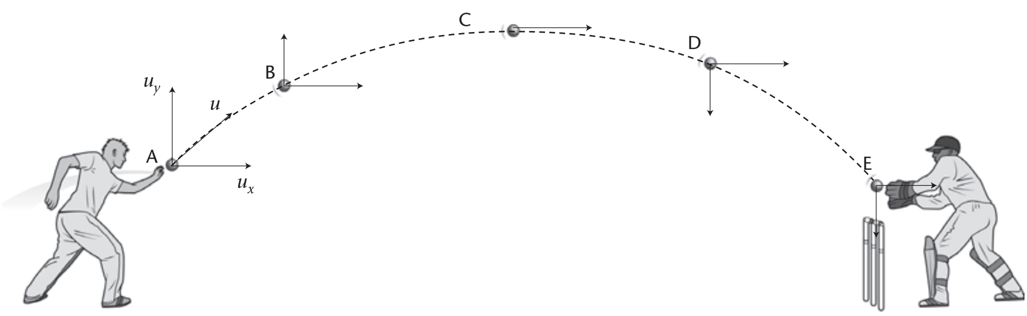
$v^2 = u^2 + 2a\Delta x$
$= (-2\ m{\cdot}s^{-1})^2 + 2(9{,}8\ m{\cdot}s^{-2})(30\ m)$
$= 592\ m^2{\cdot}s^{-2}$
$v = 24{,}33\ m{\cdot}s^{-1}$

$u = -2\ m{\cdot}s^{-1}$
$\Delta x = 30\ m$
$a = 9{,}8\ m{\cdot}s^{-2}$
$v = ?$

Activity 5: Illustrating changes in velocity that the cricket ball undergoes

INDIVIDUAL Learner's Book page 15

LO2: AS1;
LO1: AS3



The resultant velocity can be calculated by using the Theorem of Pythagoras, i.e. $v_{res}^2 = v_y^2 + v_x^2$ at each point. Note that the horizontal component of the velocity ($v_x = u_x$) remains constant throughout the motion of the ball.

Activity 6: Developing an understanding of projectile motion

PAIR Learner's Book page 22

LO3: AS1;
LO2: AS3

1. Prior to Galileo's explanation of projectile motion, it was believed that the force that initiated the motion acted over an extended period of an object's motion. This means that the horizontal motion of the object will change due to the impact of this force. The experiment of the ball being released from the top of the mast of a boat demonstrated that horizontally there was no acceleration (if air friction is ignored). The only force was the gravitational force, which acts vertically. Galileo's contribution has helped us to correct the misconception that led to an analysis of projectile motion in terms of three different phases. We now know that two independent motions govern projectiles – horizontal motion at constant velocity and a vertical motion subject to the acceleration due to gravity.
2. The food parcel will strike the ground directly below the aircraft. The moment the food parcel is released, it has the same horizontal motion as the aircraft. The food parcel maintains this horizontal component of velocity (if air friction is to be ignored), although it will accelerate vertically downwards.

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Activity 7: Applying the principles of projectile motion in 2-D

PAIR — Learner's Book page 24

LO1: AS1, AS3; LO2: AS1, AS2, AS3

1. The experiment is likely to be very simple and a stopwatch can be used to measure the time in both cases. Learners need to set out their procedures in the same way as the experiment in Activity 3. The rubric provided for Activity 3 can be adapted for this investigation.

   Two important considerations must be noted here:

   i) the table must be high enough so that the time taken for the fall can be measured

   ii) the force pushing the mass piece off the table must be horizontal – this can best be attained if, for example, a ruler is placed flat on the table and is pushed horizontally against the mass piece. The mass piece must be at the edge of the table.

2. a) A projectile is any object that is fired or thrown into the air at any angle to the horizontal.

   b) The range of a projectile is the maximum horizontal distance travelled by the projectile.

3. A low, flat throw will reduce the time taken for the ball to reach the wicketkeeper as the ball will spend less time in the air. However, a low flat throw reduces the angle θ that the ball makes with the horizontal. Thus, the horizontal component of the distance, $\Delta x = ut \cos\theta$ may not be large enough to acquire the necessary range. To get the necessary range with a smaller angle θ, the initial velocity needs to be extremely large, and therefore the force exerted on the ball by the fielder needs to be extremely large. The fielder may not be capable of exerting this extremely large force. In this case, the throw cannot be low and flat.

Activity 8: Investigating elastic and inelastic collisions

INDIVIDUAL — Learner's Book page 26

LO1: AS3; LO2 : AS1, AS3

1. a) The principle of conservation of momentum states that the total momentum in a closed or isolated system is conserved in both magnitude and direction.

   b) A collision is elastic if the total kinetic energy of the colliding objects is conserved.

   c) A collision is inelastic if the total kinetic energy after the collision is either greater than or less than the total kinetic energy before the collision.

2. Example 1

   Before collision:

$$E_k \text{ (Total)} = E_k \text{ (red)} + E_k \text{ (green)}$$
$$= \tfrac{1}{2}m_1u_1^2 + \tfrac{1}{2}m_2u_2^2$$
$$= \tfrac{1}{2}(0{,}6\text{ kg})(5\text{ m s}^{-1})^2 + \tfrac{1}{2}(0{,}3\text{ kg})(0)^2$$
$$= 7{,}5\text{ J}$$

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After collision:

E_k (Total) $= E_k$ (red) $+ E_k$ (green)

$= \frac{1}{2}m_1v_1^2 + \frac{1}{2}m_2v_2^2$

$= \frac{1}{2}(0{,}6 \text{ kg})(2 \text{ m·s}^{-1})^2 + \frac{1}{2}(0{,}3 \text{ kg})(6 \text{ m·s}^{-1})^2$

$= 6{,}6$ J

Since total E_k before collision > total E_k after collision, collision is inelastic.

Example 2

Let the mass of each trolley be m kg.

Before collision:

E_k (Total) $= E_k$ (A) $+ E_k$ (B)

$= \frac{1}{2}m_1u_1^2 + \frac{1}{2}m_2u_2^2$

$= \frac{1}{2}(m \text{ kg})(3{,}2 \text{ m·s}^{-1})^2 + \frac{1}{2}(m \text{ kg})(0)^2$

$= 5{,}12m$ J

After collision:

E_k (Total) $= E_k$ (A) $+ E_k$ (B)

$= \frac{1}{2}m_1v_1^2 + \frac{1}{2}m_2v_2^2$

$= \frac{1}{2}(m \text{ kg})(0)^2 + \frac{1}{2}(m \text{ kg})(3{,}2 \text{ m·s}^{-1})^2$

$= 5{,}12m$ J

Since total E_k before collision = total E_k after collision, collision is elastic.

LO2: AS3;
LO3: AS2, AS3

Activity 9: Applying conservation of momentum in 2-D

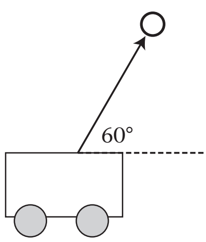
GROUP Learner's Book page 31

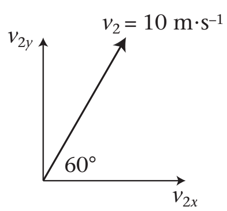
1. Initially, before the ball is thrown, the cart, student and the ball are stationary.

$m_1 = 80$ kg
$u_{1x} = 0 \text{ m·s}^{-1}$
$u_{1y} = 0 \text{ m·s}^{-1}$

$m_2 = 4$ kg
$u_{2x} = 0 \text{ m·s}^{-1}$
$u_{2y} = 0 \text{ m·s}^{-1}$

After the ball is thrown, the ball moves at a velocity of 10 m·s^{-1} at 60° to the horizontal.





$v_{1x} = ?$

$v_{1y} = 0$ (cart moves horizontally)

$v_{2x} = v_2 \cos 60 = 10 \cos 60 = 5 \text{ m·s}^{-1}$

$v_{2y} = v_2 \sin 60 = 10 \sin 60 = 8{,}66 \text{ m·s}^{-1}$

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By the principle of conservation of momentum (in the horizontal direction):

$$m_1u_{1x} + m_2u_{2x} = m_1v_{1x} + m_2v_{2x}$$
$$80(0) + 4(0) = 80v_{1x} + 4(5)$$
$$v_{1x} = -0{,}25 \text{ m}\cdot\text{s}^{-1}$$
$$= 0{,}25 \text{ m}\cdot\text{s}^{-1} \text{ opposite to the direction of the ball's motion.}$$

Therefore, the cart and the student move at 0,25 m·s^{-1} in a direction opposite to that in which the ball is thrown.

2. Assess this task using the following rubric. Again, provide learners with a copy of the rubric so that the assessment requirements are clear.

This task involves the evaluation of the intersection in terms of how it facilitates traffic flow. Some ways in which safety is promoted include clear and proper signage, road markings (to prevent overtaking, for pedestrian crossings), speed limit restrictions, traffic calming (speed bumps, rumble strips) and so on.

Poor planning around these features compromises safety.

Assessment criteria	Levels of performance
1. Description of the intersection	
Clear descriptions, with drawings/models.	3
Description not so clear; can only partly establish what intersection is like.	2
Description very unclear; cannot establish what intersection is like.	1
No description provided.	0
2. How design of intersection promotes safety for vehicles and pedestrians	
States four relevant ways in which safety is promoted.	4
States three relevant ways in which safety is promoted.	3
States two relevant ways in which safety is promoted.	2
States one relevant way in which safety is promoted.	1
States no relevant ways in which safety is promoted.	0
3. How design of intersection compromises safety of vehicles and pedestrians	
States three relevant ways in which safety is compromised.	3
States two relevant ways in which safety is compromised.	2
States one relevant way in which safety is compromised.	1
States no relevant ways in which safety is compromised.	0

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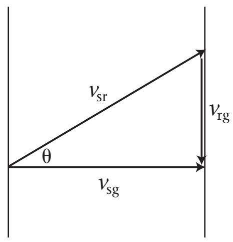
Activity 10: Calculating relative velocities

LO2: AS1, AS3

INDIVIDUAL/PAIR

Learner's Book page 38

1. a)



v_{sr}: velocity of the swimmer relative to the river

v_{rg}: velocity of the river relative to the ground

v_{sg}: velocity of the swimmer relative to the ground

b) $\sin\theta = \frac{v_{rg}}{v_{sr}} = \frac{0,3}{0,6} = 0,5$

$\theta = 30°$

Therefore, the swimmer must swim at a bearing of 60° to reach his destination.

c) $v_{sg}^2 = v_{sr}^2 - v_{rg}^2$ (by Theorem of Pythagoras)

$= 0,6^2 - 0,3^2$

$= 0,27$

$v_{sg} = 0,52 \text{ m·s}^{-1}$

Distance travelled after 4 minutes is:

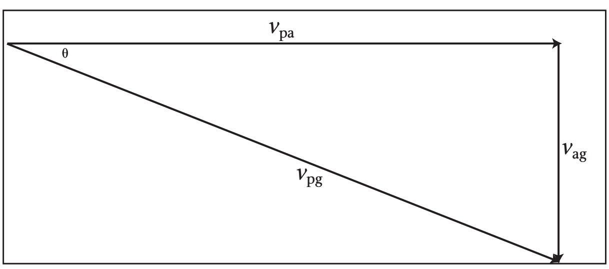
distance = speed × time

$= 0,52 \text{ m·s}^{-1} \times 240 \text{ s}$

$= 124,8 \text{ m}$

Therefore, distance of swimmer from destination after 4 minutes = 130,8 m – 124,8 m = 6 m.

2.



v_{pa}: velocity of the plane relative to the air

v_{ag}: velocity of the air relative to the ground

v_{pg}: velocity of the plane relative to the ground

a) $v_{ag} = \frac{200 \text{ km}}{2\text{h}}$

$= 100 \text{ km·h}^{-1}$

b) $v_{pg}^2 = v_{pa}^2 + v_{ag}^2$ (by Theorem of Pythagoras)

$= 400^2 + 100^2$

$v_{pg} = 412,3 \text{ km·h}^{-1}$

$\tan\theta = \frac{v_{ag}}{v_{pa}} = \frac{100}{400}$

$\theta = 14,04°$

Therefore, $v_{pa} = 412,3 \text{ km·h}^{-1}$ at a bearing of 104,04°