CHAPTER

1

# Force and Motion II

How is a resultant force determined?

Why do we resolve a single force into two components?

How are forces in equilibrium represented by a vector diagram?

What are the factors that affect the spring constant?

## You will learn:


1.1 Resultant Force
1.2 Resolution of Forces
1.3 Forces in Equilibrium
1.4 Elasticity

**Learning Standards and List of Formulae in Chapter 1**

## Information Portal

The Langkawi Skybridge is located at the peak of Gunung Mat Cincang, Pulau Langkawi, Kedah. It is the longest curved pedestrian bridge in the world.

The span of the bridge which is 125 metres in length is suspended by eight cables from a single pylon. Although the 81.5-metre high pylon is inclined and the bridge is curved, the Langkawi Skybridge is always in a stable condition. The design of the bridge has taken into account the actions of external forces such as the wind, the movement of tourists and the distribution of load. All these forces acting on the bridge have to be in equilibrium to ensure the integrity of the structure of the bridge and the safety of its users.

http://bit.ly/2t0aOXv

## Importance of the Chapter

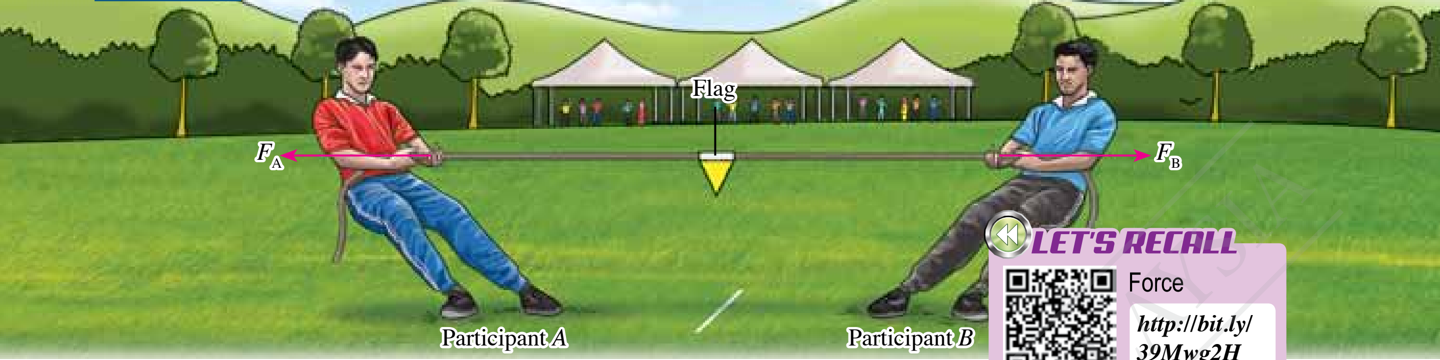
Engineers and designers of structures need to understand and apply the fundamental concepts of physics such as resultant force, resolution of forces and forces in equilibrium when designing a unique structure. These aspects are important to guarantee the integrity of the building structure.

## Futuristic Lens

Futuristic architecture combines the knowledge and skills in physics, engineering, materials science and creative thinking to create building structures beyond the human imagination. Therefore, the concepts and principles of physics are still fundamental for futuristic architecture.

http://bit.ly/2R2cZSi

# 1.1 Resultant Force




**LET'S RECALL**

Force

*http://bit.ly/39Mwg2H*

***Figure 1.1*** *Tug-of-war*

Figure 1.1 shows two participants who are competing in a tug-of-war competition. Participant *A* and participant *B* exert forces $F_A$ and $F_B$ respectively on the rope. What determines whether the flag tied to the rope is at rest, moves to the left or moves to the right?

## Activity 1.1

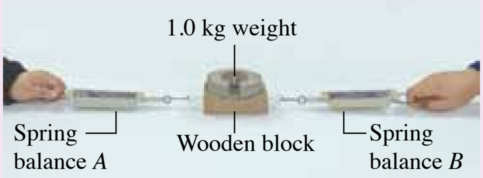
**Aim:** To generate the idea of resultant force and to determine its direction

**Apparatus:** Two spring balances and a 1.0 kg weight

**Material:** A wooden block with a hook at both ends

**Instructions:**

1. Set up the apparatus as shown in Photograph 1.1.
2. Pull the wooden block using spring balance *A* and spring balance *B* in opposite directions, so that the wooden block does not move.
3. Record the readings of the spring balances in Table 1.1.
4. Repeat steps 2 and 3 so that the wooden block moves:
   (a) to the right (b) to the left.




***Photograph 1.1***

**Results:**

***Table 1.1***

| Condition of the wooden block | Reading of spring balance *A* / N | Reading of spring balance *B* / N |
|---|---|---|
| Stationary | | |
| Moves to the right | | |
| Moves to the left | | |

**Discussion:**

1. Compare the readings of the two spring balances when the wooden block is:
   (a) at rest (b) moving to the right (c) moving to the left
2. State the relationship between the direction of motion of the wooden block and the direction of the force acting on the wooden block.

When two forces of the same magnitude acting in opposite directions are applied on a stationary object, the object remains at rest. Assuming the two opposing forces have different magnitudes, the object will move in the direction of the larger force. **The resultant force** is **the single force that represents the vector sum of two or more forces acting on an object**.

Figure 1.2 shows three situations that can be observed in the tug-of-war competition between participant *A* and participant *B*. Observe also the magnitude of forces $F_A$ and $F_B$ which are represented by the lengths of the arrows as well as the motion produced.

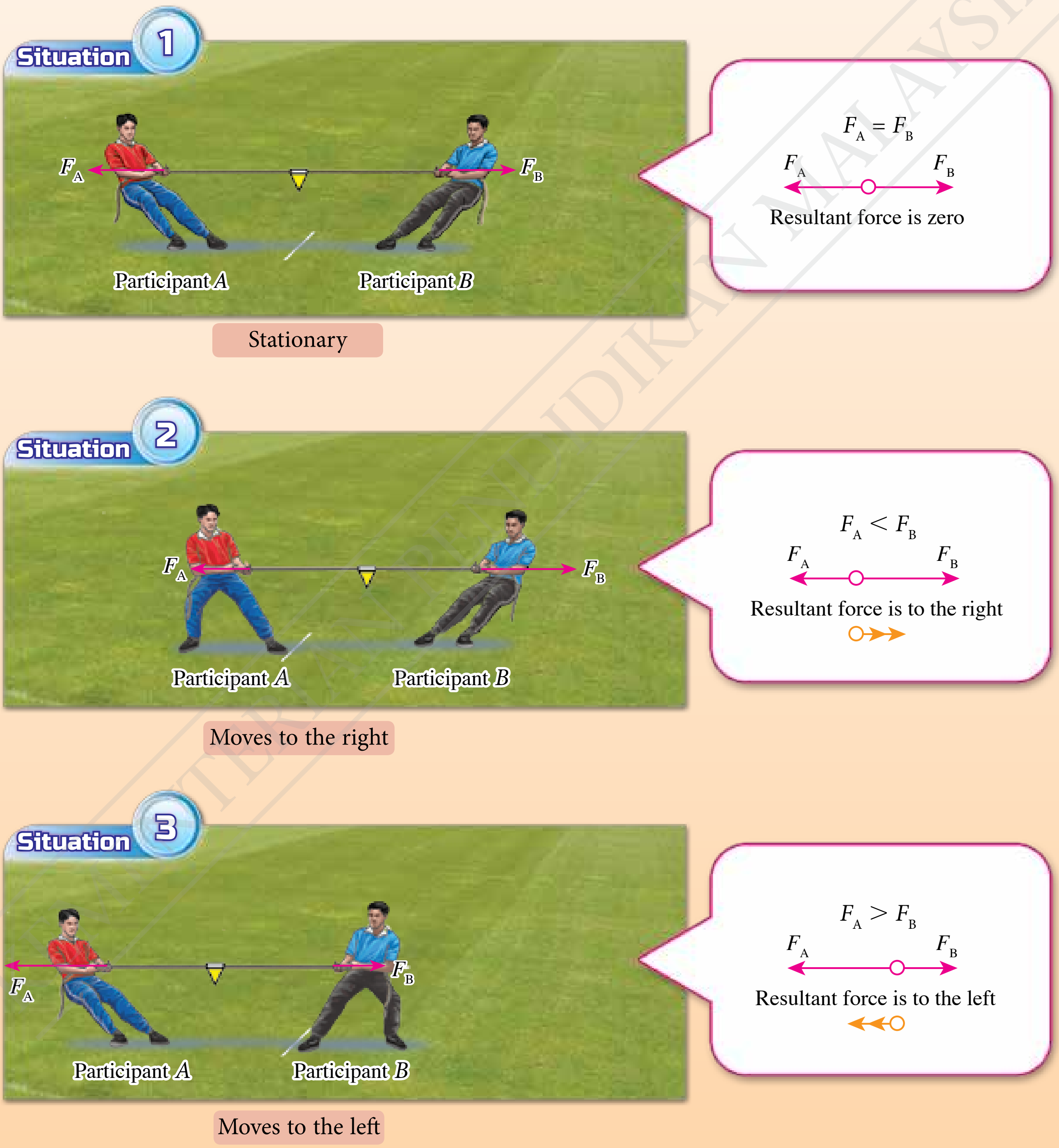



***Figure 1.2*** *Three situations in a tug-of-war competition between participant A and participant B*

## Determining a Resultant Force

A resultant force is the vector sum of the forces acting on a point. How do we determine the resultant force of two forces acting on a point?

### Activity 1.2

Pattern Recognition

**Aim:** To determine the resultant force produced when two forces are acting on an object on a plane

**Instructions:**

1. Carry out a Think-Pair-Share activity.
2. Observe the four situations that involve two forces acting on a point.
3. Examine the suggested method and the sample calculation.
4. Scan the QR code and print the worksheet. Calculate the resultant force for each situation.

SCAN ME
Worksheet Activity 1.2
https://bit.ly/32ijdmS

**Situation 1: Two forces acting on an object in the same direction**

Method and sample calculation


(i) The magnitude of the resultant force is equal to the sum of the two forces.
(ii) The direction of the resultant force is the same as the direction of the two forces.
(iii) The resultant force is stated by its magnitude and direction.

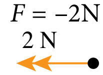
Assume that the force to the right is positive:
(i) Magnitude of the resultant force,
$F = 6 + 8$
$= 14$ N
(ii) Direction of the resultant force is to the right
(iii) Resultant force,
$F = 14$ N to the right


**Situation 2: Two forces acting on an object in the opposite directions**

Method and sample calculation


(i) The magnitude of the resultant force is obtained from the vector sum of the two forces.
(ii) The direction of the resultant force is in the direction of the force with the larger magnitude.
(iii) The resultant force is stated by its magnitude and direction.

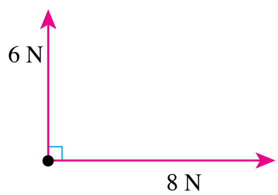
(i) Assume that the force to the right is positive:
Resultant force,
$F = -8 + 6$
$= -2$ N
Magnitude of the resultant force = 2 N
(ii) Direction of the resultant force is to the left
(iii) Resultant force,
$F = 2$ N to the left or
$F = -2$N



### Situation 3: Two forces acting on an object perpendicular to each other

Method and sample calculation

Consider the two forces as the sides of a rectangle.



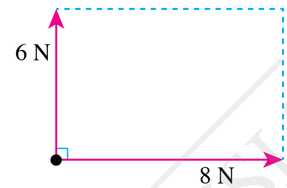

(i) Complete the diagram with the sides representing the two forces that are perpendicular to each other.

(ii) Draw the diagonal of the rectangle that represents the resultant force, $F$ of the two forces.

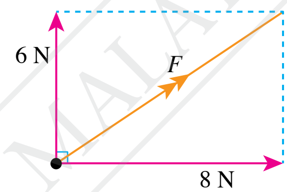
(iii) Calculate the length of the diagonal using Pythagoras' Theorem.

(iv) Calculate the angle between the diagonal and one of the sides of the rectangle.

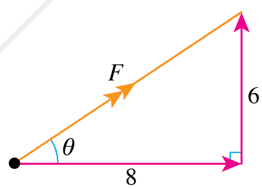
(i)




(ii)

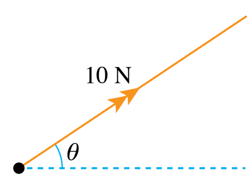



(iii)




$F = \sqrt{6^2 + 8^2}$

$F = 10$ N

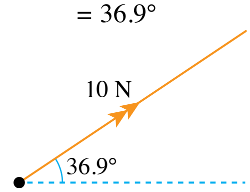



(iv) $\tan \theta = \dfrac{6}{8}$

$= 0.75$

$\theta = \tan^{-1}(0.75)$

$= 36.9°$

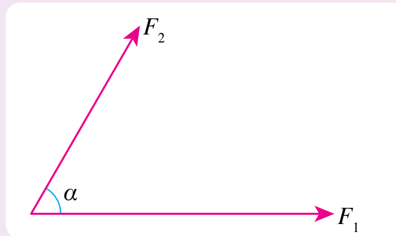



**Info GALLERY**

The resultant force can also be determined by drawing a scaled diagram.

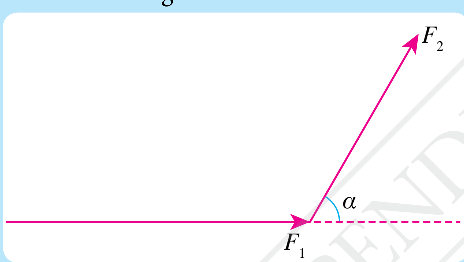
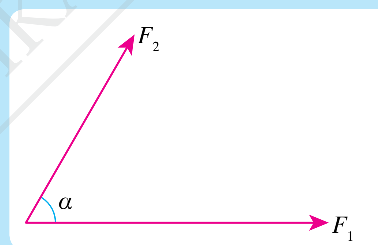
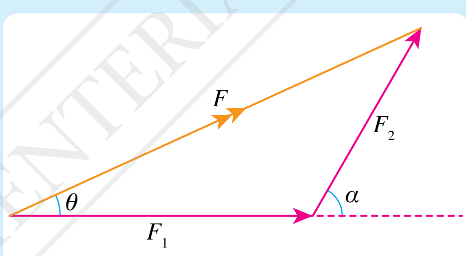
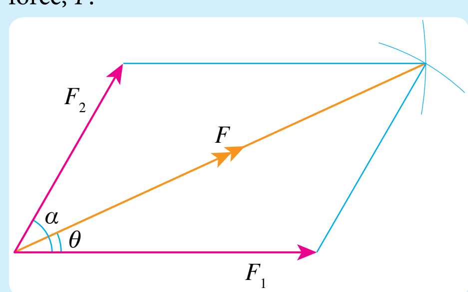
**Situation 4: Two forces acting on an object in directions that are not perpendicular to each other**

Method and sample of scaled drawing




SCAN ME
Video of triangle of forces method
http://bit.ly/2T2joj0

**Table 1.2**

<table>
<tr><th>Triangle of forces method</th><th>Parallelogram of forces method</th></tr>
<tr><td>(i) Choose a suitable scale to draw lines that represent the magnitude of the forces.</td><td>(i) Choose a suitable scale to draw lines that represent the magnitude of the forces.</td></tr>
<tr><td>(ii) By using a ruler and a protractor, draw the force $F_1$ followed by force $F_2$ to form two sides of a triangle.<br><br></td><td>(ii) By using a ruler and a protractor, draw the force $F_1$ and force $F_2$ from a point to form two adjacent sides of a parallelogram.<br><br></td></tr>
<tr><td>(iii) Complete the triangle. The third side represents the resultant force, $F$.<br><br></td><td>(iii) With the aid of a pair of compasses, complete the parallelogram. Draw the diagonal from the point of action of the forces. The diagonal represents the resultant force, $F$.<br><br></td></tr>
<tr><td>(iv) Measure the length of side $F$ and calculate the magnitude of the resultant force using the scale you have chosen.</td><td>(iv) Measure the length of the diagonal and calculate the magnitude of the resultant force using the scale you have chosen.</td></tr>
<tr><td>(v) Measure the angle, $\theta$.</td><td>(v) Measure the angle, $\theta$.</td></tr>
</table>

The magnitude and direction of two forces that are at an angle with each other can be determined by practical means using a Vector Force Table Kit.

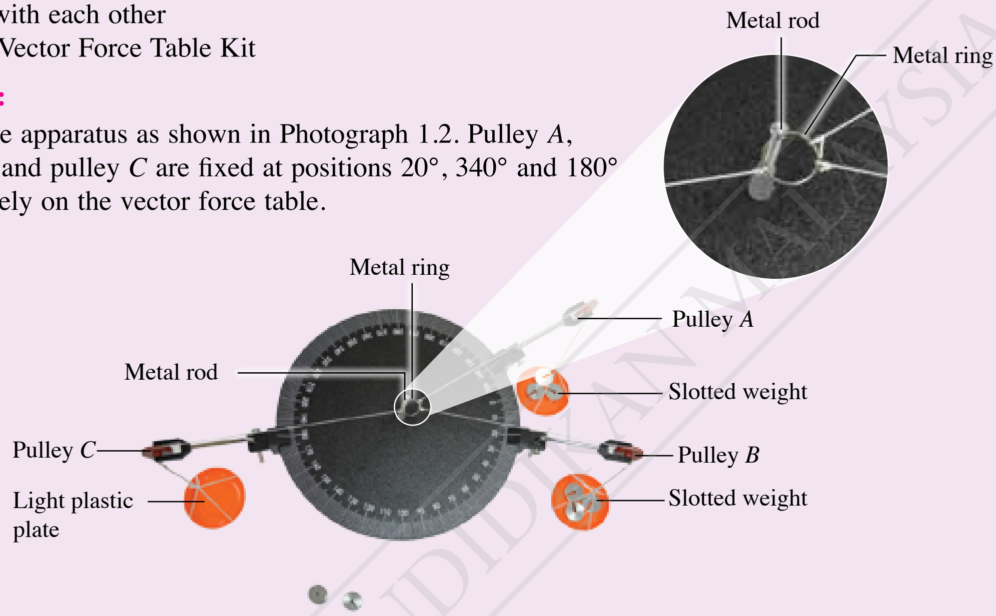
## Activity 1.3

**Aim:** To determine the magnitude and direction of the resultant force of two forces that make an angle with each other

**Apparatus:** Vector Force Table Kit

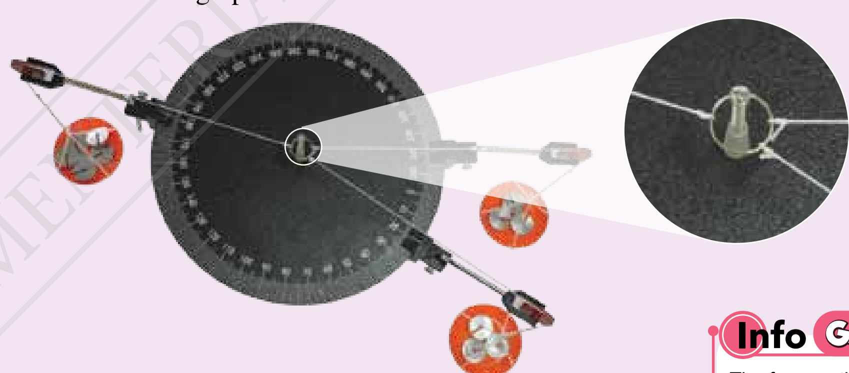
**Instructions:**

1. Set up the apparatus as shown in Photograph 1.2. Pulley *A*, pulley *B* and pulley *C* are fixed at positions 20°, 340° and 180° respectively on the vector force table.




***Photograph 1.2***

2. Place slotted weights of mass 150 g on the plastic plate below pulley *A* and slotted weights of mass 150 g on the plastic plate below pulley *B*. The metal ring will be displaced and will touch the metal rod at the centre of the vector force table.
3. Add slotted weights on the plate below pulley *C* until the metal ring no longer touches the metal rod as shown in Photograph 1.3.



***Photograph 1.3***

4. Record the total mass on the plate below pulley *C* in Table 1.3.
5. Repeat steps 1 to 4 with:
   (i) pulley *A* at the 40° position and pulley *B* at the 320° position
   (ii) pulley *A* at the 60° position and pulley *B* at the 300° position

**Info GALLERY**

The force acting on the metal ring through pulley *C* balances the resultant force acting on the metal ring through pulley *A* and pulley *B*.

**Results:**

***Table 1.3***

| Pulley *A* | | | Pulley *B* | | | Pulley *C* | |
|---|---|---|---|---|---|---|---|
| Position | Mass / g | Force applied / N | Position | Mass / g | Force applied / N | Mass / g | Force applied / N |
| 20° | 150 | 1.5 | 340° | 150 | 1.5 | | |
| 40° | 150 | 1.5 | 320° | 150 | 1.5 | | |
| 60° | 150 | 1.5 | 300° | 150 | 1.5 | | |

**Discussion:**

1. What is the direction of the resultant force of the two forces that act on the metal ring through pulley *A* and pulley *B*?
2. Why is the magnitude of the force acting on the metal ring through pulley *C* equal to the magnitude of the resultant force?
3. How does the magnitude of the resultant force change when the angle between the two forces increases?

## Resultant Force on an Object in Various States of Motion

**A free body diagram of an object** is a **diagram that shows all the forces acting on that object only**. Figure 1.3 shows the free body diagram of a book on a table. The forces labelled are the forces acting on the book while the force acting on the table is not shown. Figure 1.4 shows the free body diagram of a bag on an inclined plane.

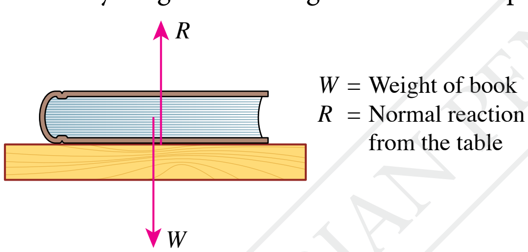



***Figure 1.3*** *Free body diagram of a book on a table*

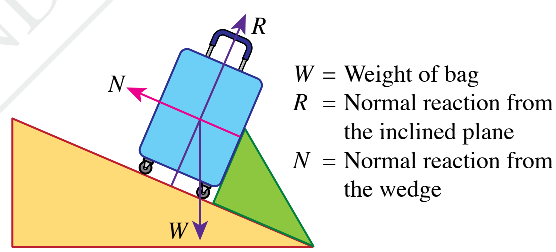
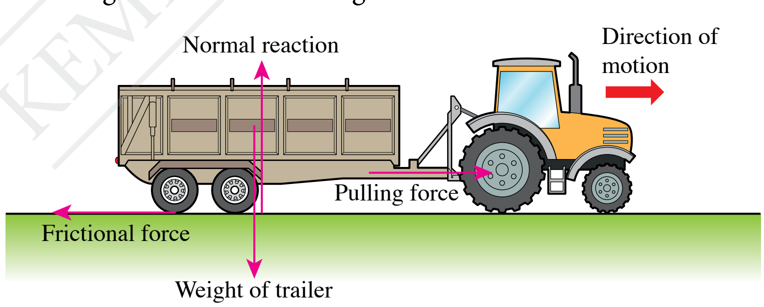



***Figure 1.4*** *Free body diagram of a bag on an inclined plane*

When considering the effect of the resultant force on an object, you only need to draw the free body diagram of the object. Figure 1.5 shows two examples of free body diagram of a moving trailer and a moving rocket.



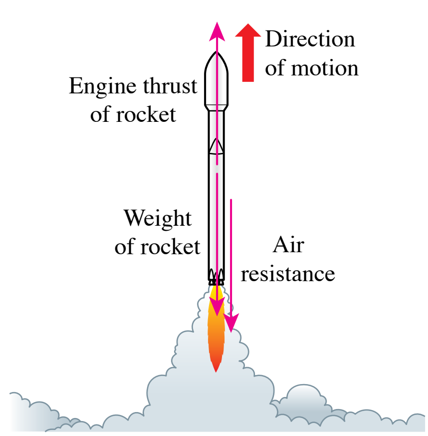
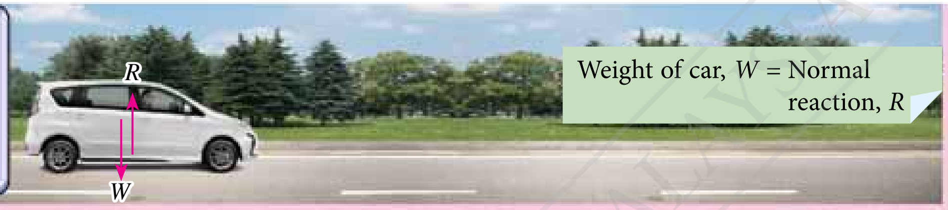




***Figure 1.5*** *Free body diagram of a moving trailer and a moving rocket*

Newton's Second Law of Motion can be expressed as $F = ma$. If a number of forces act on an object at the same time, $F$ represents the resultant force on the object. Figure 1.6 shows the information on the magnitude of the resultant force on an object in different states of motion.

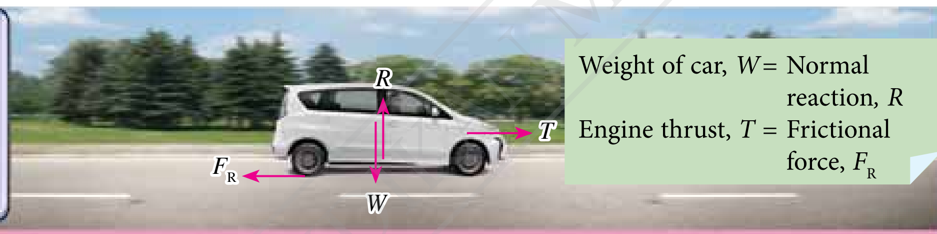
**Object in a stationary state**

- Velocity, $v = 0$
- Acceleration, $a = 0$
- Resultant force, $F = 0$ N




**Object moving with a uniform velocity**

- Velocity is constant or not changing
- Acceleration, $a = 0$
- Resultant force, $F = 0$ N




**Object moving with a uniform acceleration**

- Velocity is increasing
- Acceleration, $a \neq 0$
- Resultant force, $F \neq 0$ N

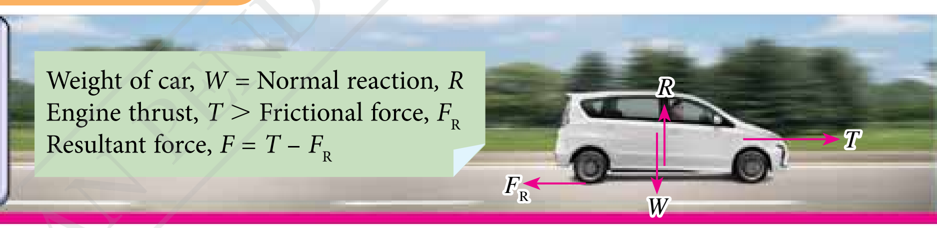



***Figure 1.6** Forces acting on an object in different states of motion*

**Activity 1.4** Evaluation

**Aim:** To discuss the resultant force that acts on an object with the aid of free body diagrams

**Instructions:**

1. Carry out this activity in pairs.
2. You are given an object in a certain state of motion in Table 1.4. For each situation:
   (a) sketch a free body diagram and label all the forces acting on the object
   (b) state the value of the acceleration, either zero or not zero
   (c) state the magnitude of the resultant force, $F$ either zero or not zero
   (d) compare the forces acting on the object

LS 1.1.3

*Table 1.4*

| State of motion | Stationary on the ground (engine is switched off) | Moves upwards with acceleration | Moves upwards with constant velocity |
|---|---|---|---|
| Free body diagram |  |  |  |
| Acceleration, *a* | | | |
| Resultant force, *F* | | | |
| Comparison between forces | | | |

**3.** Scan the QR code and print Table 1.4.

SCAN ME
Worksheet (Table 1.4)
*http://bit.ly/2SXwcqO*

**Discussion:**
Based on the example in this activity, summarise the relationship between the resultant force and the state of motion of an object in the form of a suitable thinking map.

## Solving Problems Involving Resultant Force, Mass and Acceleration of an Object

### Example 1

Figure 1.7 shows a coconut of mass 2.0 kg falling with an acceleration of 9.0 m s$^{-2}$.

(a) Sketch the free body diagram of the coconut.
(b) Calculate the resultant force acting on the coconut.
(c) State the direction of resultant force.
(d) What is the magnitude of the air resistance acting on the coconut?
[Gravitational acceleration, $g$ = 9.81 m s$^{-2}$]

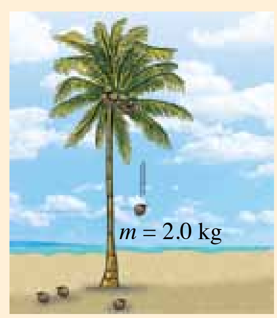


*Figure 1.7*

LET'S ANSWER
*http://bit.ly/2ZW39FA*

### Solution

(a) The forces acting on the coconut are its weight and air resistance (Figure 1.8).

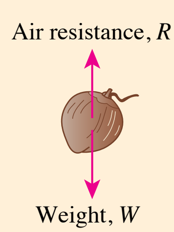


*Figure 1.8*

(b)

| Step 1: Identify the problem | Step 2: Identify the information given | Step 3: Identify the formula that can be used | Step 4: Solve the problem numerically |
|---|---|---|---|

1. Resultant force acting on the coconut, $F$
2. Mass of coconut, $m$ = 2.0 kg
   Acceleration of coconut, $a$ = 9.0 m s$^{-2}$
3. $F = ma$
4. $F = 2.0 \times 9.0$
   $= 18.0$ N

(c) The coconut accelerates downwards. Therefore, the resultant force is downwards.

(d) Mass of coconut, $m$ = 2.0 kg
Gravitational acceleration, $g$ = 9.81 m s$^{-2}$
Weight of coconut, $W = mg$
$= 2.0 \times 9.81$
$= 19.62$ N

$F = W - R$
$18.0 = 19.62 - R$
$R = 19.62 - 18.0$
$= 1.62$ N

## Example 2

A passenger of mass 60 kg is in a lift.

(a) Sketch the free body diagram using the symbol $W$ to represent the weight of the passenger and symbol $R$ for the normal reaction from the floor of the lift.

(b) Calculate the magnitude of the normal reaction, $R$ when the lift is:
(i) stationary
(ii) moving upwards with an acceleration of 1.2 m s$^{-2}$
(iii) moving with a uniform velocity of 8.0 m s$^{-1}$
[Gravitational acceleration, $g$ = 9.81 m s$^{-2}$]

### Solution

(a) Figure 1.9 shows the free body diagram of the passenger in the lift.

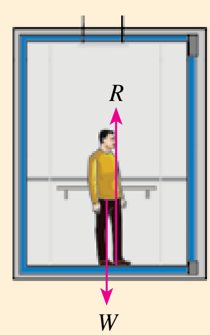



*Figure 1.9*

(b) (i) Resultant force, $F = 0$
$R = W$
$R = mg$
$= 60 \times 9.81$
$= 588.6$ N

(ii) The resultant force acts upwards
$F = ma$
$R - W = ma$
$R - 588.6 = 60 \times 1.2$
$R = 72 + 588.6$
$= 660.6$ N

(iii) Resultant force, $F = 0$
$R = W$
$R = 588.6$ N

## Example 3

Figure 1.10 shows a trolley of mass 1.2 kg being pulled on a table by a load through a pulley. The trolley moves with an acceleration of 4.0 m s$^{-2}$ against a friction of 6.0 N.

(a) Sketch the free body diagram of the trolley and the load. Use $W$ = the weight of the trolley, $R$ = normal reaction on the trolley, $F_R$ = friction, $T$ = tension of the string and $B$ = the weight of the load.

(b) Compare the weight of the trolley, $W$ with the normal reaction, $R$.

(c) Calculate the resultant force acting on the trolley, $F$.

(d) Calculate the tension in the string pulling the trolley, $T$.

(e) What is the mass of the load, $m$?
[Gravitational acceleration, $g$ = 9.81 m s$^{-2}$]

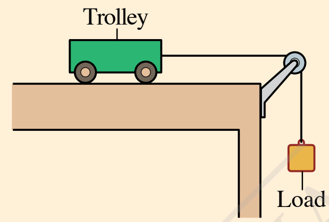


*Figure 1.10*

**Note**

Based on Figure 1.11, the two forces, $T$ (the action and the reaction) are acting along the string between the trolley and the load. Since the trolley and the load are connected by a string, both will move with the same acceleration.

### Solution

(a) Figure 1.11 shows the free body diagram of the trolley and the load.

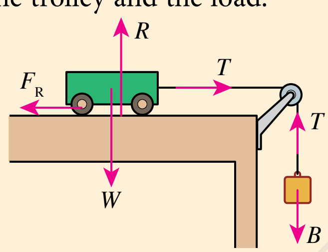


*Figure 1.11*

(b) Weight of trolley, $W$ = normal reaction, $R$

(c) Mass of trolley, $m$ = 1.2 kg
Acceleration of the trolley, $a$ = 4.0 m s$^{-2}$

$F = ma$
$= 1.2 \times 4.0$
$= 4.8$ N

(d) Resultant force, $F$ = 4.8 N
Friction, $F_R$ = 6.0 N

$F = T - F_R$, thus $T = F + F_R$
$T = 4.8 + 6.0$
$= 10.8$ N

(e) Acceleration of the load, $a$ = 4.0 m s$^{-2}$
Gravitational acceleration, $g$ = 9.81 m s$^{-2}$

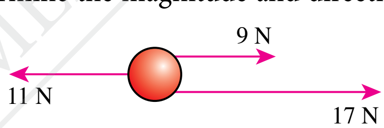
$F = ma$
$= m \times 4.0$
$= 4m$
$B = mg$
$= m \times 9.81$
$= 9.81m$

$F = B - T$
$4m = 9.81m - 10.8$
$5.81m = 10.8$
$m = \dfrac{10.8}{5.81}$
$= 1.86$ kg

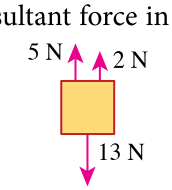
## Formative Practice 1.1

1. Determine the magnitude and direction of the resultant force in the following situations.

(a)




(b)




2. Figure 1.12 shows the forces acting on a ball that is kicked simultaneously by two players.

(a) Sketch a diagram that shows the 240 N force, the 180 N force and the resultant force.

(b) Calculate the magnitude of the resultant force on the ball.

(c) State the direction of motion of the ball.

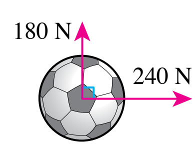


*Figure 1.12*

# 1.2 Resolution of Forces


*Figure 1.13* Tarik upih game

Figure 1.13 shows a boy pulling his friend during a *tarik upih* game at the school sports carnival. Why is the motion of the friend to the right while the direction of the applied pulling force is inclined upwards? This is due to the pulling force having a horizontal component and a vertical component. **Resolution of forces** is **the process of resolving a force into two components**.

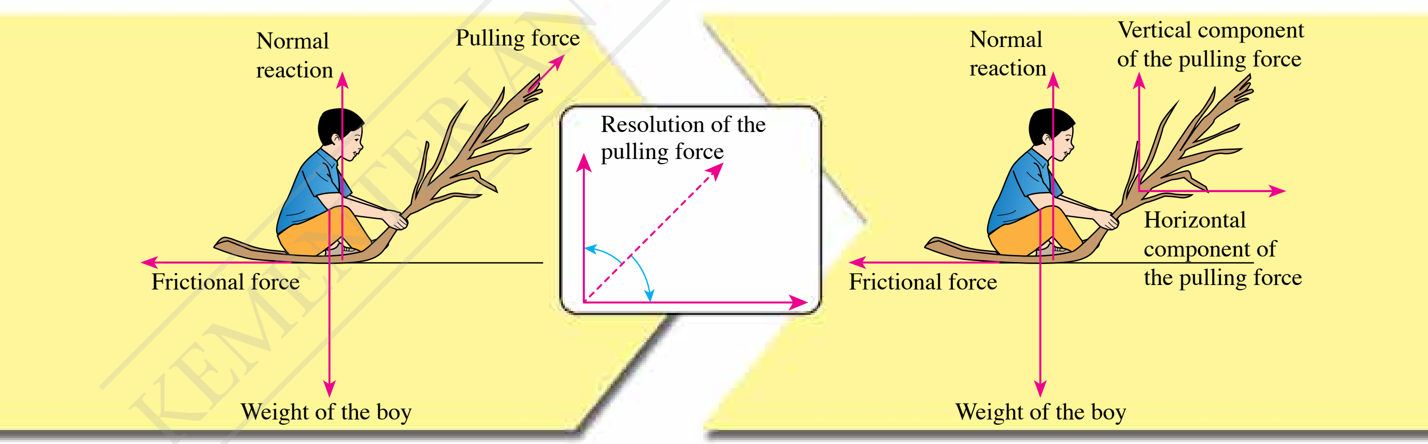



***Figure 1.14*** *Resolution of the pulling force when the boy is being pulled*

The pulling force acting on the boy can be resolved into two perpendicular components as shown in Figure 1.14. The vertical component is to balance the weight of the boy while the horizontal component overcomes friction and moves the boy to the right. How do we determine the magnitudes of the two components?

LS 1.2.1

Figure 1.15 shows a force, $F$ acting on a small block at an angle, $\theta$ above the horizontal. The resolution of force, $F$ into two components and the magnitudes of the two components can be determined by following the steps (Figure 1.16).

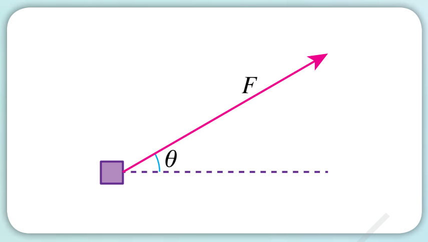
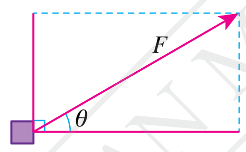



***Figure 1.15*** *Force, F acting on a block*

**1**

Draw the horizontal component, $F_x$ and the vertical component, $F_y$ to form a rectangle as shown in the diagram.




**2**

Calculate the magnitude of the components.

$F_x = F \cos \theta$

$F_y = F \sin \theta$

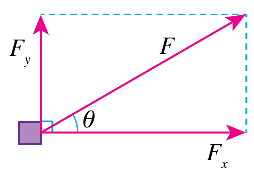



***Figure 1.16*** *Steps in determining the resolution of forces*

**BRIGHT Info**

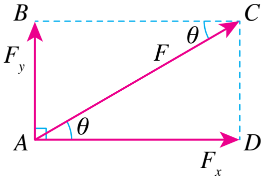
Explanation with trigonometry:

Triangle $ACD$: $\cos \theta = \dfrac{F_x}{F}$

$F_x = F \cos \theta$

Triangle $ABC$: $\sin \theta = \dfrac{F_y}{F}$

$F_y = F \sin \theta$



## Activity 1.5

Decomposition

**Aim:** To resolve a force into two components for an object moving in a direction not parallel to the direction of the force

**Instructions:**

1. Carry out this activity in pairs.
2. Study Figure 1.17 and determine the magnitudes of:
   (a) the horizontal component of the pushing force.
   (b) the vertical component of the pushing force.
3. Study Figure 1.18 and determine the magnitudes of:
   (a) the component of the weight of the boy in the direction parallel to the inclined plane.
   (b) the component of the weight of the boy in the direction perpendicular to the inclined plane.

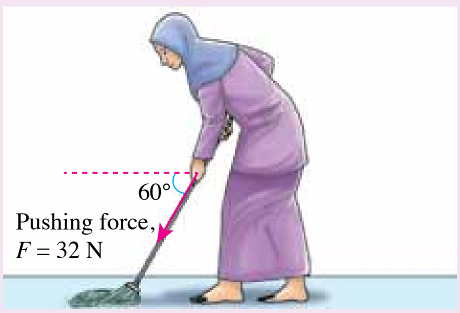



***Figure 1.17** Mopping the floor*

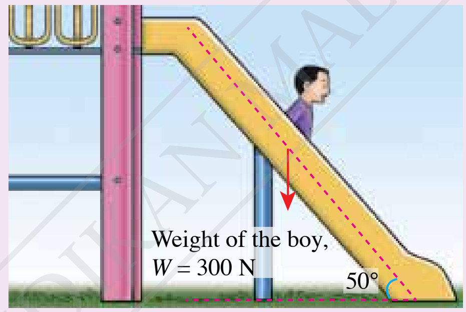



***Figure 1.18** Going down the slide*

**Discussion:**

1. What is the purpose of resolving a force into two perpendicular components?
2. Discuss the suitability of resolving a force into two components that are not perpendicular.

## Solving Problems Involving Resultant Force and Resolution of Forces

LET'S ANSWER
*http://bit.ly/36yhJWl*

### Example 1

Figure 1.19 shows a wooden block being pulled by force, $T$ that inclines at an angle of 30° above the horizontal surface. Table 1.5 shows the magnitudes of the forces acting on the block.

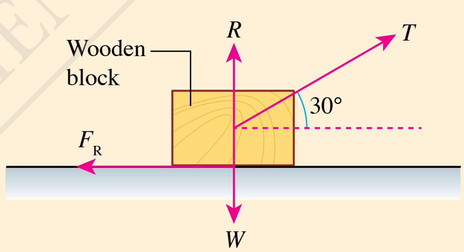



***Figure 1.19***

***Table 1.5***

| Force | Magnitude |
|---|---|
| Pull, $T$ | 36 N |
| Weight, $W$ | 24 N |
| Normal reaction, $R$ | 6 N |
| Frictional force, $F_R$ | 20 N |

(a) Calculate the magnitudes of the horizontal component and vertical component of the pull, $T$.
(b) Determine the magnitude and direction of the resultant force acting on the block.
(c) What is the acceleration of the block if its mass is 2.4 kg?

LS 1.2.1 1.2.2

## Solution

(a)

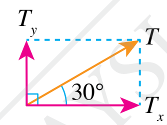
| Step 1: | Step 2: | Step 3: | Step 4: |
|---|---|---|---|
| Identify the problem | Identify the information given | Identify the formula that can be used | Solve the problem numerically |

1. Magnitude of the horizontal component, $T_x$ and vertical component, $T_y$ of the pull, $T$

2. Angle above the horizontal surface = 30°
Magnitude of the pulling force, $T$ = 36 N

3. $T_x = T \cos 30°$
$T_y = T \sin 30°$

4. $T_x = 36 \cos 30°$
$= 31.18$ N (to the right)
$T_y = 36 \sin 30°$
$= 18.00$ N (upwards)




(b) Horizontal component to the right,
$T_x = 31.18$ N
Frictional force, $F_R = 20$ N

Resultant of horizontal components
$= T_x + F_y$
$= 31.18 + (-20)$
$= 11.18$ N

Vertical component upwards, $T_y = 18.00$ N
Normal reaction, $R = 6$ N
Weight, $W = 24$ N
Resultant of vertical components
$= T_y + R + W$
$= 18 + 6 + (-24)$
$= 0$ N

Resultant force on the block, $F$ is 11.18 N to the right.

(c) Resultant force, $F = 11.18$ N
Mass of block, $m = 2.4$ kg
$F = ma$

Acceleration of the block, $a = \dfrac{F}{m}$
$= \dfrac{11.18}{2.4}$
$= 4.66$ m s$^{-2}$

## Example 2

Figure 1.20 shows the free body diagram of a block sliding down a smooth inclined plane.

(a) Sketch the component of the weight of the block parallel to the inclined plane and the component of the weight of the block perpendicular to the inclined plane.

(b) Determine the resultant force acting on the block.

(c) Calculate the acceleration of the block if its mass is 2.4 kg.

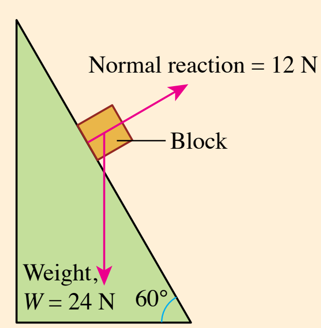



***Figure 1.20***

## Solution

(a) Figure 1.21 shows a sketch of the component of the weight of the block parallel to the inclined plane, $W_x$ and the component of the weight of the block perpendicular to the inclined plane, $W_y$.

(b) $W_x = 24 \sin 60°$
$= 20.78$ N
$W_y = 24 \cos 60°$
$= 12$ N
Resultant of the forces perpendicular to the inclined plane $= 12 + (-12)$
$= 0$ N
Resultant force on the block = 20.78 N

(c) Resultant force, $F = 20.78$ N
Mass of block, $m = 2.4$ kg
$F = ma$
Acceleration of block, $a = \dfrac{F}{m}$
$= \dfrac{20.78}{2.4}$
$= 8.66 \text{ m s}^{-2}$

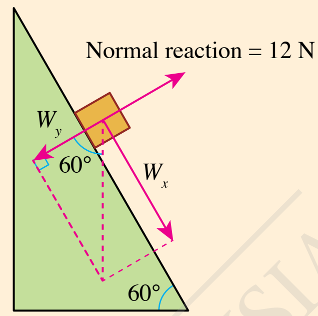
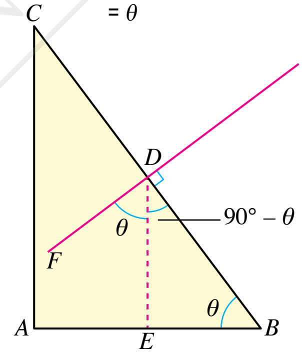


Figure 1.21

### BRIGHT Info

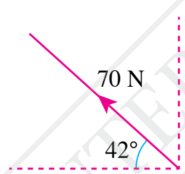
Resolution of forces for object on inclined plane
Given $\angle ABC = \theta$
Thus, $\angle BDE = 90° - \theta$
and $\angle EDF = 90° - (90° - \theta)$
$= \theta$



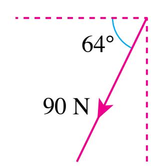

## Formative Practice 1.2

1. Resolve the following forces into horizontal component and vertical component.

(a)




(b)




2. Figure 1.22 shows a man pushing a lawn mower with a force of 90 N.

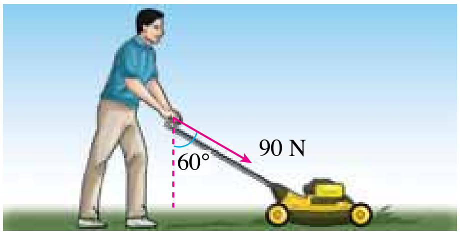


Figure 1.22

(a) Resolve the pushing force into its horizontal component and vertical component.
(b) State the function of the horizontal component and vertical component of the pushing force when the lawn mower is being pushed.

# 1.3 Forces in Equilibrium

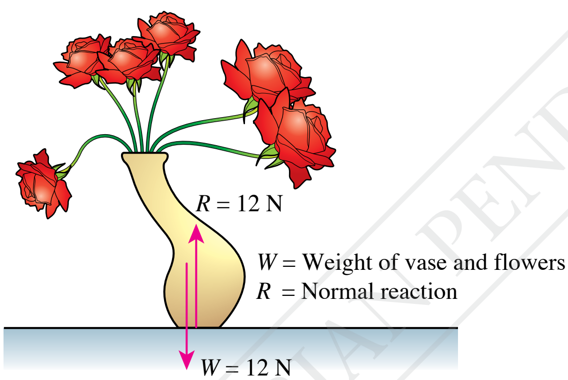
Photograph 1.4 shows a *Ngajat* dancer standing still for a while during the dance. What is the relationship between the forces acting on the dancer? Since the acceleration of the dancer is zero, there is no resultant force acting on him. Therefore, the forces are said to be in equilibrium.

**An object is said to be in equilibrium of forces when the forces acting on it produce a zero resultant force.** Observe the free body diagrams for two examples of forces in equilibrium as shown in Figure 1.23.

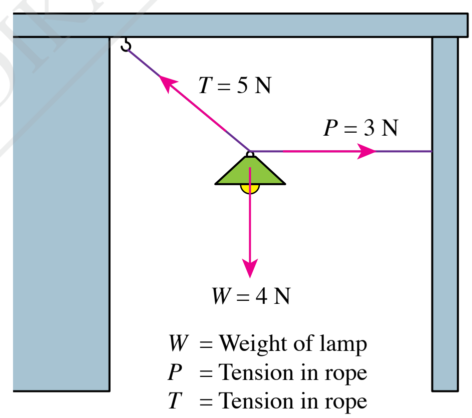
***Photograph 1.4*** *Ngajat Dance*

**BRIGHT Info**

$F = ma$
$a = 0, \ F = 0$




Resultant force of $W$ and $R = 0$
*(a) Vase of flowers on a table*




Resultant force of $W$, $P$ and $T = 0$
*(b) Lamp hung from two strings*

***Figure 1.23*** *Examples of forces in equilibrium*

In Figure 1.23(a), the vase is in equilibrium of forces. The resultant force of $W$ and $R$ is zero. In Figure 1.23(b), the lamp also in equilibrium of forces. However, there are three forces acting on the lamp. This can be represented by a **triangle of forces**.

A triangle of forces can be drawn to show the equilibrium of three forces acting on an object. The magnitudes of the three forces are represented by the lengths of the sides of a triangle and they are drawn in sequence according to the directions of the forces.

The three forces $W$, $P$ and $T$ in Figure 1.24 are in equilibrium. Therefore, the three forces drawn in sequence will form a triangle.

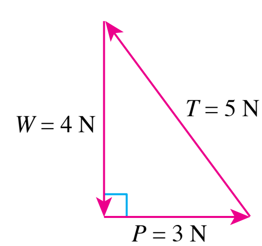



***Figure 1.24*** *Triangle of forces*





LS 1.3.1

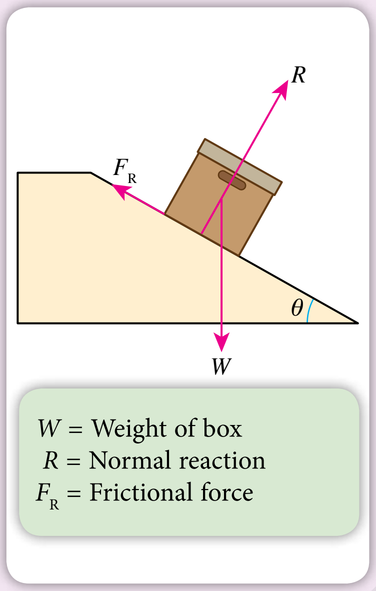
## Activity 1.6

**Aim:** To draw the triangle of forces

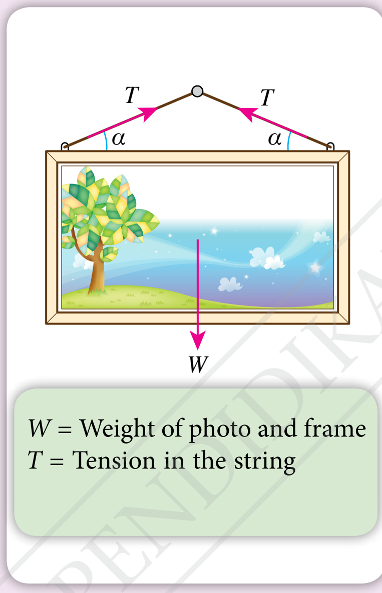
**Instructions:**

1. Carry out this activity in pairs.
2. Scan the QR code for the guide to draw the triangle of forces.
3. By referring to Figure 1.25, sketch the triangle of forces for the following situations:

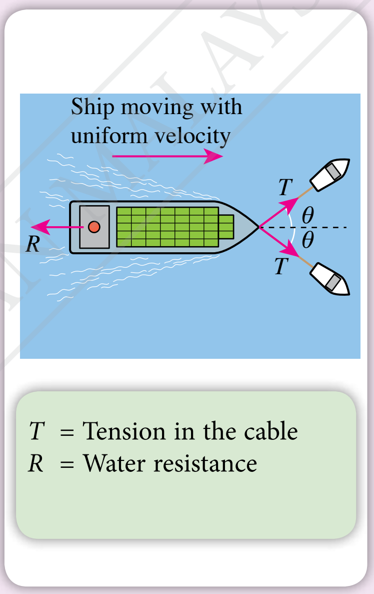
SCAN ME
Method to draw triangle of forces
http://bit.ly/2QU7vZW




(a) *A box stationary on an inclined plane*




(b) *Photo and frame hung by a string*




(c) *A container ship being pulled by two tug boats with a uniform velocity*

***Figure 1.25***

4. Put up your sketch at the Physics Corner of the notice board in your class.

**Discussion:**

1. Discuss two more examples of three forces in equilibrium.
2. Sketch the triangle of forces for the two examples that you have suggested.

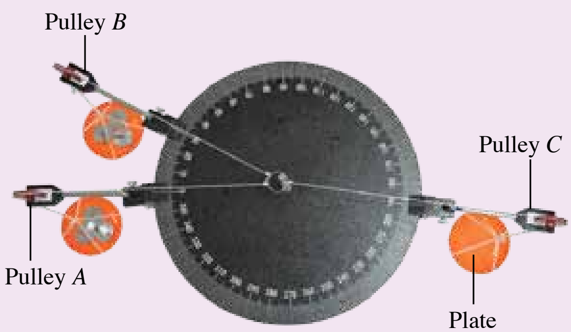
## Activity 1.7

**Aim:** To use a Vector Force Table Kit to demonstrate forces in equilibrium

**Apparatus:** Vector Force Table Kit and slotted weights of various masses

**Instructions:**

1. Set up the apparatus as shown in Photograph 1.5. Pulley *A* and pulley *B* are fixed at positions 0° and 30° respectively at the vector force table.




***Photograph 1.5***

***Photograph 1.6***

2. Place slotted weights of mass 200 g on the plate below pulley *A* and slotted weights of mass 150 g on the plate below pulley *B*. The metal ring will be displaced and will touch the metal rod at the centre of the vector force table.
3. Add slotted weights on the plate below pulley *C* until the metal ring no longer touches the metal rod, as shown in Photograph 1.6. Record the mass of the slotted weights and determine the position of pulley *C*.
4. Repeat steps 1 to 3 with pulley *B* at positions 90° and 150°.
5. Record your results in Table 1.6.

SCAN ME
Video of method to achieve forces in equilibrium
*http://bit.ly/36wG4vP*

**Results:**

***Table 1.6***

| Pulley *A* | | | Pulley *B* | | | Pulley *C* | | |
|---|---|---|---|---|---|---|---|---|
| Position | Mass / g | Force applied / N | Position | Mass / g | Force applied / N | Mass / g | Position | Force applied / N |
| 0° | 200 | 2.0 | 30° | 150 | 1.5 | | | |
| 0° | 200 | 2.0 | 90° | 150 | 1.5 | | | |
| 0° | 200 | 2.0 | 150° | 150 | 1.5 | | | |

**Discussion:**

Based on the results of this activity, predict the angles between the three forces in equilibrium when the three forces have the same magnitude.

## Solving Problems Involving Forces in Equilibrium

### Example 1

Figure 1.26 shows a stationary lamp hanging from two strings. The tension, $T$ is 8 N and the string is inclined at an angle of 60° above the horizontal as shown in the diagram.

Calculate the magnitude of the:

(a) tension, $P$

(b) weight of the lamp, $W$.

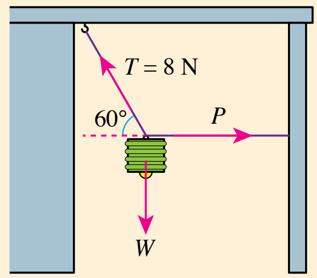



**Figure 1.26**

LET'S ANSWER

http://bit.ly/35xp8UG

### Solution

**Method 1: Resolution of Forces**

The tension, $T$ can be resolved into a horizontal component, $T_x$ and a vertical component, $T_y$ as shown in Figure 1.27.

The lamp is in equilibrium, thus resultant force on the lamp = 0.

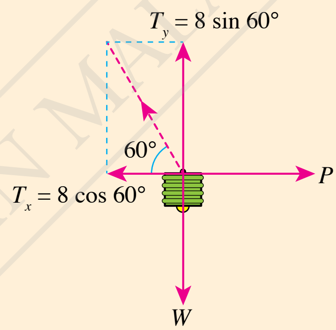



**Figure 1.27**

(a) The resultant of the horizontal forces = 0, that is, the horizontal forces are balanced.
Tension in the string, $P = T_x$
$= 8 \cos 60°$
$= 4$ N

(b) The resultant of the vertical forces = 0, that is, the vertical forces are balanced.
Weight of the lamp, $W = T_y$
$= 8 \sin 60°$
$= 6.93$ N

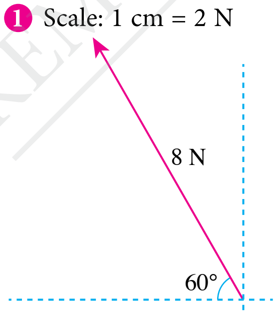
**Method 2: Scaled drawing of the triangle of forces**

**Step 1:**
Choose a scale. Draw the force, $T$ with known magnitude and direction.

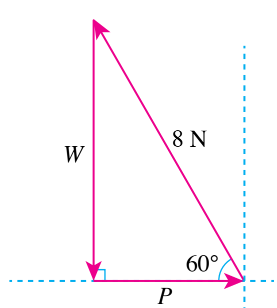
**Step 2:**
Draw a vertical line downwards representing $W$ and a horizontal line to the right representing $P$ to form a triangle.

**Step 3:**
Measure the length of the sides of the triangle. Use the scale you have chosen to calculate the magnitude of the force.

1 Scale: 1 cm = 2 N




2




3

(a) $P$ = 2.0 cm
= 2.0 × 2 N
= 4.0 N

(b) $W$ = 3.5 cm
= 3.5 × 2 N
= 7.0 N

## Example 2

Figure 1.28 shows a box of weight 50 N stationary on an inclined plane.

(a) Draw a free body diagram of the box showing the weight of the box, $W$, normal reaction, $R$ and the frictional force, $F_R$.

(b) By drawing a scaled triangle of forces diagram, determine the magnitudes of the normal reaction, $R$ and the frictional force, $F_R$.

(c) By resolving the weight of the box, $W$ into a component parallel to the inclined plane and a component perpendicular to the inclined plane, determine the magnitudes of the normal reaction, $R$ and the frictional force, $F_R$.

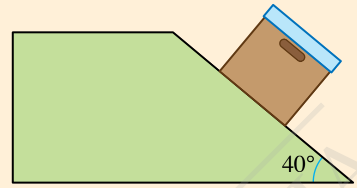



**Figure 1.28**

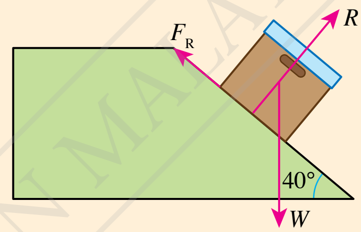



**Figure 1.29**

### Solution

(a) Figure 1.29 shows the free body diagram of the box.

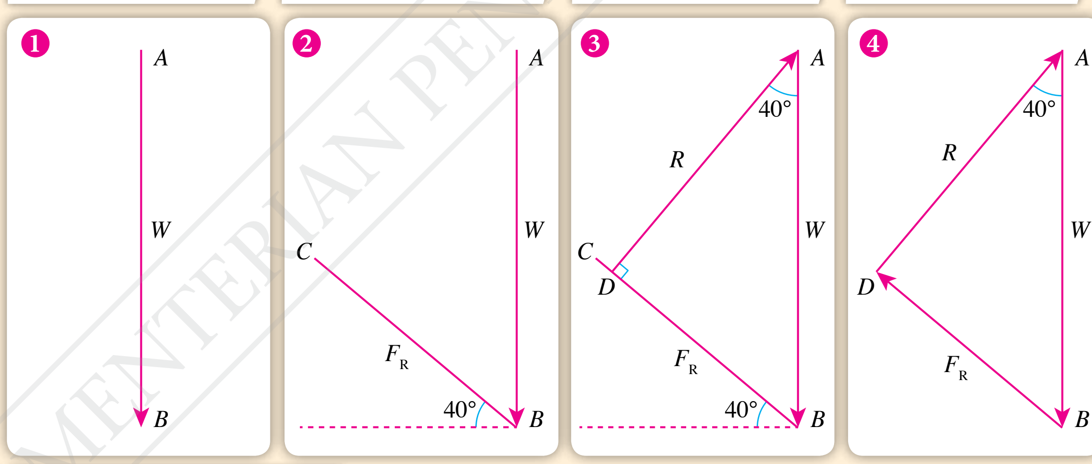
(b) Scale: 1 cm = 10 N

**Step 1:** Draw the line $AB$ of length 5.0 cm to represent the weight, $W$.

**Step 2:** Mark the angle 40° and draw the line $BC$ to show the direction of force, $F_R$.

**Step 3:** Mark the angle 40° and draw the line $AD$ to represent the force, $R$.

**Step 4:** Complete the triangle $ABD$ with direction of forces.



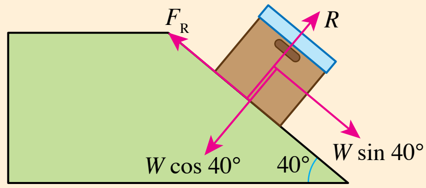

**Step 5:** Measure the length of the side $BD$, which represents the force, $F_R$.

$$\left\{\begin{aligned} BD &= 3.2 \text{ cm} \\ F_R &= 3.2 \times 10 \\ &= 32 \text{ N} \end{aligned}\right.$$

**Step 6:** Measure the length of the side $AD$, which represents the force, $R$.

$$\left\{\begin{aligned} AD &= 3.8 \text{ cm} \\ R &= 3.8 \times 10 \\ &= 38 \text{ N} \end{aligned}\right.$$

(c)




The box is in equilibrium.
Resultant force = 0 N
Forces parallel to the inclined plane are balanced.
Forces perpendicular to the inclined plane are balanced.

$$F_R = W \sin 40^\circ = 50 \sin 40^\circ = 32.14 \text{ N}$$

$$R = W \cos 40^\circ = 50 \cos 40^\circ = 38.30 \text{ N}$$

**Info GALLERY**

The method of calculation will give a more accurate answer compared to the answer obtained by the method of scaled drawing.

## Example 3

Figure 1.30 shows a poster hanging on the wall of the laboratory with a string and a nail. The weight of the poster is 12.0 N.

(a) Draw the triangle of forces for the weight of the poster and the tensions in the string.

(b) Calculate the value of $T$.

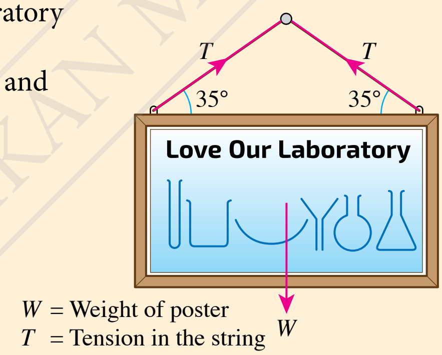
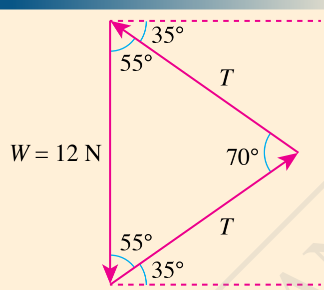



*Figure 1.30*

### Solution

(a)




(b) Using the sine rule:

$$\frac{T}{\sin 55^\circ} = \frac{12}{\sin 70^\circ}$$

$$T = \frac{12 \times \sin 55^\circ}{\sin 70^\circ}$$

$$= 10.46 \text{ N}$$

Using the cosine rule:

$$W^2 = T^2 + T^2 - 2(T \times T \times \cos 70^\circ)$$

$$12^2 = T^2 + T^2 - 2(T \times T \times \cos 70^\circ)$$

$$144 = T^2 (1 + 1 - 2 \cos 70^\circ)$$

$$T^2 = \frac{144}{(1 + 1 - 2 \cos 70^\circ)}$$

$$T = 10.46 \text{ N}$$

## Formative Practice 1.3

1. State the meaning of forces in equilibrium.
2. Figure 1.31 shows a block that is stationary on an inclined plane when a stopping force, $P$ is applied horizontally.
   (a) Sketch and label the weight of the block, $W$ and the normal reaction from the surface of the plane, $R$.
   (b) Sketch the triangle of forces for $P$, $W$ and $R$.

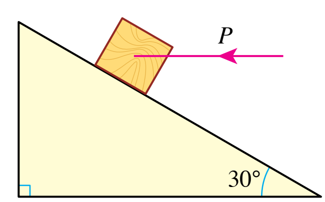



*Figure 1.31*

# 1.4 Elasticity

A man pulls an elastic cord during an exercise routine as shown in Photograph 1.7. After his exercise, the cord returns to its original length. What property is shown by the elastic cord?

(a) *During exercise* (b) *After exercise*

***Photograph 1.7*** *Stretching exercise with an elastic cord*

## Activity 1.8

**Aim:** To generate ideas on elasticity

**Apparatus:** Half-metre rule

**Materials:** Spring, sponge, plasticine and white A4 paper

### A Spring

**Instructions:**

1. Measure the length of a spring.
2. Apply small forces on the spring to change its shape and size in a few different ways by pulling, bending and other ways that you can think of as shown in Photograph 1.8.
3. Observe whether the spring can return to its original shape and size after the external force is removed by measuring it again.

***Photograph 1.8***

### B Sponge

**Instructions:**

1. Hold the sponge in your hand as shown in Photograph 1.9 and observe its shape and size.
2. Apply forces on the sponge to change its shape and size in a few different ways by pressing, squeezing, twisting and other ways that you can think of.
3. Observe whether the sponge can return to its original shape and size.

***Photograph 1.9***

### C Plasticine

**Instructions:**

1. Place a piece of plasticine on a piece of white paper. Observe the size and shape of the plasticine.
2. Press the plasticine with your thumb to change its shape as shown in Photograph 1.10.
3. Remove your thumb from the plasticine. Observe the size and shape of the plasticine.

***Photograph 1.10***

**Discussion:**

1. Discuss the change in the shape and size of the spring and sponge when a force is applied and removed.
2. Discuss whether the plasticine can return to its original size and shape when the force applied on it is removed.

The force applied on an object can change its shape and size. **Elasticity** is **the property of material that enables an object to return to its original shape and size after the force applied on it is removed**.

**SCAN ME**
Video of elasticity demonstration
*http://bit.ly/2ZWutU8*

## Relationship Between Force and Extension of a Spring

A spring extends when a pulling force is applied on it. What is the relationship between the applied force and the extension of the spring?

## Experiment 1.1

**Inference:** The force applied on a spring affects the extension of the spring

**Hypothesis:** The larger the force applied on a spring, the larger the extension of the spring

**Aim:** To determine the relationship between the force and extension of a spring

**Variables:**

(a) Manipulated: Force, $F$
(b) Responding: Extension of the spring, $x$
(c) Constant: Stiffness of the spring

**Apparatus:** Spring with length not less than 10 cm, five pieces of 10 g slotted weights, five pieces of 20 g slotted weights, five pieces of 50 g slotted weights, half-metre rule and two retort stands with clamps

**Materials:** Pin, plasticine and thread

**Procedure:**

1. Set up the apparatus as shown in Figure 1.32. Ensure that the zero mark of the half-metre rule is at the same level as the upper end of the spring.

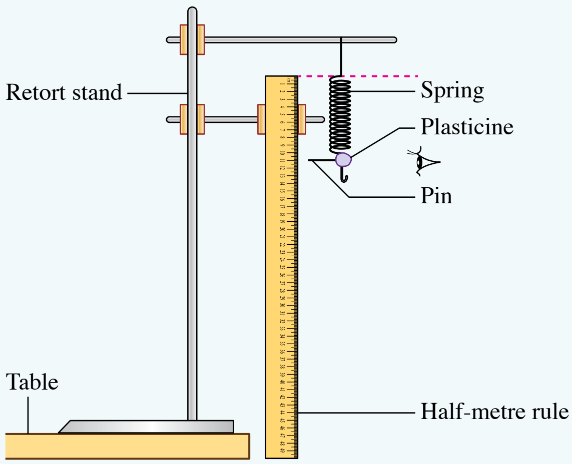
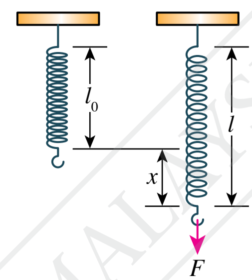



***Figure 1.32***

2. Determine the original position of the pin, that is, the original length of the spring, $l_0$.
3. Plan steps to:
   (a) increase the force applied on the spring using the slotted weights supplied.
   (b) measure the extension of the spring.
4. Carry out the experiment according to the steps you have planned.

**Info GALLERY**

The extension of a spring is the increase in length of the spring when a stretching force is applied on it.




The extension of a spring is the difference between the extended length, $l$ and the original length, $l_0$.

$$x = l - l_0$$

**Note**

Ensure that the extension of the spring does not exceed half of the original length so that the spring is not overstretched and able to return to its original length.

**Results:**

Prepare a table to record:
(a) the mass of the slotted weights used to stretch the spring
(b) the force applied on the spring
(c) the extended length of the spring
(d) the extension of the spring

**Data analysis:**

Identify and plot a graph that will help you to test your hypothesis.

**Conclusion:**

What conclusion can be drawn from this experiment?

**Prepare a complete report for this experiment.**

**Discussion:**

1. What are the precautions needed to be taken so that the spring is not overextended?
2. Do the points plotted on the graph form a perfect straight line? Discuss the reasons.

The results of Experiment 1.1 produces a graph with a straight line passing through the origin as shown in Figure 1.33. This shows that the extension of the spring is directly proportional to the force applied on the spring.

SCAN ME
Elastic limit
http://bit.ly/39K9MPS

**Hooke's law** states that the extension of a spring is directly proportional to the force applied on the spring provided the elastic limit of the spring is not exceeded.

This relationship can be written as:

$$x \propto F$$
$$F \propto x$$
$$F = kx$$

where $F$ = applied force
$x$ = extension of the spring
$k$ = spring constant

$F = kx$ is the formula for Hooke's law

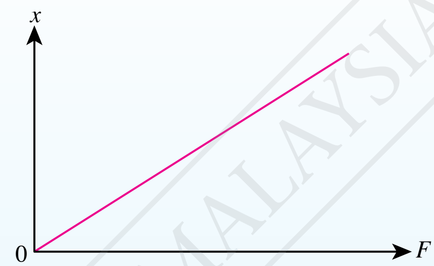



***Figure 1.33*** *Graph of x against F*

## Analysis of the Graph of Force Against the Extension of a Spring

Figure 1.34 shows the graph of force against the extension of a spring.

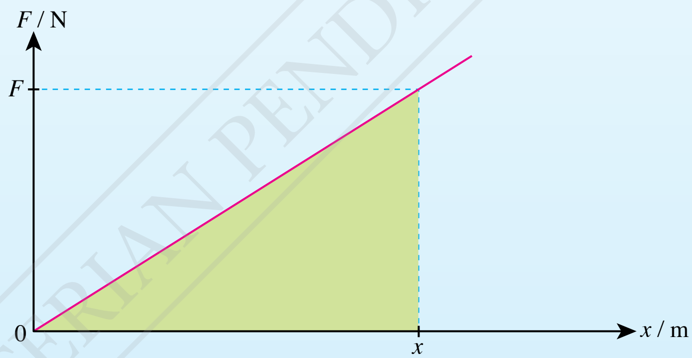



***Figure 1.34*** *Graph of F against x*

Hooke's law: $F = kx$
Spring constant, $k = \dfrac{F}{x}$

Based on the graph of $F$ against $x$, the gradient of the graph $= \dfrac{F}{x}$

Spring constant, $k$ = Gradient of the graph of $F$ against $x$

***Figure 1.35*** *Relationship between spring constant and gradient of the graph*

SCAN ME
Spring constant
http://bit.ly/2s1GhrL

Figure 1.36 shows the method to obtain elastic potential energy formula from the area under the graph of force against extension of the spring.

Elastic potential energy, $E_p$
= work done to stretch the spring
= (average force) × extension of the spring
$= \frac{(0 + F)}{2} \times x$
$= \frac{1}{2}Fx$

Based on the graph of $F$ against $x$:
Area under the graph = area of the right-angled triangle
$= \frac{1}{2} \times F \times x$
$= \frac{1}{2}Fx$

Elastic potential energy = area under the graph of $F$ against $x$
$E_p = \frac{1}{2}Fx$
Substitute $F = kx$, $E_p = \frac{1}{2}(kx) \times x$
$E_p = \frac{1}{2}kx^2$

***Figure 1.36** The elastic potential energy formula*

## Activity 1.9

Evaluation

**Aim:** To analyse graphs of $F$ against $x$ to determine the values of:
- Spring constant, $k$
- Elastic potential energy, $E_p$

**Instructions:**

1. Carry out this activity in pairs.

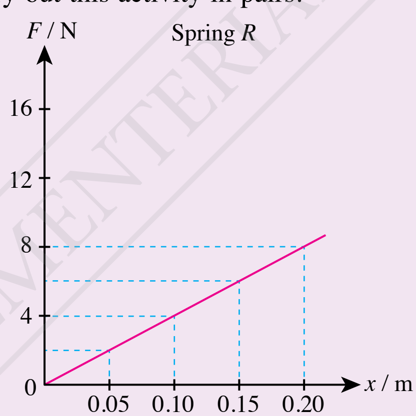


***Figure 1.37** Graph of F against x for spring R*

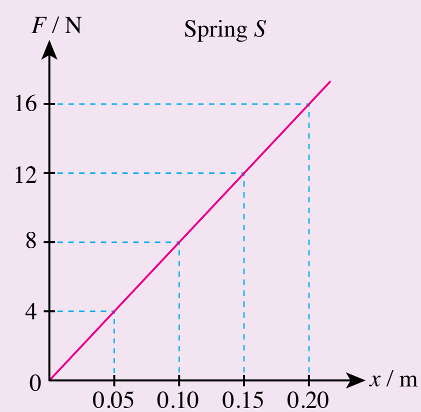


***Figure 1.38** Graph of F against x for spring S*

2. From the graph of $F$ against $x$ for spring $R$ in Figure 1.37:
   (a) determine the value of the spring constant, $k$ by calculating the gradient of the graph
   (b) determine the elastic potential energy, $E_p$ when the spring is stretched to an extension, $x$ = 0.20 m by calculating the area under the graph.

3. From the graph of $F$ against $x$ for spring $S$ in Figure 1.38:
   (a) determine the value of the spring constant, $k$ by calculating the gradient of the graph.
   (b) determine the elastic potential energy, $E_p$ when the spring is stretched to an extension, $x = 0.20$ m by calculating the area under the graph.

**Discussion:**
Based on your answers in steps 2 and 3, compare spring $R$ and spring $S$ from the aspects of:
(a) the stiffness of the spring.
(b) the elastic potential energy that can be stored in the spring.

There are various types of springs and each spring has its own spring constant. What are the factors that affect the value of the spring constant?

## Activity 1.10

**Aim:** To discuss the factors that affect the value of the spring constant
**Apparatus:** Two pieces of 50 g slotted weights, half-metre rule and retort stand
**Materials:** Four pairs of springs with different characteristics (Figure 1.39)

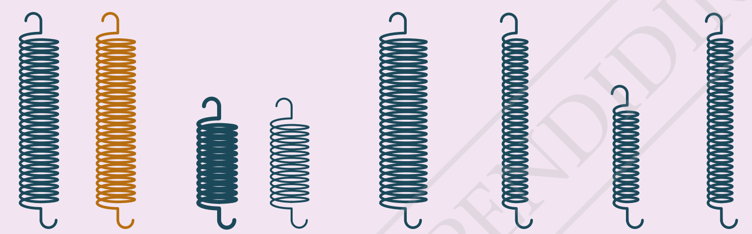



*Figure 1.39*

**Note**
The pairs of springs *B*, *C* and *D* are made of the same material.

**Instructions:**
1. Hang the two springs from pair $A$ on the retort stand as shown in Figure 1.40.
2. Stretch the two springs by hanging the 50 g slotted weights at the ends of the springs.
3. Observe the extension of the two springs. Compare the spring constants of the two springs.
4. Record your observations.
5. Repeat steps 1 to 4 for the pairs of springs $B$, $C$ and $D$.

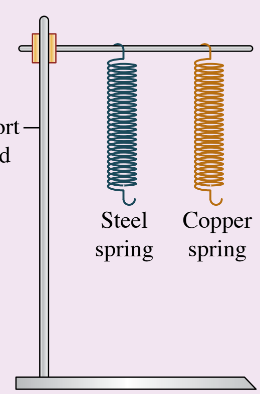



*Figure 1.40*

**Discussion:**
1. Identify four factors that affect the value of the spring constant.
2. How do the four factors affect the value of the spring constant? Explain your observations using a suitable thinking map.

The value of the spring constant is affected by the material of the spring, the length of the spring, the diameter of the spring and the thickness of the spring wire. Table 1.7 shows a summary of the four factors that affect the value of the spring constant.

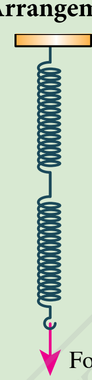
***Table 1.7** Four factors that affect the value of the spring constant*

| Factor | Change in the factor | Effect on the value of the spring constant |
|---|---|---|
| Material of the spring | Different material | Changes according to the type of material |
| Length of spring | Shorter | Higher |
| | Longer | Lower |
| Diameter of spring | Smaller diameter | Higher |
| | Larger diameter | Lower |
| Thickness of spring wire | Wire with smaller diameter | Lower |
| | Wire with larger diameter | Higher |

## Solving Problems Involving Force and Extension of a Spring

In a system made up of two or more identical springs, the springs can be arranged in series or in parallel. Figure 1.41 shows two identical springs arranged in series and in parallel.

**Arrangement of identical springs in series**



Tension = $F$
Extension = $x$

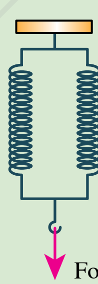
Tension = $F$
Extension = $x$

Extension of system of springs $= x + x$ $= 2x$

Force, $F$

The stretching force applied on the springs acts on each spring in the series arrangement.

**Arrangement of identical springs in parallel**



Tension = $\frac{F}{2}$
Extension = $\frac{x}{2}$

Tension = $\frac{F}{2}$
Extension = $\frac{x}{2}$

Extension of system of springs $= \frac{x}{2}$

Force, $F$

The stretching force applied on the springs is divided equally among the springs.

***Figure 1.41** Arrangement of springs in series and in parallel*

## Example 1

(a) A spring with original length 50 mm extends by 6 mm when stretched by a force of 12 N. Calculate the spring constant of the spring.

(b) Figure 1.42 shows three arrangements of springs consisting of springs identical to the one mentioned in (a). For each arrangement, determine:

(i) the tension in each spring

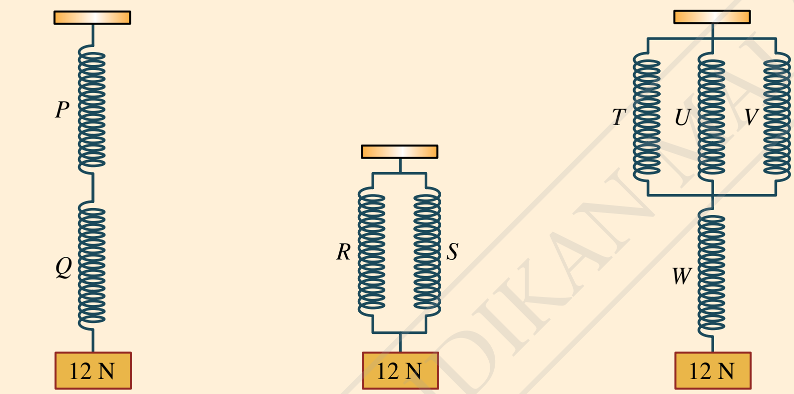
(ii) the extension of each spring

(iii) the total extension of the system of springs

(iv) the total length of the arrangement of springs

**LET'S ANSWER**

*http://bit.ly/2FEgv09*




Arrangement *A* Arrangement *B* Arrangement *C*

***Figure 1.42***

### Solution

(a)

**Step 1:** Identify the problem

**Step 2:** Identify the information given

**Step 3:** Identify the formula that can be used

**Step 4:** Solve the problem numerically

❶ Spring constant, $k$

❷ Force, $F = 12$ N
Extension of spring, $x = 6$ mm

❸ $F = kx$

$k = \dfrac{F}{x}$

❹ $k = \dfrac{12}{6}$

$= 2 \text{ N mm}^{-1}$

(b)

<table>
<tr><td rowspan="2">Arrangement of springs</td><td colspan="2">Arrangement A: Two springs in series</td><td colspan="2">Arrangement B: Two springs in parallel</td><td colspan="4">Arrangement C: Three springs T, U and V in parallel which are in series with spring W</td></tr>
<tr><td>P</td><td>Q</td><td>R</td><td>S</td><td>T</td><td>U</td><td>V</td><td>W</td></tr>
<tr><td>(i) Tension / N</td><td>12</td><td>12</td><td>$\frac{12}{2} = 6$</td><td>$\frac{12}{2} = 6$</td><td>$\frac{12}{3} = 4$</td><td>$\frac{12}{3} = 4$</td><td>$\frac{12}{3} = 4$</td><td>12</td></tr>
<tr><td rowspan="2">(ii) Extension / mm</td><td rowspan="2">6</td><td rowspan="2">6</td><td rowspan="2">3</td><td rowspan="2">3</td><td>2</td><td>2</td><td>2</td><td rowspan="2">6</td></tr>
<tr><td colspan="3">2</td></tr>
<tr><td>(iii) Extension of the system of springs / mm</td><td colspan="2">6 + 6 = 12</td><td colspan="2">3</td><td colspan="4">2 + 6 = 8</td></tr>
<tr><td>(iv) Total length of the arrangement of springs / mm</td><td colspan="2">50 + 50 + 12 = 112</td><td colspan="2">50 + 3 = 53</td><td colspan="4">50 + 50 + 8 = 108</td></tr>
</table>

## Formative Practice 1.4

1. What is the meaning of elasticity?
2. Figure 1.43 shows the graph of force, $F$ against extension, $x$ for a spring.
   (a) State Hooke's law.
   (b) Does the spring obey Hooke's law?
   (c) Calculate the spring constant.
   (d) What is the elastic potential energy in the spring when stretched to an extension of 0.04 m?

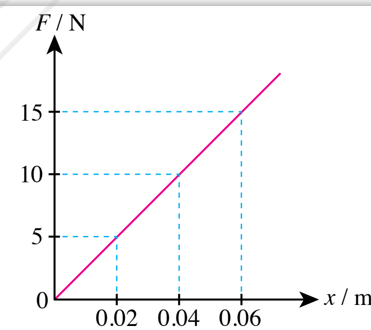



**Figure 1.43**

3. Figure 1.44 shows an arrangement consisting of three identical springs $P$, $Q$ and $R$. The spring constant is 4 N cm$^{-1}$. The arrangement is compressed by an 8 N force. Determine:
   (a) the force experienced by each spring
   (b) the compression of each spring
   (c) the compression of the system of springs

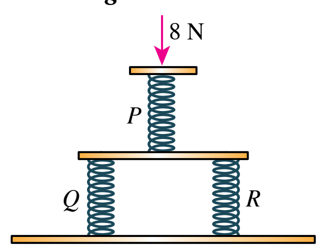



**Figure 1.44**

4. Figure 1.45 shows the graph of $F$ against $x$ for a spring. The shaded area in the graph has a value of 0.4 J.
   (a) What is the force that produces the extension of 5 cm in the spring?
   (b) Calculate the spring constant.

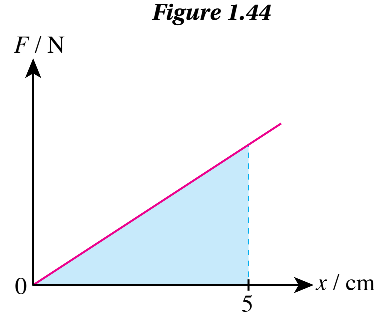
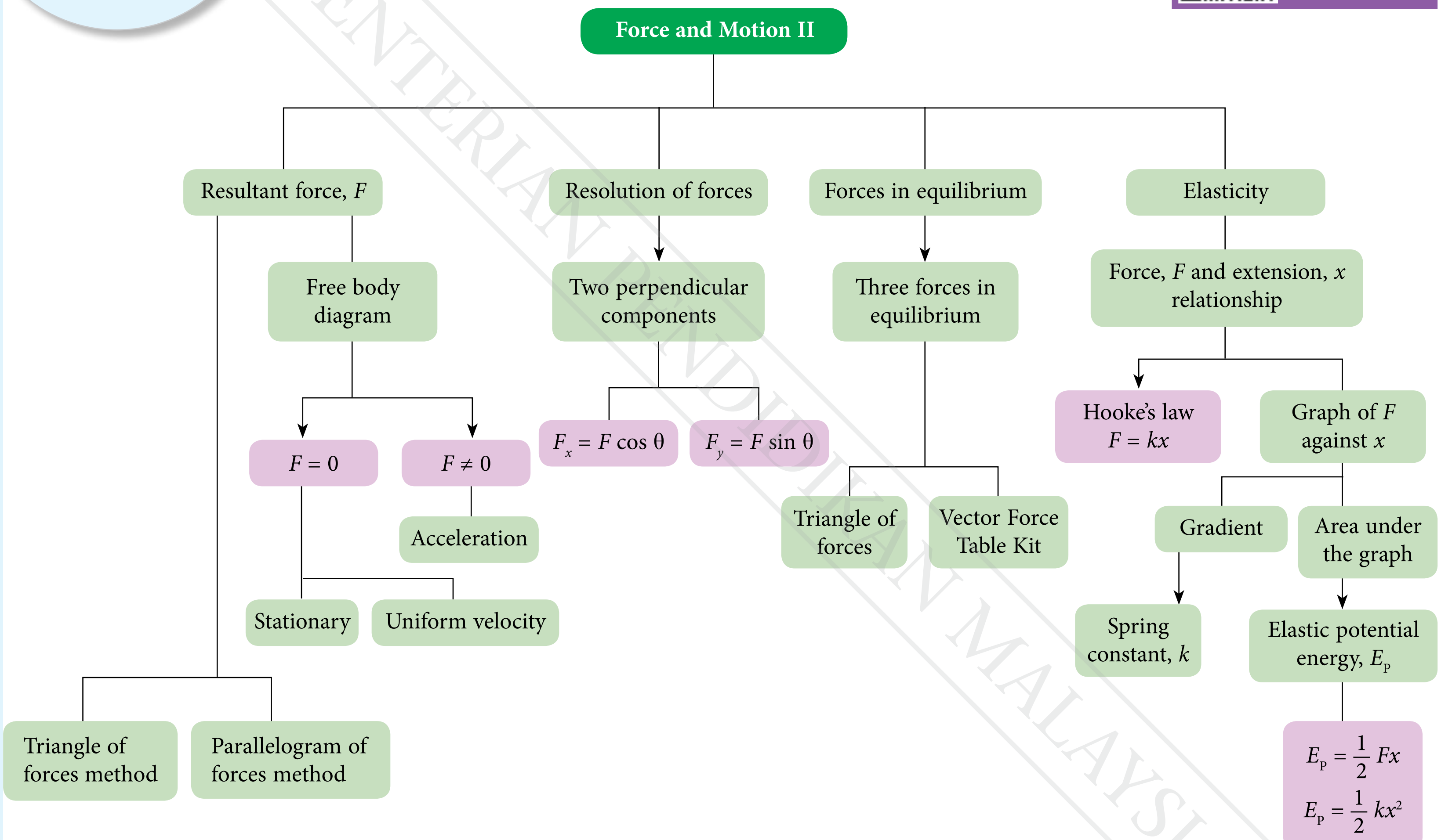



**Figure 1.45**

## Concept Chain

Interactive Games
http://bit.ly/2QRzDwB



## Self-Reflection

SCAN ME
Download and print Self-Reflection
http://bit.ly/2ZV2R1U

1. New things I have learnt in the chapter on 'Force and Motion II' are ______.

2. The most interesting thing I have learnt in this chapter is ______.

3. The things I still do not fully understand are ______.

4. My performance in this chapter.

   Poor 1 2 3 4 5 Very good

5. I need to ______ to improve my performance in this chapter.

QUIZ PORTAL
http://bit.ly/2FukrQI

## Summative Practice

1. Figure 1 shows the top view of a worker, *X* who is applying a pulling force of 70 N on a sack of flour on a track. Another worker, *Y* is able to apply a pulling force of 60 N on the sack. Determine the direction of the pulling force that must be applied by worker *Y* on the sack so that the sack moves along the line *PQ*.

   [Ignore the friction between the sack and the surface of the track]

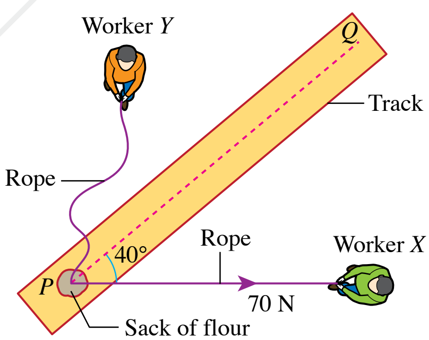



***Figure 1***

2. Figure 2 shows the top view of a pulling force applied by two persons, *P* and *Q* in an attempt to pull down a tree.

   (a) By using the method of parallelogram of forces, determine the magnitude and direction of the resultant force on the tree.

   (b) Discuss the advantage and disadvantage of having a large angle between the directions of the two forces.

   (c) Which person has to be more careful when the tree begins to topple?

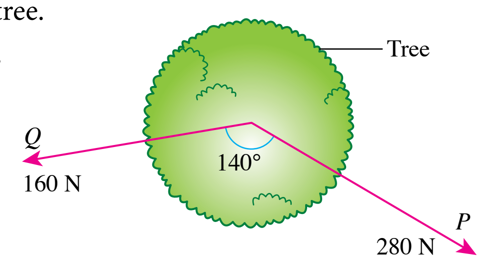



***Figure 2***

**3.** Figure 3 shows a children's playground equipment. The spring in the equipment experiences a compression of 5.0 cm when a child of mass 28 kg sits on it. What is the spring constant of the spring in N m$^{-1}$?
[Gravitational acceleration, $g$ = 9.81 m s$^{-2}$]

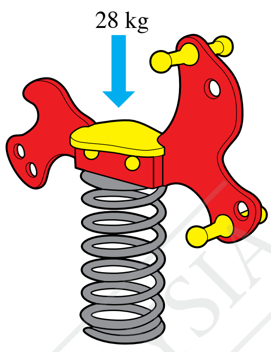



***Figure 3***

**4.** Justify the following statement.

> When two forces of 17 N and 13 N act on a point, the resultant force produced cannot be smaller than 4 N or larger than 30 N.

**5.** The motion of a motorcycle of mass 180 kg is as follows.

> Stage I: Stationary at a junction
> Stage II: Moves towards the East with velocity that increases from zero to 20 m s$^{-1}$ in a time of 8 s.
> Stage III: Continues to move with a uniform velocity of 20 m s$^{-1}$.

For each stage, state the magnitude and direction of the resultant force on the motorcycle.

**6.** Figure 4 shows a chef exerting a force of 12 N to cut an onion.

(a) Calculate the horizontal component and vertical component of the 12 N force.

(b) What is the function of the horizontal component and vertical component in the action of cutting the onion?

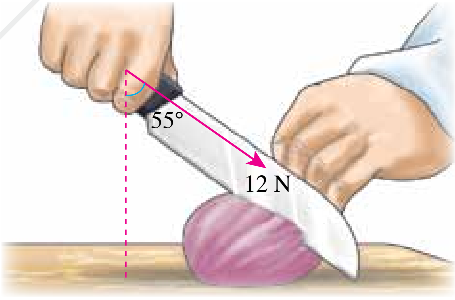



***Figure 4***

**7.** Figure 5 shows three forces acting on an object. The object is at rest. Calculate the magnitude of forces $S$ and $T$.

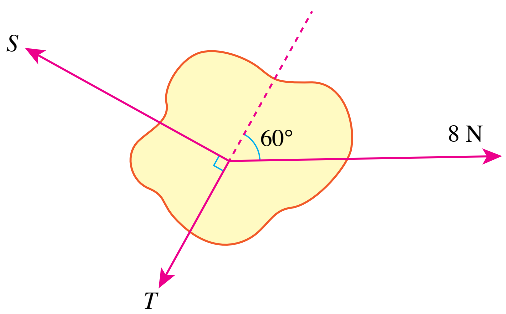
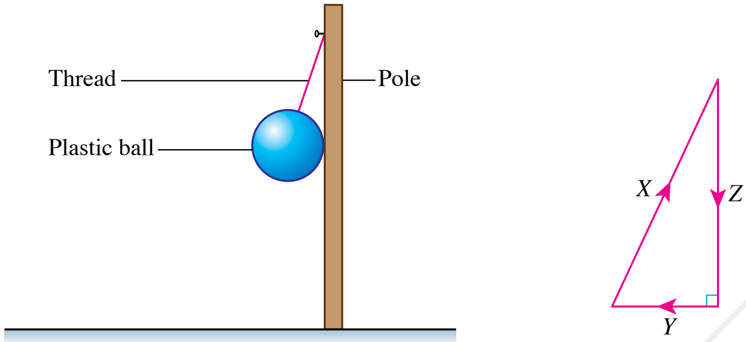



***Figure 5***

**8.** Figure 6(a) shows a plastic ball hanging from a pole. Figure 6(b) is the triangle of forces for forces *X*, *Y* and *Z* acting on the ball.
On Figure 6(a), sketch a free body diagram of the plastic ball.




(a) (b)

***Figure 6***

**9.** Three coplanar forces, 10 N, 24 N and 26 N act on an object. Draw a triangle of forces for the three forces if the object is in equilibrium.

**10.** Figure 7 shows the graph of force against extension for steel spring *M* and steel spring *N*.

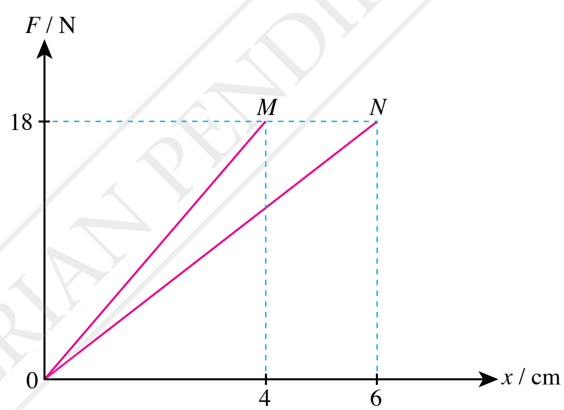



***Figure 7***

(a) Calculate the spring constant for steel spring *M*.

(b) What is the elastic potential energy stored in steel spring *N* when it is stretched to an extension of 6 cm?

(c) Compare and contrast steel spring *M* with steel spring *N*.

**11.** A spring stores elastic potential energy of 18 J when the extension of the spring is 4.0 cm. What is the force required to stretch the spring to an extension of 3.0 cm?

**12.** A technician was assigned to study the use of three types of springs, $X$, $Y$ and $Z$ with spring constants given in Table 1.

(a) Table 2 shows four arrangements of springs considered by the technician.

***Table 1***

| Types of spring | Spring constant / N $cm^{-1}$ |
|---|---|
| $X$ | 200 |
| $Y$ | 300 |
| $Z$ | 600 |

***Table 2***

| Arrangement | Force applied / N | Extension of system of springs / cm |
|---|---|---|
| Two springs of type $X$ in series | 400 | |
| Two springs of type $X$ in parallel | 600 | |
| Two springs of type $Y$ in series | 300 | |
| Two springs of type $Z$ in parallel | 600 | |

For each arrangement of springs, determine the extension and complete Table 2.

(b) What is the assumption that you have made based on your calculation in 12(a)?

## 21st Century Challenge

**13.** Figure 8 shows an iron plate on the floor of a warehouse. The iron plate is to be supported by a system of springs below it. The system of springs is capable of supporting a maximum load of 3 600 kg with a compression of 5.0 cm.

Figure 9 shows two types of springs that can be used.

You are given the task of suggesting a suitable design for the system of springs to support the iron plate.

Your suggestion should consider the following aspects:

(a) the type of spring used

(b) the number of springs used

(c) the position of each spring

Justify the design that you have suggested.

[Gravitational acceleration, $g$ = 9.81 m $s^{-2}$]

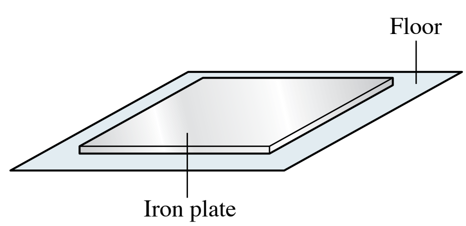



***Figure 8***

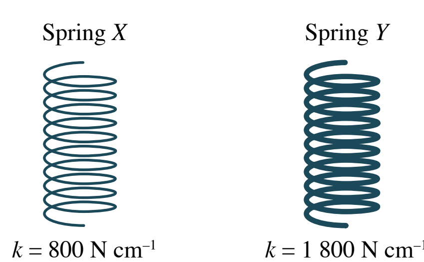



***Figure 9***