Science Education Centre

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Physical Science

Vectors & Scalars

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VECTORS AND SCALARS

Summary of Relevant Content

1. A **scalar quantity** is one, which is fully defined by **magnitude** alone.
   Important scalars: distance, speed, mass, time, work, energy, power, etc.

2. A **vector quantity** is fully defined by **magnitude and direction**.
   Important vectors: displacement, velocity, acceleration, force, impulse, momentum, etc.

4. A **resultant** is one vector, which has the same effect on a body as the two or more vectors that are actually acting on that body. It starts at the beginning of the first vector and ends at the end of the last one.

5. An **equilibrant** is one vector, which cancels out the effect that the two or more vectors actually have on a body. It is equal in size to the resultant but opposite in direction.

6. Positive (+) and negative (-) signs are used to indicate direction in vectors. (Not their magnitude.)

7. Arrows are used in vectors to give magnitude (length of arrow) and direction (head of arrow).

8. **Zero acceleration** means that:
   a) the body is either at rest **or** travelling at constant speed in one direction (constant velocity).
   b) the forces acting on the body are in equilibrium.
   c) the forces acting on the body have a resultant of zero. (The last vector is the equilibrant of the others.)

9. **Distance** moved is the actual length of the path along which an object travelled. It is a **scalar**.

10. **Displacement** is the straight line distance from the beginning to the end of the path along which an object moved. It is a **vector** and has nothing to do with how the object got there.
    (Remember if a body returns to its original starting point its displacement is zero and its velocity is therefore zero since velocity = displacement ÷ time. But its speed = total distance travelled ÷ time taken)

    NB *velocity* = *displacement ÷ time*
    speed = *total distance travelled ÷ time taken*

TIPS ON VECTOR DRAWINGS

1. Always **draw a sketch** first. Make the sketch approximately to scale. Most questions can be solved using a triangle. Remember to draw a triangle accurately you need to know three facts about the triangle, one of which must be the length of one side.

2. If a scale is not given, choose one as big as possible. Write down your choice.

3. If compass directions are given, draw a small compass like the one to the right.

4. Never give a compass direction in the answer if a compass direction is not given in the question.

5. "**Bearing**" ("heading") is the number of degrees clockwise from north. It must have **3 digits**. i.e. 20 E of N = Bearing 020

6. When the answer asked for is a **vector**, two answers are required: **magnitude** and **direction**.

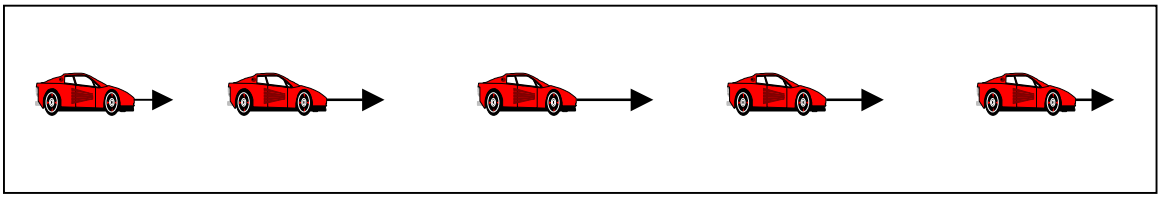
HOW TO TACKLE A QUESTION ON VECTORS

Lines with arrowheads are used to describe a vector.

- The length of the line gives the **magnitude** (or size) of the vector.
- The direction in which the arrow points gives the **direction** of the vector.

VECTOR DIAGRAMS

1. **Vector diagrams** are diagrams, which describe the direction and relative magnitude of a vector quantity by a vector arrow. Vector diagrams can be used to describe the velocity of a moving object during its motion. For example, the velocity of a car moving down the road could be represented by the following vector diagram:



In a vector diagram, the magnitude of a vector is represented by the size of the vector arrow. If the size of the arrow in each consecutive frame of the vector diagram is the same, then the magnitude of that vector is constant. The diagrams below depict the velocity of a car during its motion. In the top diagram - figure 1 - the size of the velocity vector is constant, so the diagram is representing a motion with constant velocity. In the bottom diagram - figure 2 - the size of the velocity vector is increasing, hence the diagram is describing a motion with increasing velocity - i.e., acceleration.

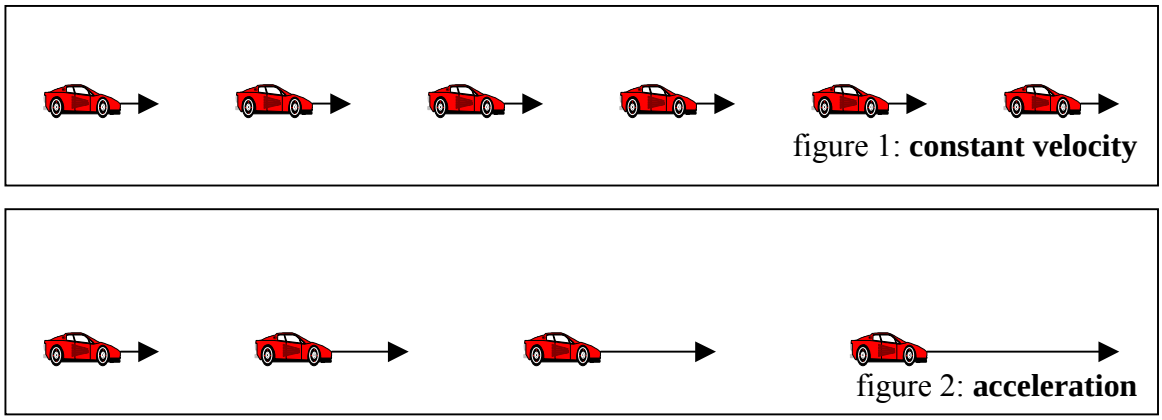


figure 1: **constant velocity**

figure 2: **acceleration**

Vector diagrams can be used to represent any vector quantity. In physical science, vector diagrams will be used to represent a variety of physical quantities such as acceleration, force, and momentum. Be familiar with the concept of using a vector arrow to represent the direction and relative size of a quantity. It will become a very important representation of an object's motion.

Problem Solving Strategies

There are two basic types of vector questions:

1. Where a second vector occurs after the first one has finished

Example: A man walks 4 km north and then 3 km east.

In a case like this we

1. draw a small compass (because the question has used north, south east and/or west)

2. use arrows, one after the other to tell the story of what the man did

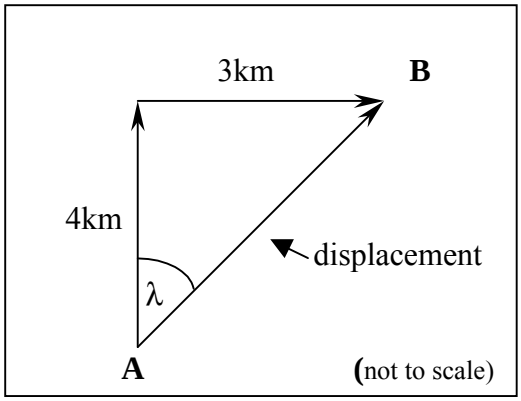
Notice

1. the direction of each arrow
2. how the 3 km arrow starts where the 4 km arrow ends (head to tail method)
3. how the 4 km arrow is longer than the 3 km arrow
4. we know that the angle between the 4 km and 3 km is 90^0 (the angle between north and east)

3. now it depends on what you are asked:
If you are asked the **distance** the man moved from start to finish it is simply:

4 km + 3 km = 7 km (no direction since 'distance' is a scalar.)

However, if you are asked what was the man's **displacement** from start to finish, you are being asked for the straight line distance (and the direction of the line) from A to B.



There are two methods to find this displacement:

I. Scale Drawing

This is where you decide (if a scale is not given) to make 1 km say 2 cm long. This makes the 4 km line 8 cm long - and you draw this line going north exactly 8 cm long. You then use a protractor (or set square) to make an angle of 90^0 and you then draw the 3 km line going east (to the right) at 90^0 to the 4 km and make it exactly 6cm long (1 km ≙ 2 cm; 3km ≙ 6cm). At the end of this line (at 6 cm) you have found the exact position of B.

You now join A to B and measure the length of AB. You will find it to be 10 cm long. Now you use the scale in reverse. For every 2 cm you have along AB you have 1 km. Hence 10cm means AB represents 5 km - and this is the magnitude of the resultant. To get direction you use a protractor to measure the angle λ. When you do this accurately you will find it to be about 37^0. You can, in your answer give this direction in several ways (to say that $\lambda = 37^0$ is not good enough).

You can say:

1) Displacement = 5 km 37 E of N
2) Displacement = 5 km 53 N of E (unusual)
3) Displacement = 5 km on a bearing of 037
4) Displacement = 5 km on a heading of 037
5) Displacement = 5 km at an angle of 37^0 clockwise from the 4km vector.

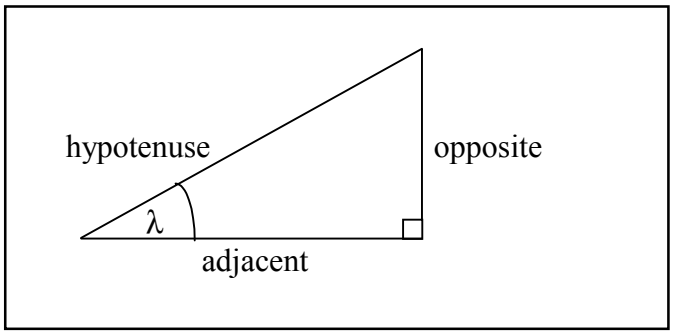
The best answer would be 1) or 3).

Note: If you were asked how far he would have to walk from B straight back to A, you would reverse the arrow from A to B and make it go from B to A. The magnitude of the distance would still be 5km but if you needed direction, it would be the other way i.e. 37^0 W of S or bearing 217.

II. By Calculation

This is divided into two main sections:

A) Provided we have a right angle (90^0) between two of the vectors.
If we do, we use the **trigonometric ratios**: sin, cos or tan.



To refresh your memory:

$\sin \lambda = \text{opp} / \text{hyp}$

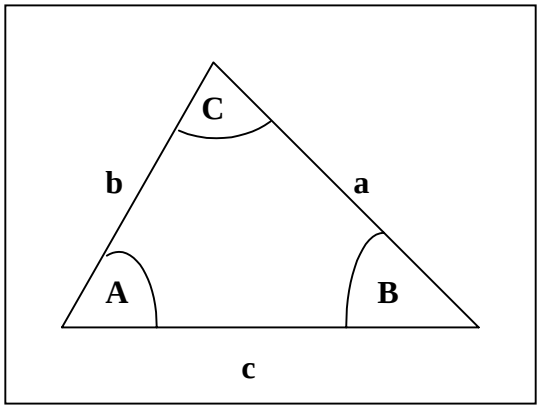
$\cos \lambda = \text{adj} / \text{hyp}$

$\tan \lambda = \text{opp} / \text{hyp}$

B) If we do not have a right angled triangle we use either the **sine rule or the cosine rule**.
(It is rare that this type of question is asked in the matric examination.)

1.) $$\frac{a}{\sin A} = \frac{b}{\sin B} = \frac{c}{\sin C}$$

2.) $$a^2 = b^2 + c^2 - 2bc\cos A$$



The drawing of a triangle

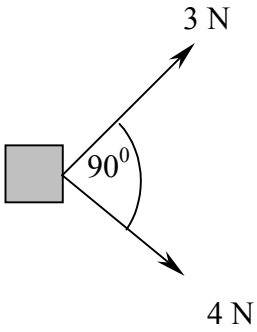
In most vector problems the simplest approach and best method is to use a triangle. To construct a triangle to scale we need to know three facts about the triangle we wish to draw.

- two sides and the included angle
- two angles and the included side
- three sides (not usual in vectors)

2. When two vectors act on a body simultaneously

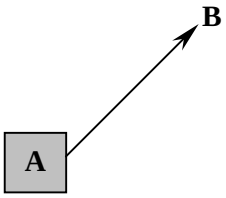
a) When two forces for example act on a body at the same time and we need to find the resultant force (one force that will have the same result on the body that the two forces together are having), we follow much the same as before - we pretend that one of the vectors starts after the other has finished.

Question: Find the resultant force acting on the body below?

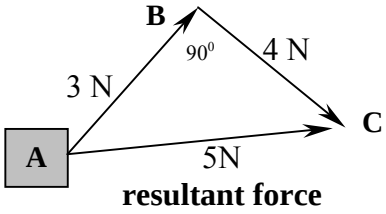


We start with either the 3 N force or the 4 N force (it does not matter which).

Let's start with the 3 N force.
This force would have moved the body from A to B.



We now give the 4 N force its turn, but it starts when the 3 N force stops at B (head to tail again).

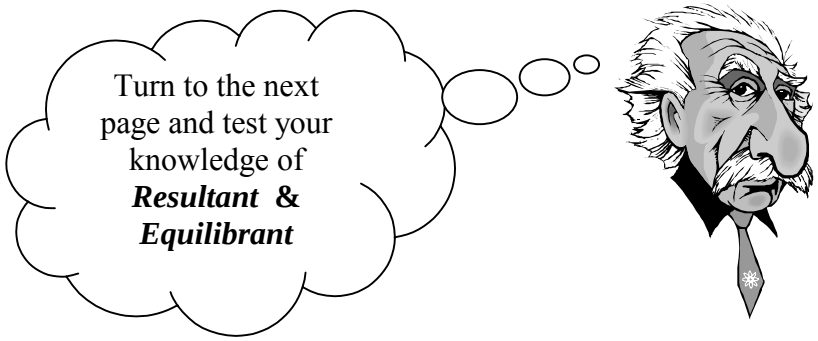


So as a result of the 3 N from A to B and the 4 N from B to C, the body has moved from A to C (and to do this in one step we would have needed a force directly from A to C) - and this is the **resultant** force (5 N).

Now we are back to a triangle, which needs to be solved either by a scale drawing or by calculation - as we did in the previous section.

b) Three forces in equilibrium

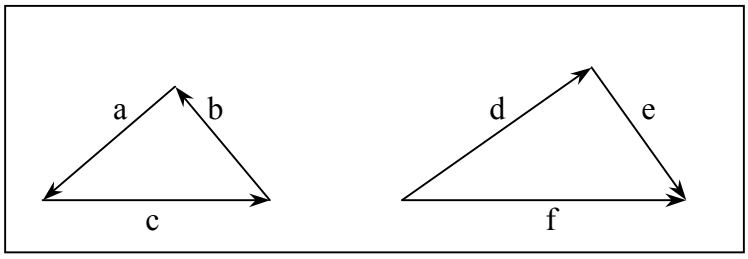
If a body has two or more forces acting on it and it does not move (accelerate) then the forces are balanced: the forces are in equilibrium. Any one force is the **equilibrant** of the others.



Question: Which of the six vectors at the right is / are

A) resultants

B) equilibrants



Answer:

A) The only resultant is f. It is the result of d and e.

B) a, b and c are all equilibrants of the other two forces.

SUMMARY

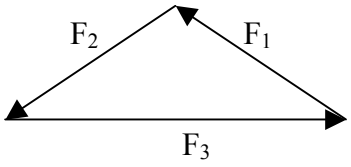
- If a body accelerates, there must be a resultant of the vectors that are acting on the body and the resultant acts in the direction of the acceleration.
- If a body does not move, any one vector is the equilibrant of the others (same magnitude as the resultant but in the opposite direction).
- If you are at point A and you wish to get to point B, the straight-line vector from A to B is the resultant of whatever you do.
- Draw a sketch of the vectors and then translate the sketch into a triangle, giving each vector its own turn (head to tail method).
- Right-angled triangles are best done by using sin, cos and tan, while those with no right angle are best done using a scale drawing (or the sin or cosine rule).

Topic: **VECTORS & SCALARS**

Worksheet 1: Multiple Choice Questions Time: 30 Minutes

Instructions: Make a cross over the letter A, B, C, D or E (if applicable) to show the correct answer.

1.) According to the vector diagram below



which is correct?

A $F_2 + F_3 = F_1$ **B** $F_1 + F_2 = F_3$

C $F_1 + F_3 = F_2$ **D** $F_1 + F_2 + F_3 = 0$

2.) Two forces of magnitude 3 N and 4 N respectively act on a body. The maximum possible magnitude of the resultant of these forces is

A 12 N **B** 7 N **C** 5 N **D** 1 N

3.) A man, who has walked a certain distance, but not in a straight line, can …

A have a zero displacement
B not have a negative displacement
C have a displacement higher in magnitude to the distance
D have a displacement equal in magnitude to the distance

4.) Which one of the following is not a vector quantity:

A velocity **B** force **C** energy **D** momentum

5.) A girl runs once around a circular track with a radius of 65m at a speed of 2m/s. Her displacement is:

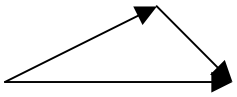
A 0 **B** 65m west **C** 65m east **D** 130m

6.) If a car rounds a bend at constant speed, then …

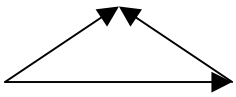
A it will undergo zero acceleration
B it will accelerate
C its velocity will remain constant
D its rate of change of velocity will be zero.

7.) In which of the following vector diagrams is the resultant of the three vectors zero?

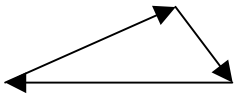
A



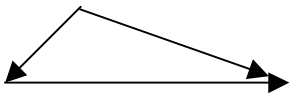
B



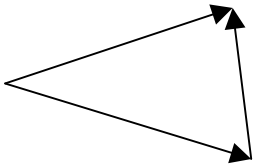
C



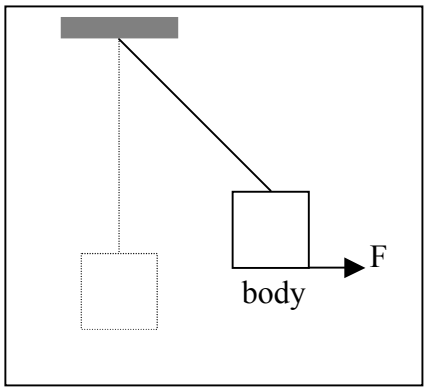
D



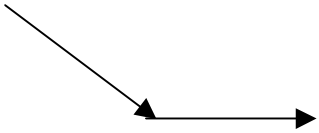
E



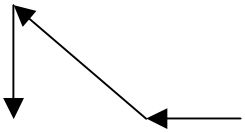
8.) A force F is used to pull a body, which is suspended from a string, to one side as shown in the diagram to the right. The body is in equilibrium.
Which of the following vector diagrams represents all the forces acting on the body?



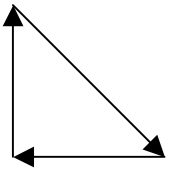
A



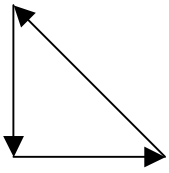
B



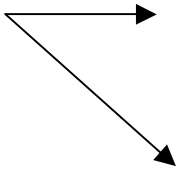
C



D

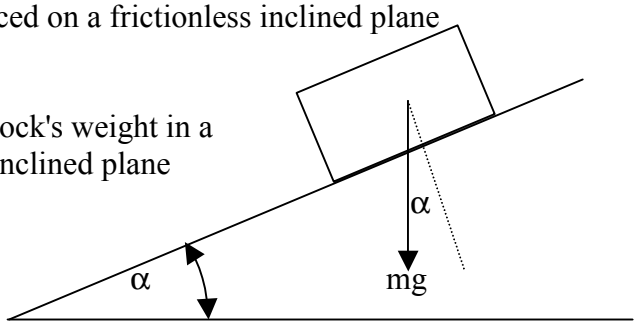


E



9.) A body of mass m is placed on a frictionless inclined plane (as shown in the sketch).

The component of the block's weight in a direction parallel to the inclined plane is given by …



A mg cos α **B** mg sin α **C** mg tan α **D** none of the above

10.) A force of magnitude F acts at an angle α to the horizontal. The magnitude of the horizontal component of the force is …

A F cos α **B** F sin α **C** F sin $(90^0 - \alpha)$ **D** 0

Topic: **VECTORS & SCALARS**

Worksheet 2: Multiple Choice Questions Time: 30 Minutes

Instructions: Make a cross over the letter A, B, C, D or E to show the correct answer.

1.) Which of the following pairs are both scalar quantities?

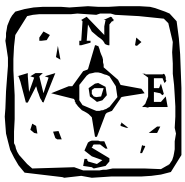
A energy and force
B speed and mass
C temperature and velocity
D volume and weight
E density and acceleration

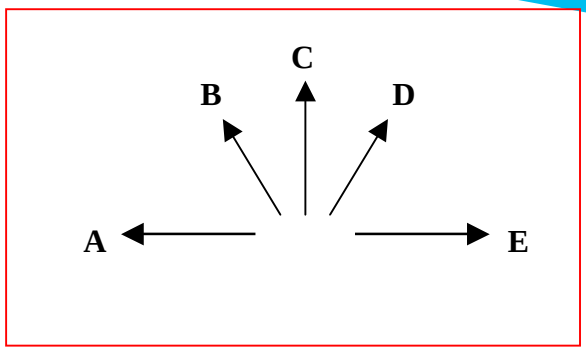
2.) Which of the following pairs are both vector quantities?

A weight and mass
B velocity and speed
C force and acceleration
D acceleration and speed
E velocity and energy

3.) The wind is blowing towards east. The pilot of an airplane wishes to fly due North.

In which direction should he aim the airplane?

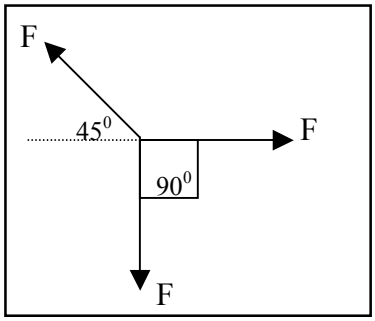


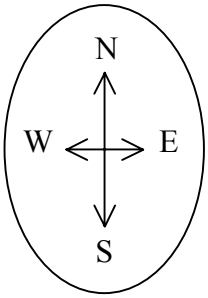


4.) Two forces of magnitude 20 N and 50 N act simultaneously on a body. Which one of the following forces cannot be a resultant of the two forces?

A 20 N
B 30 N
C 40 N
D 70 N

5.) Three forces of equal magnitude F act on a body as shown as in the diagram below. The body …





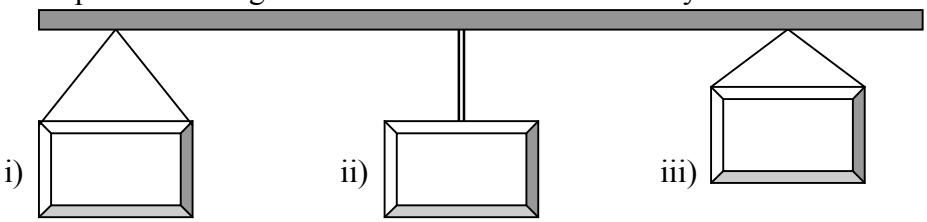
A does not accelerate

B accelerates towards north-west

C accelerates towards south-east

D accelerates towards north-east

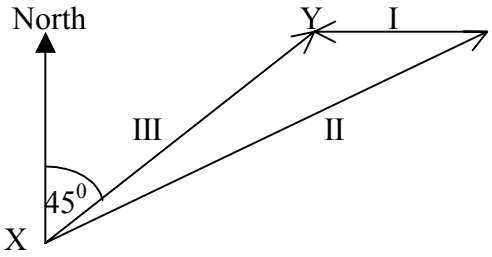
6.) A picture is hung on the wall in three different ways:

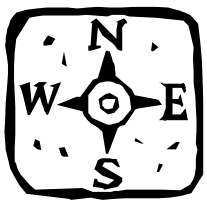


The tension in the string is

A least in i)
B greatest in i)
C greatest in ii)
D least in iii)
E greatest in iii)

7.) The pilot of a small aircraft needs to fly from town X to town Y which lies north-east of X. while flying the aircraft will encounter a steady wind blowing from the East, so he draws a velocity - vector diagram to assist in setting his course correctly.





What is the correct label for the vector marked II in the diagram below?

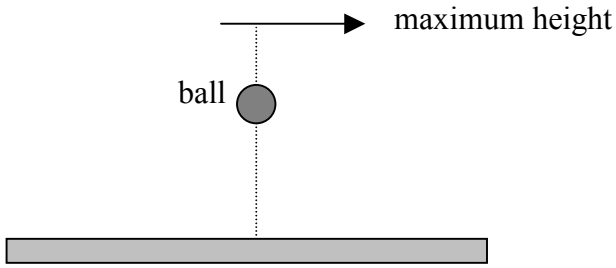
A Velocity of aircraft relative to air

B Velocity of aircraft relative to the ground

C Velocity of air relative to the ground

D Resultant velocity of aircraft.

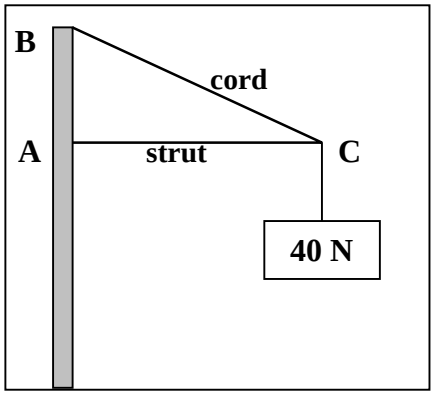
8.) A ball is thrown vertically into the air. The path travelled by the ball is indicated by the dotted line in the diagram below:



Which of the following diagrams represents the forces acting on the ball before it reaches maximum height?

A **B** **C** **D**

9.) The diagram to the right shows a weight of 40 N suspended by an arrangement consisting of a light strut hinged at A and a light cord tied at C and to the wall at B.



Which statement about forces acting in this situation is true?

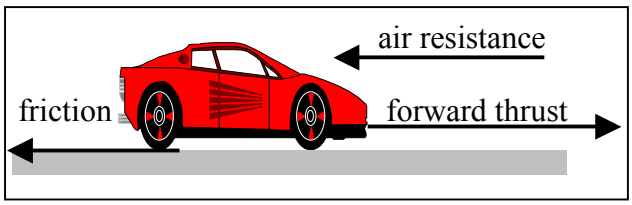
A The tension in cord BC must be 40 N.

B The tension in cord BC is less than 40 N.

C The vector sum of the three forces acting at C must be 40 N.

D The vertical component of the force cord BC exerts on C is equal to 40 N.

10.) The diagram to the right shows the direction of three forces acting on a moving sports car. The car is travelling at constant speed.



Which one of the following is correct?

	forward thrust	friction	air resistance
A	2500 kN	1200 kN	1500 kN
B	2500 kN	2500 kN	2500 kN
C	3000 kN	1500 kN	2000 kN
D	3000 kN	1000 kN	2000 kN

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Topic: **Vectors and Scalars**

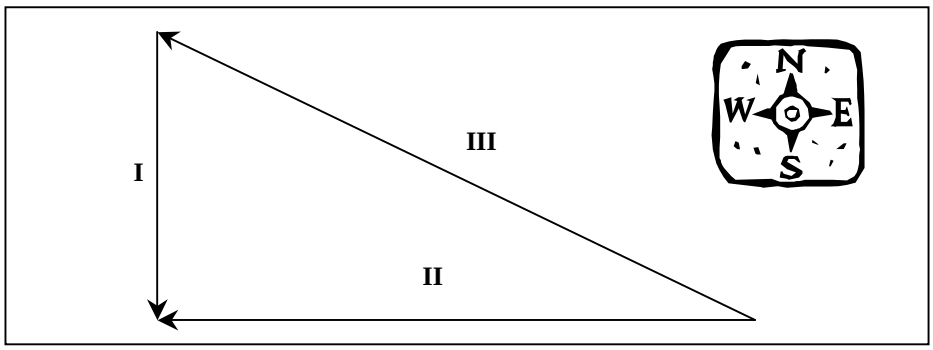
Worksheet 3: Multiple Choice Questions Time: 30 Minutes

Instructions: Make a cross over the letter A, B, C or D to show the correct answer.

1.) Which one of the following represents a scalar quantity?

A The change in momentum of a rubber ball bouncing off the floor.
B The velocity of an airplane flying at 300 $km.h^{-1}$ on a bearing 040^0.
C The speed of a car travelling at 100 $km.h^{-1}$.
D The acceleration of an object thrown vertically upwards and which has reached the highest point of its motion.

2.) An aircraft is flying due West in a cross-wind that blows from north to south. The pilot draws the following vector diagram to establish the aircraft's correct heading.

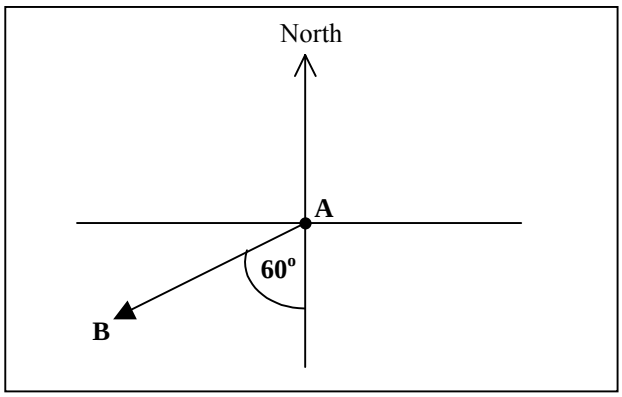


What is the correct label for the vector marked III in the diagram?

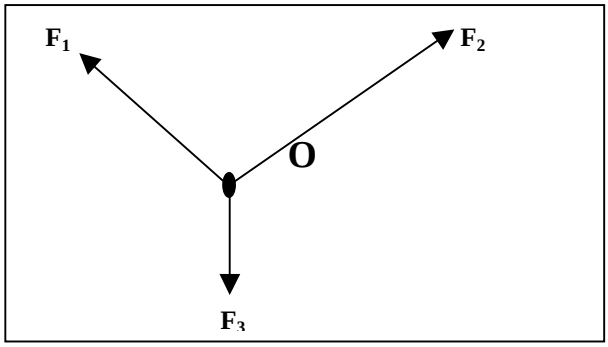
A Resultant velocity of aircraft relative to the ground.
B Velocity of aircraft relative to the ground.
C Velocity of air relative to the ground.
D Velocity of aircraft relative to the air.

3.) Which one of the following statements is CORRECT?
The direction of vector AB on the sketch can be written as a bearing of …

A 240^0
B 120^0
C 210^0
D 060^0



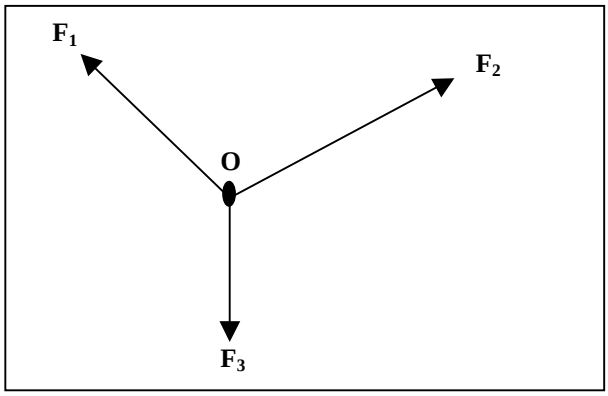
4.) Three forces F_1, F_2 and F_3 act simultaneously on object O, which is in equilibrium.



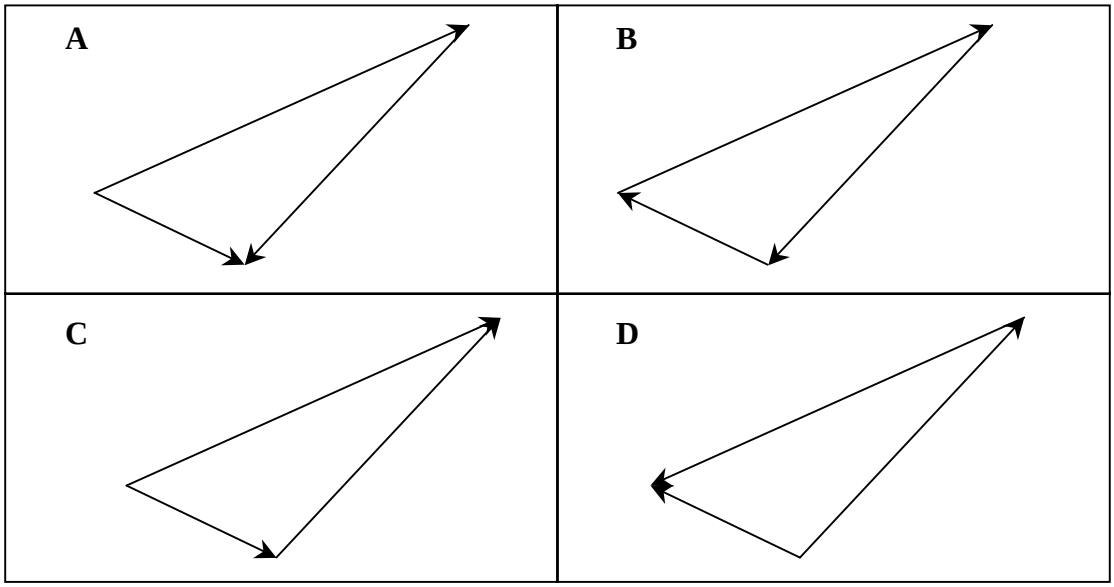
Which ONE of the following statements is NOT TRUE with reference to the three forces?

A The resultant of forces F_1, F_2 and F_3 is zero.
B The forces F_1, F_2 and F_3 lie in the same plane.
C Force F_3 is the resultant of forces F_2 and F_3.
D The sum of the components of all forces in any chosen direction is zero.

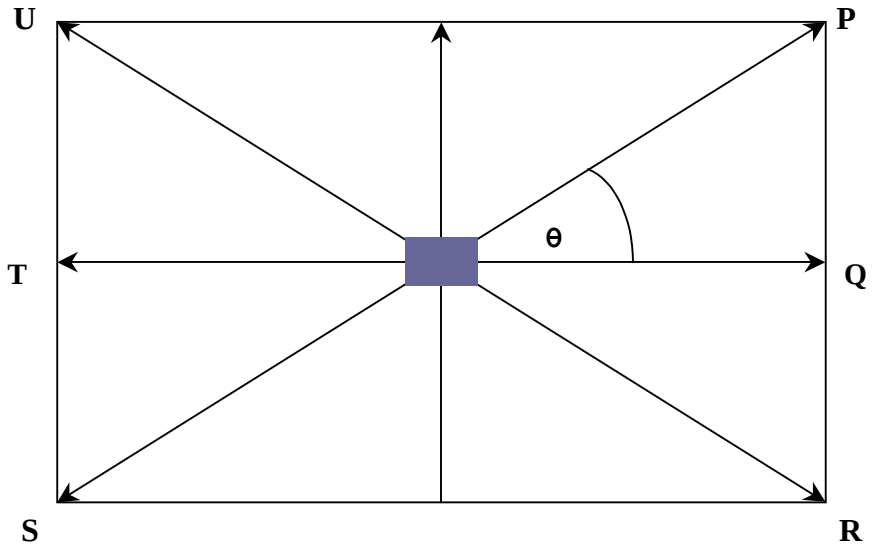
5.) Three forces F_1, F_2 and F_3 act simultaneously on object O, which is in equilibrium.



Which one of the following vector diagrams correctly represents the above situation?



Questions 6, 7 and 8 refer to the following diagram, showing a number of forces acting on an object.



6.) The resultant of force V and force R is force …

A P
B Q
C S
D T

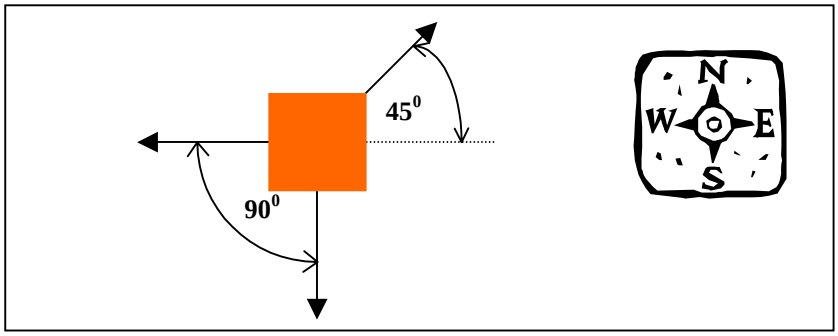
7.) The equilibrant of force V and force S is force …

A P
B Q
C U
D T

8.) If force P is 100 N and angle $\theta = 30^0$, than the magnitude of force V is …

A 50,0 N
B 57,7 N
C 86,6 N
D 88,9 N

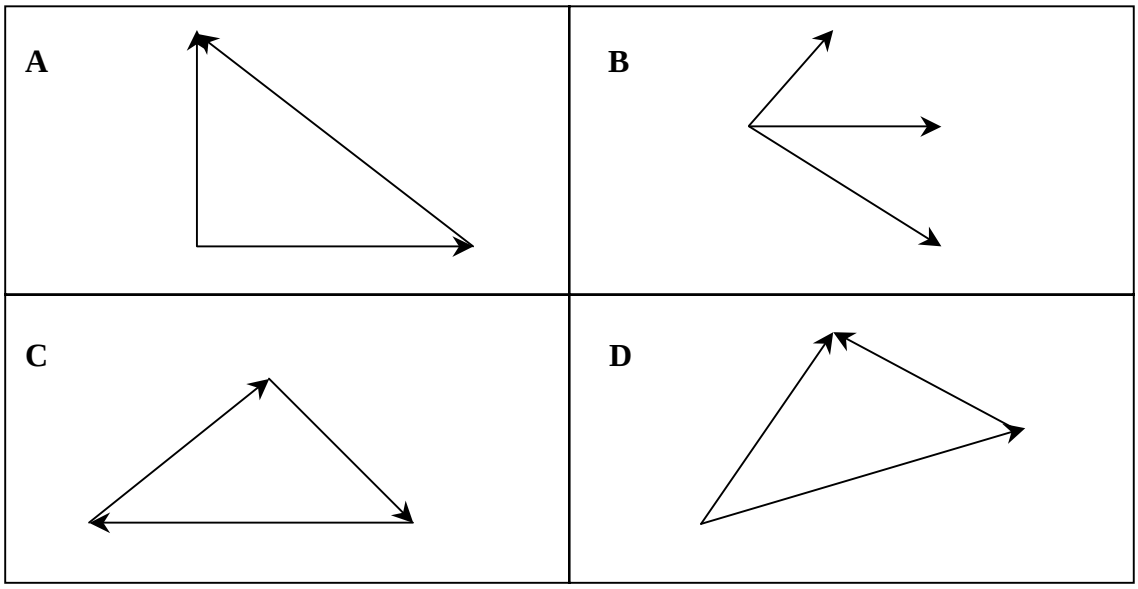
9.) Three horizontal forces of equal magnitude act on a box at rest as shown in the diagram below.



The box …

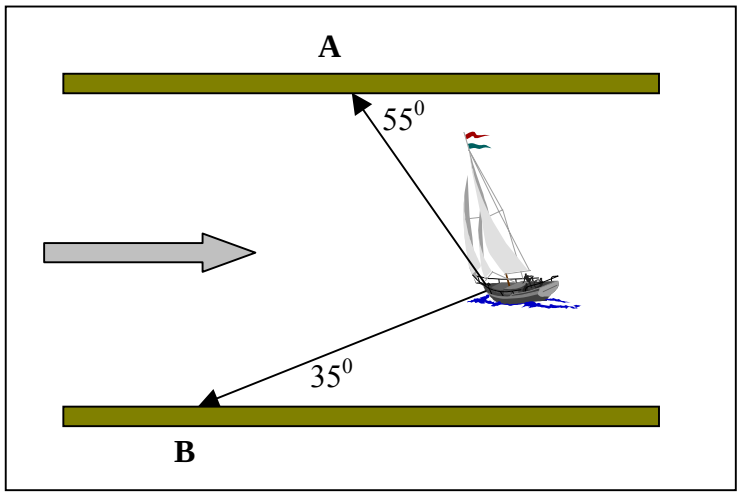
A accelerates towards the north-east.
B accelerates towards the south-east.
C accelerates towards the south-west.
D does not accelerate.

10.) In which one of the following vector diagrams is the resultant of the three vectors zero?



STRUCTURED QUESTIONS:

Q1)
A sailing boat is kept motionless in a fast flowing river by ropes held by two boys, A and B, on opposite banks as shown in the diagram below. The water exerts a force of 450 N (parallel to the bank) on the boat. The angles of the ropes connecting A and B with the boat, with respect to the river bank, are 55^0 at A and 35^0 at B as shown in the diagram below.



1.1.1 Give a reason why it is correct to say that the forces acting on the boat are in equilibrium.

1.1.2 Draw a fully labelled diagram of forces indicating all the forces acting on the boat.

1.1.3 By means of an accurate vector diagram, using a scale of 1 cm = 50 N, or by calculation, determine the magnitude of the forces acting on the boat.

Q2)
A freighter is 240 km due east of a harbour. A current is flowing due south and the freighter captain wishes to set a course so that he can reach the harbour directly. He sets the course at $22{,}6^0$ north of west and sets a speed through the water of 13 $km \cdot h^{-1}$ and the freighter eventually reaches the harbour in 20 hours.

2.1 Define the RESULTANT of two vectors.

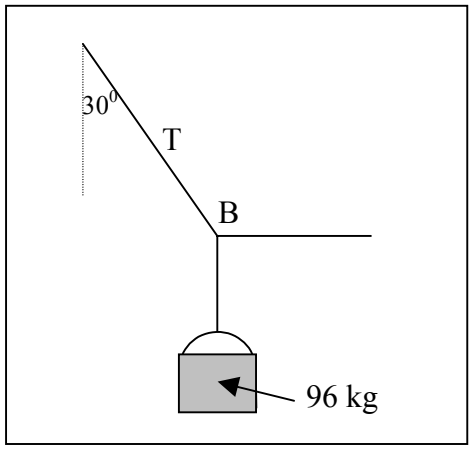
2.2 Calculate the resultant velocity of the freighter.

2.3 Draw a velocity vector diagram indicating the velocity of the current v_c, the velocity of the freighter through the water v_f and the resultant velocity of the freighter v_r, showing how they are related.

2.4 Determine the velocity of the current.

Q3)

A bricklayer on top of a building runs short of bricks. He lowers a bucket on a cable to a worker on a truck. The worker pulls the bucket horizontally to the right to bring it close to the truck. The worker holds the bucket stationary so that it makes an angle of 30^0 to the vertical (as shown in the diagram at the right). Another worker then fills the bucket with bricks until the total mass of the bucket is 96 kg.



3.1 What is the weight of the bucket?

3.2 Are the forces acting on the bucket in equilibrium? Explain.

3.3 Draw a fully labelled force diagram (not to scale) showing all the forces acting on the bucket. (Represent the bucket with a large dot.)

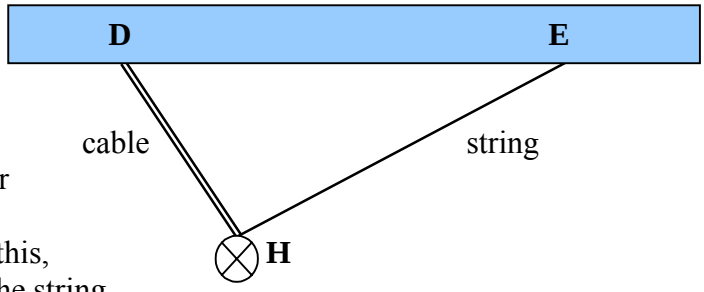
3.4 Draw a labelled vector diagram showing the relationship between the forces.

3.5 Determine the horizontal force exerted on the bucket by the worker to hold it in place

3.6 Determine the tension in cable T. You can use a scale diagram (scale: 10 mm = 100 N) or trigonometry.

Q4

An electric lamp of mass 0,8 kg is attached by an electric cable to the ceiling at point D. To position it directly over her desk, Thembi has pulled the lamp to one side by a string tied to the lamp holder H and fixed to point E on the ceiling. Thembi is curious as to whether the tension in the electric cable is affected when the lamp is pulled aside. To investigate this, she measures the angles which the cable and the string make with the ceiling and finds them to be 60^0 and 40^0 respectively as shown in the diagram at the right.



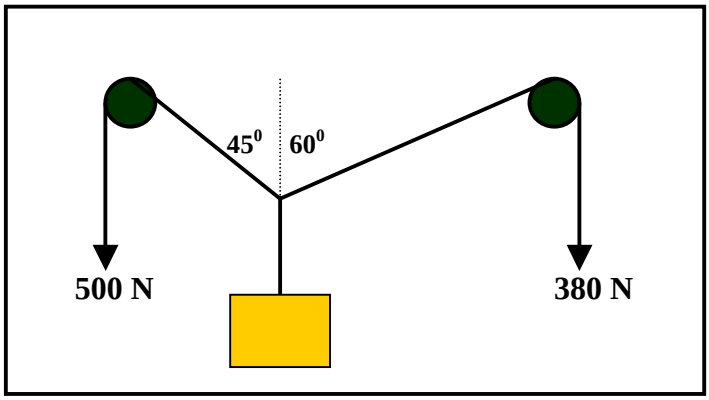
4.1 What would be the tension in the electric cable if the lamp were hanging down straight?

4.2 Draw a force diagram for the lamp holder H and label all the forces acting on it.

4.3 Find the tensions in the electric cable and the string either by calculation or by accurate scale drawing.

4.4 Has the tension in the electric cable been affected when the lamp is pulled aside?

Q5
Two forces act over pulleys to support a block of wood as shown in the diagram below.



Calculate:

1. The vertical component of each force acting on the object.
2. The resultant vertical force acting on the object.
3. The weight of the block.

ANSWERS TO MULTIPLE CHOICE QUESTIONS:

(Worksheet 1)	
1	D
2	B
3	A
4	C
5	A
6	B
7	C
8	D
9	B
10	A

(Worksheet 2)	
1	B
2	C
3	B
4	A
5	C
6	E
7	A
8	A
9	D
10	D

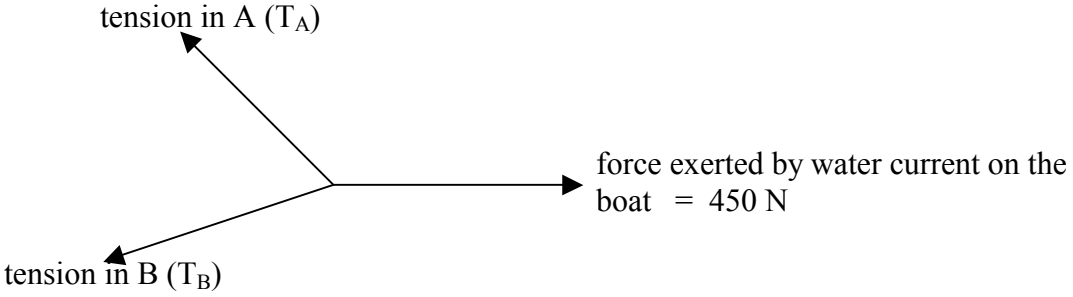
(Worksheet 3)	
1	C
2	D
3	A
4	C
5	B
6	B
7	B
8	A
9	C
10	C

Answers to structured questions:

Q1

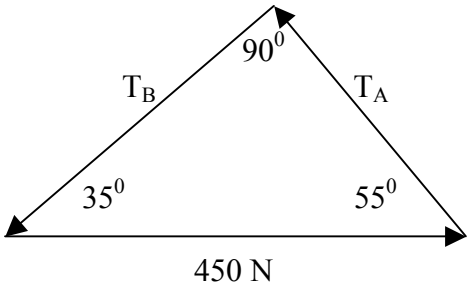
1.1 The boat is at rest / stationary. According to Newton's 1. law: no resultant force acting on the boat.

1.2



1.3 **By calculation**:

(cos = adj / hyp)

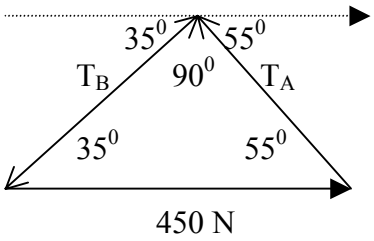


T_A / 450 = cos 55 ∴ 450 x cos 55 = **258,1 N** at 55^0 to the river bank.

T_B / 450 = cos 35 ∴ 450 x cos 35 = **368,6 N** at 35^0 to the river bank.

By scale drawing:

scale: 1 cm represents 50 N



line representing T_A measures 5,2 cm ∴ T_A = 5,2 x 50 = 260 N

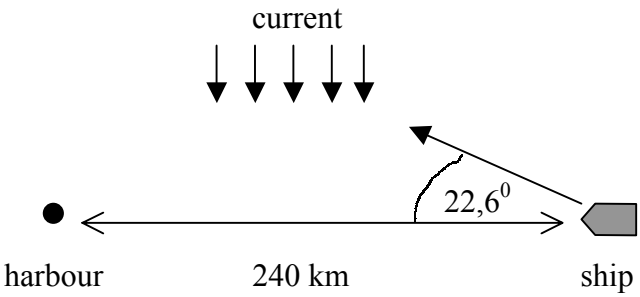
line representing T_B measures 7,4 cm ∴ T_A = 7,4 x 50 = 370 N

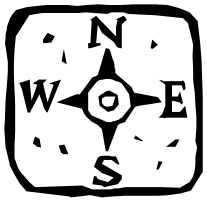
Draw a line 9 cm long to represent 450 N. Use a protractor to draw angles of 55^0 and 35^0 and complete the triangle. Measure the sides representing T_A and T_B.

Q2

2.1 The resultant of two vectors of a number of vectors is that single vector which has the same effect as all the vectors acting together.

Sketch:

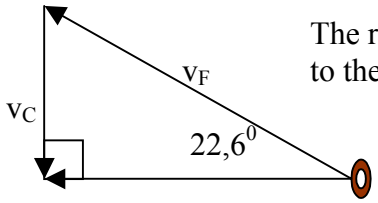




2.2 Covers the 'straight line distance' (displacement) from east to west in 20 hours:

resultant velocity = displacement / time
= 240 km / 20 h
= <u>12 km/h West</u>

2.3



The resultant is from the tail of v_F to the head of v_R.

v_R = 12 km/h

2.4 by Pythagoras: $v_F^2 = v_C^2 + v_R^2$

$\therefore$ $v_C^2 = v_F^2 - v_R^2$

$= (13)^2 - (11)^2 = 169 - 144 = 25$

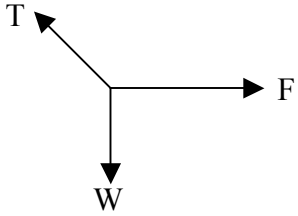
$\underline{v_C = 5 \text{ km/h South}}$

Q3

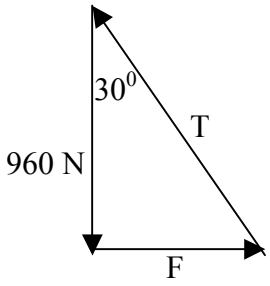
3.1 W = m g
= 96 kg x 10 m/s^2
= **<u>960 N</u>**

3.2 Yes - since the bucket is at rest / stationary.

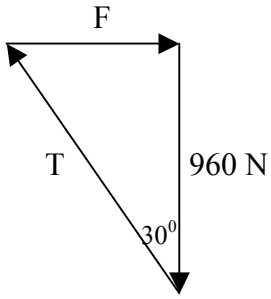
3.3 F - worker's force
T - tension in the cable
W - weight of the bucket
(for all forces:
they must be represented by arrows)



3.4



or:



3.5 F = 960 N · tan 30^0
= **<u>554,25 N</u>**

3.6 T = 960 / cos 30^0
= **<u>1108,5 N</u>**

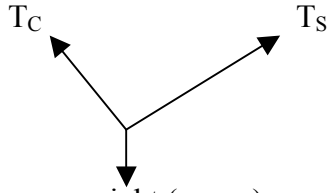
for scale drawing: 3.5 & 3.6 can be answered from the same diagram

---

Q4

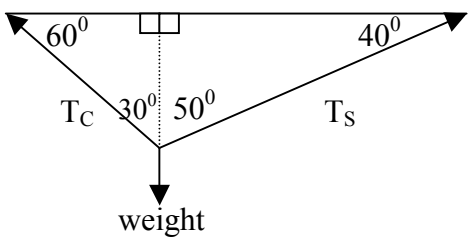
4.1 weight = m g
= 0,8 x 10
= **<u>8 N</u>** ∴ tension in cable is 8 N

4.2 tension in cable T_C tension in string T_S



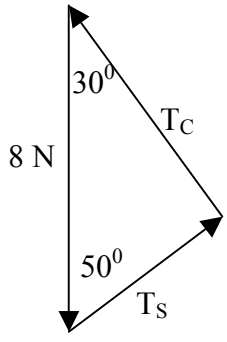
4.3 for drawing scale: let 1cm represent 1N
Draw vertical line 8 cm long to represent the weight.
Draw angles of 50^0 and 30^0 as shown and complete the triangle.
Forces are balanced ∴ vector diagram is closed.

force diagram:



N.B. T_S makes an ∠ of 50^0 with the vertical
T_C makes an ∠ of 30^0 with the vertical

vector diagram



By **calculation**: using the **sine rule** ($\measuredangle$ of 30^0, 50^0 and hence 100^0)

$T_S / \sin 30^0 = 8 / \sin 100^0$

$\therefore T_S = (8 \times \sin 30^0) / \sin 100^0$

$= \underline{\mathbf{4{,}06\ N}}$

$T_C / \sin 50^0 = 8 / \sin 100^0$

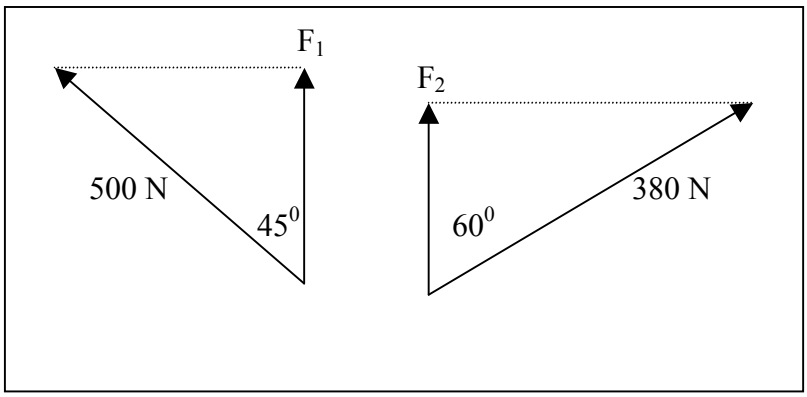
$\therefore T_S = (8 \times \sin 50^0) / \sin 100^0$

$= \underline{\mathbf{6{,}22\ N}}$

4.4 The tension in the cable has decreased (more of the weight is supported by the string).

Q5

Start with a **diagram**:



1.)

First let us find F_1:

Cos $45^0 = F_1 / 500$ N

$\underline{F_1} = 500 \times \cos 45 = \underline{353{,}55\ N}$

Accordingly we find F_2:

cos $60^0 = F_2 / 380$ N

$\underline{F_2} = \cos 60^0 \times 380\ N = \underline{190\ N}$

2.) Resultant vertical force $= F_1 + F_2$

$= 353{,}55\ N + 190\ N$

$= \underline{543{,}55\ N\ \text{upwards}}$

3.) Since the block of wood is not moving the upward force equals the weight:

weight = mass x g

$\therefore$ **mass** = weight / g $= 543{,}55 / 10 = \underline{54{,}355\ kg}$