GIVE FEEDBACK

CONTINUE >

The concept of **force** is one of the most important for an engineer.

In mechanics, forces are usually associated with any action that tends to:

- maintain the position of a body
- alter the position of a body, or
- distort the position of a body.

It is very useful to think about forces in terms of push, pull or effort.

In this section the concept of force is introduced, together with some important principles associated with the mathematical and graphical analysis of forces.

Another very important type of force is also introduced – **gravity**. The weight of of a body and local variations in gravity are discussed in this section.

In engineering, an understanding of forces and gravity is essential in designing the stability of structures and machines. Engineers must have a thorough understanding of the action and effects of forces in the connected elements of building structures, engines, machine tools and mechanical devices.

The concept of force

Forces are usually associated with any action that tends to maintain the position of a body (e.g. support, hold), alter the position of a body (e.g. lift, throw) or distort it (e.g. stretch, bend).

It is very useful to continue thinking about forces in terms of push or pull, or effort.

There are many kinds of forces—muscular effort, tractive effort at the wheels of a vehicle, cutting force at the tip of a cutting tool, forces due to gas pressure in an engine cylinder—which are a type of push or pull produced as a result of interaction between two or more bodies.

GIVE FEEDBACK

OK

Which of these following statements are true about force?

Check all that apply.

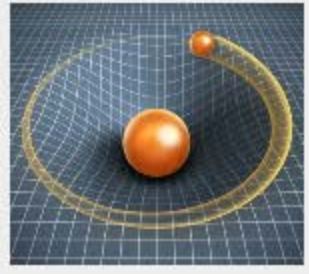
- [ ] Force can be described as effort
- [ ] Force can only be push and pull
- [ ] Force can be seen as an interaction between two or more bodies
- [ ] There are many kinds of forces
- [ ] There is no force required to maintain a position of a body
- [ ] Multiple forces can apply on the same object

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

Gravity and friction

A very important type of force is gravity, or gravitational attraction, i.e. the pull exerted by the Earth on every physical object located on or near its surface.



There is also a group of forces which are the result of friction, often described as resistance to motion, e.g. friction between two surfaces sliding relative to each other, air resistance, etc.

These forces usually oppose some applied force such as tractive effort, which tends to cause or maintain motion.

GIVE FEEDBACK

OK

Gravity, or gravitational attraction, is the pull exerted by the Earth on objects located on or near its surface.

Click the correct answer.

True

False

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

Friction force strictly refers to resistance between moving physical objects and the Earth's surface.

Click the correct answer.

False

True

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

Statics and static equilibrium

Forces are often discussed and classified with respect to their effects. The science of statics deals with the equilibrium of bodies at rest under the combined action of several balanced forces.

When all forces acting on a body are balanced, the body is said to be in **static equilibrium**.

A bridge is a structure subjected to a large number of forces. The forces acting on the bridge at any one time must be in equilibrium for the bridge to remain in its position.

GIVE FEEDBACK

OK

Type your answer in the box.

The science that deals with the equilibrium of bodies at rest is called _____.

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

Select all the true statements about static equilibrium.

Check all that apply.

- [ ] A body is in static equilibrium when forces acting on the body are balanced
- [ ] A bridge is considered to be in static equilibrium
- [ ] There are no forces acting on the object
- [ ] Static equilibrium is about maintaining the position of the body

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

Kinetics

If a force, or forces, acting on a body are not balanced, the condition of rest or motion will be altered and the body will accelerate or slow down.

For example, an object dropped from a height falls with increasing speed under the influence of the unbalanced force of gravity.

The part of mechanics dealing with the analysis of bodies in motion under the influence of various forces acting on the bodies is called **kinetics**.

Kinetics uses such relationships to predict the motion caused by given forces or determine the forces required to produce a given motion.

GIVE FEEDBACK

OK

Which of the following statements are true about kinetics?

Check all that apply.

- [ ] Kinetics is the study of objects in motion under the influence of various forces
- [ ] The body can accelerate or slow down
- [ ] A resting apple is an example of kinetics
- [ ] In kinetics, forces acting on the body are balanced

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

The SI unit of force

The SI unit of force is the **newton**, symbol N.

The exact definition of the newton is based on the ability of a unit force, when applied to a unit mass, to impart to that mass a unit of acceleration.

The equivalent SI unit of force in terms of mass and acceleration is $\mathrm{kgm/s^2}$:

$$1\,\mathrm{N} = 1\,\mathrm{kg\,m/s^2}$$

In order to fully appreciate the significance of this definition, a good understanding of the laws of linear motion is required. The newton is used to describe the exact relationship between the forces acting on a body, the mass of the body and the motion of the body.

GIVE FEEDBACK

OK

Newton is the only SI unit used in engineering.

Click the correct answer.

False

True

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

Type your answer in the box.

The SI unit of force is _____. The symbol of the unit is _____.

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

1 newton is also equivalent to the SI unit _____.

Click the correct answer.

- $1\,\mathrm{kg\,m/s^2}$
- 1 pound force
- 1 kg
- $1\,\mathrm{g\,cm/s^2}$

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

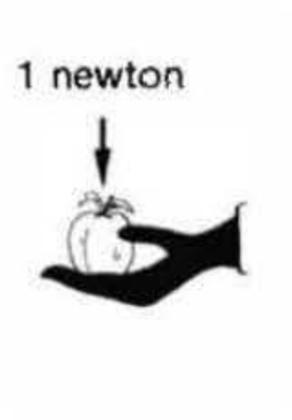
Force is a push or pull motion.

The unit of force, the newton, is therefore a push or pull of a particular strength, which is taken to be the standard for comparing forces.

It is not possible to describe the newton as we can describe a material object such as an apple.

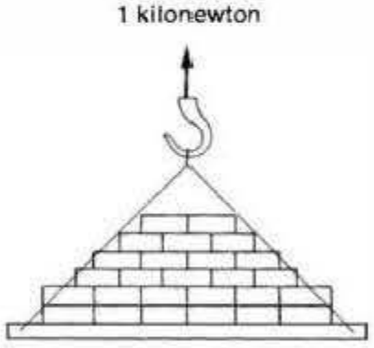
However, a small apple is a convenient aid for our learning purposes.

If you put an apple on the palm of your hand, you can feel a small downward force acting on your hand. The force is approximately one newton. The newton, as can be seen from this simple demonstration, is not very large.



In engineering practice, a force one thousand times stronger than the newton is a more useful unit.

With the aid of SI decimal prefixes, such a unit is called the **kilonewton**, symbol kN. The force required to support 26 common house bricks is approximately equal to one kilonewton.



< BACK GIVE FEEDBACK OK

Which of the following can be measured by force?

Check all that apply.

- [ ] Pushing a door
- [ ] A physics textbook
- [ ] Pulling a chair
- [ ] Lifting ten bricks
- [ ] Pressing a lift button
- [ ] Meat on a butcher's scales

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

Rank the following forces of action in order from the smallest to the largest magnitude.

↑↓ **Place these in the proper order.**

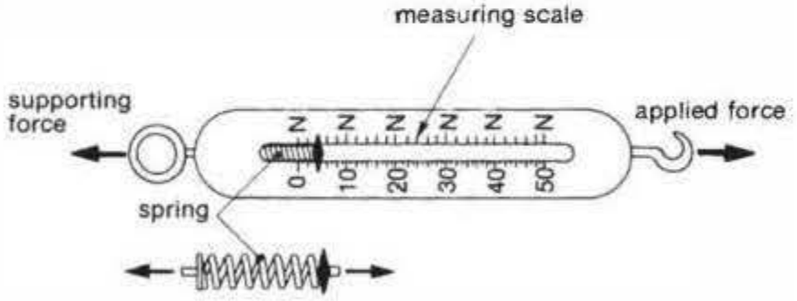
- Lifting an apple
- Lifting a laptop computer
- Lifting 30 textbooks
- Lifting a car
- Lifting a house

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

Forces are usually measured by means of a spring dynamometer. A simple dynamometer consists of a spring with one end restrained and the other movable, where the force is applied.

The extension of the spring is proportional to the applied force within the normal operating range of a given instrument. As the force stretches the spring, a marker attached to the movable end of the spring moves along a graduated scale, indicating the magnitude of the applied force. As a force-measuring device, a spring is calibrated in the units of force, i.e. newtons or kilonewtons. Simple spring dynamometers are not very accurate. More sophisticated ones are capable of accuracies in the order of percentages.



GIVE FEEDBACK

CONTINUE >

The term 'dynamometer' is also used for a device for testing power output of engines or electric motors.

It should be noted that many mass-measuring devices, e.g. butcher's scales, are in fact spring balances calibrated to read in kilograms and/or grams. However, their use is limited to measuring a quantity, e.g. meat, and should not be extended to measures of force.

Note: Kilogram is not a unit of force.

Sophisticated spring dynamometers can measure forces accurately with no errors.

Click the correct answer.

False

True

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

Other force-measuring instruments

Other force-measuring instruments, such as hydraulic and pneumatic load cells and strain gauges, are used extensively in many varied engineering applications, particularly where the force cannot be transmitted through a dynamometer and must therefore be measured indirectly.

Strain gauge load cells are probably the most common devices for measuring forces of large magnitudes. Accuracies of ± 0.1 per cent are common. Strain gauges are devices built around a strip of elastic material that is attached to a member of a structure or machine which is being compressed or stretched by a force. Connected to this strip is an electric device that measures its compression or elongation but provides an output calibrated in units of force.

GIVE FEEDBACK

OK

Which of the following instruments can measure force?

Check all that apply.

- [ ] Dynamometer
- [ ] Hydraulic load cell
- [ ] Human hand
- [ ] Midi-chlorians
- [ ] Strain gauge

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

Strain gauge load cells are the most commonly used devices for measuring forces of large magnitudes.

Click the correct answer.

True

False

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

The characteristics of force

A force is characterised by its magnitude, direction and point of application.

The **magnitude** of a force is a measure of the strength of the pushing or pulling effort, expressed in standard units of force, usually newtons or kilonewtons, e.g. 560 N, 3.75 kN.

The **direction** of a force is defined by the line of action and the sense of the force.

The **line of action** is a straight line along which the force acts. It can be described by the angle it forms with a reference axis, e.g. 30° to the horizontal.

The **sense** can be indicated descriptively as to the right or left, up or down, etc.

Finally, when applied to an actual object or component, a force must have a **point of application**, e.g. the point at which a cable is attached to a mast.

GIVE FEEDBACK

OK

Type your answer in the box.

A force must have a point of _____ when the force is applied to an actual object.

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

Which of the following statements is true for the magnitude of a force?

Check all that apply.

- [ ] It is a measure of the strength of the pushing and pulling effort
- [ ] It is expressed in standard units of force, N or kN
- [ ] It is the ordering or ranking of the forces
- [ ] It is always expressed as positive numbers
- [ ] It can be expressed as positive or negative numbers

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

Type your answer in the box.

The direction of a force is defined by the line of _____ and the _____ of the force.

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

Select the three characteristics of a force.

Check all that apply.

- [ ] Magnitude
- [ ] Direction
- [ ] Point of application
- [ ] Point of reaction
- [ ] Gravity direction
- [ ] Push or pull action

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

Select the correct sense of direction of the force.

Check all that apply.

- [ ] Left ------ right
- [ ] Up ------ down
- [ ] Northwest ------ southeast
- [ ] 0° ------ 180° to the horizontal
- [ ] Forward ------ backward

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

The line of action of the force can be drawn as a parametric curve.

Click the correct answer.

False

True

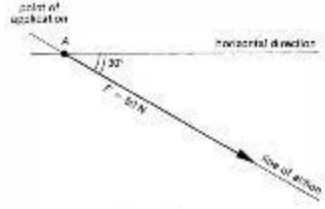
Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

Graphically a force can always be represented by a straight line, drawn to scale, in the direction corresponding to that of the force.

Three characteristics of a force using graphical presentation

For example, a force of 50 N acting down and to the right along a line inclined to the horizontal at $30°$ and applied at point A can be represented by a line 50 mm long, i.e. a scale of $1\ \text{mm} = 1\ \text{N}$, as shown below.



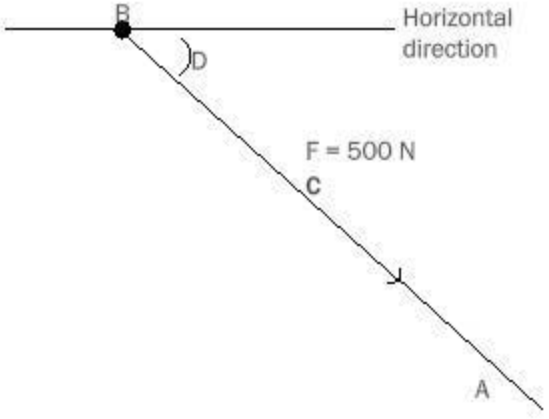
Notice how the graphical representation is clearer than the verbal description.

Those familiar with the mathematical concept of vectors will easily recognise that, as a quantity which has both magnitude and direction, force is a vector.

As a vector, a force can not only be represented graphically as shown, but can also be manipulated according to the rules of vector algebra.

GIVE FEEDBACK

OK



SMALL | MEDIUM | LARGE

Match the characteristics of a force to the correct labels (A, B, C, D) in the diagram.

Drag statements on the right to match the left.

A	Line of action
B	Point of application
C	Magnitude
D	Angle to the horizontal

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

Match the characteristics of a force to the correct labels (A, B, C, D) in the diagram.

Drag statements on the right to match the left.

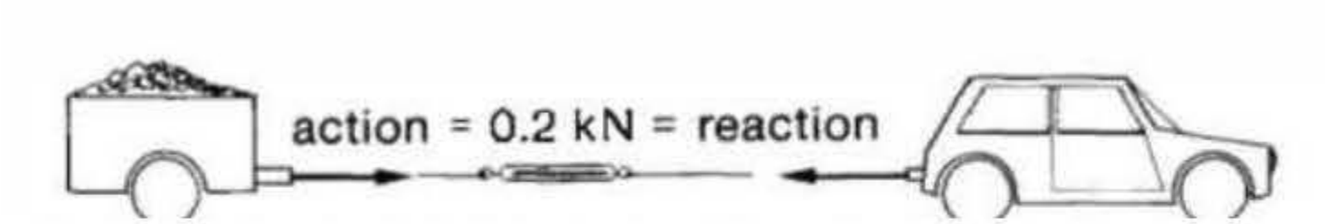
A	Line of action
B	Point of application
C	Magnitude
D	Angle to the horizontal

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

The **principle of action and reaction** was formulated by Sir Isaac Newton, who pointed out that whenever a force acts on a body, there must be an equal and opposite force or reaction acting on some other body. Expressed in a simple form, this principle states that action and reaction are equal and opposite.

Take the example of a car pulling a trailer with a force of 0.2 kN. The trailer experiences a pull of 0.2 kN exerted by the car. At the same time, the trailer exerts an equal but opposite reaction equal to 0.2 kN on the car. Note that if a spring dynamometer were fitted between the car and the trailer, it would indicate a force of 0.2 kN.



Action and reaction forces are always collinear (i.e. they act along the same line) and equal in magnitude but opposite in sense. However, they are applied to two different bodies and should always be considered with respect to the body to which they are applied. In the example above, the action is applied to the trailer and the reaction is applied to the car.

Which of the following statements are correct for the principle of action and reaction?

Check all that apply.

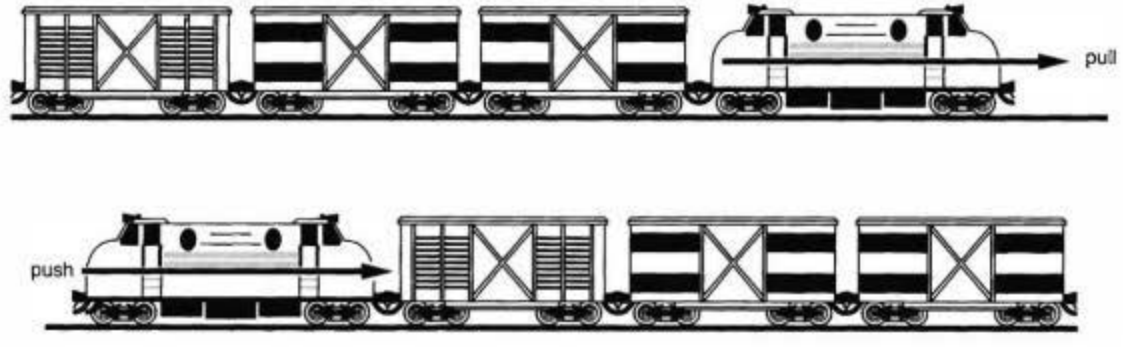
- [ ] The principle is formulated by Sir Isaac Newton
- [ ] The principle states that what goes around (action) comes around (reaction)
- [ ] The principle states that what goes up (action) must come down (reaction)
- [ ] The principle states that the action and reaction forces are equal and opposite
- [ ] Whenever a force acts on a body, there is an opposite reaction force acting on another body

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

The transmissibility of a force

The **principle of transmissibility** states that the effect of a force on a body to which it is applied is not altered when the point of application of the force is moved to some other position on the line along which the force acts. In short, a force can be moved along its line of action without changing its effect. For example, a locomotive can pull or push a train with equal force and effect.



GIVE FEEDBACK

OK

The principle of transmissibility states that a force can be moved along its line of action without changing its effect.

Click the correct answer.

True

False

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

A train can be pulled or pushed by a car with equal force and effect.

Click the correct answer.

True

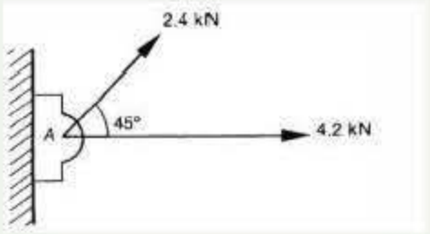
False

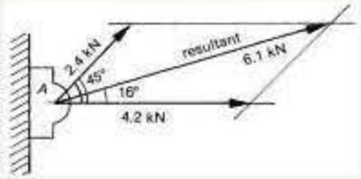
Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

The resultant of two or more forces and the principle of the parallelogram of forces

The **principle of the parallelogram of forces,** formulated by Stevin in 1586, states that if two forces intersecting at a point are represented in magnitude and direction by the adjacent sides of a parallelogram, their combined action is equivalent to the action of a single force, represented both in magnitude and direction by the diagonal of the parallelogram.





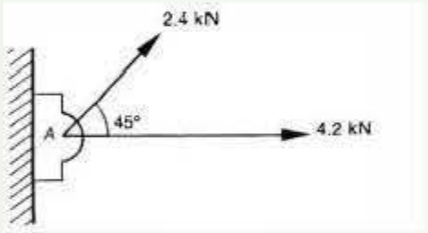
This example shows the resultant force found by constructing the parallelogram of forces with the two given forces.

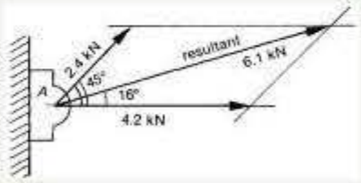
GIVE FEEDBACK

OK

The resultant of two or more forces and the principle of the parallelogram of forces

The single force, which has exactly the same effect as the two given forces, is called the **resultant** force.





This example shows the resultant force found by constructing the parallelogram of forces with the two given forces.

GIVE FEEDBACK

OK

Type your answer in the box.

A single force which has the same effect as two or more given forces is called the _____ force.

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

Select the statements that explain the principle of the parallelogram of forces.

Check all that apply.

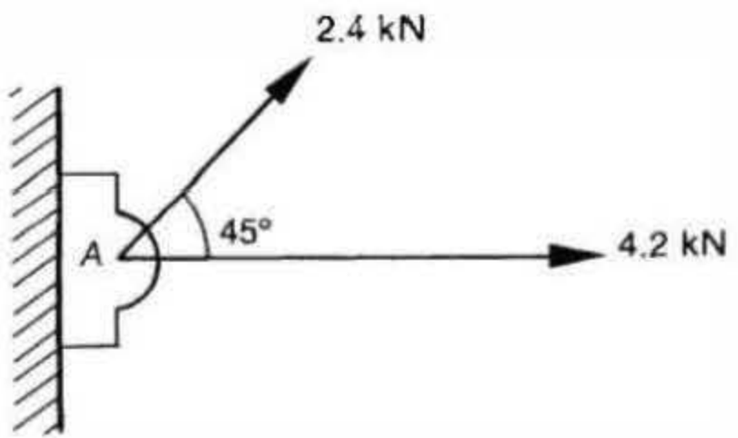
- [ ] The diagonal of the parallelogram is the resultant force represented correctly in both magnitude and direction
- [ ] The resultant force is calculated in relation to the horizontal
- [ ] Two intersecting forces at a point are represented in direction and magnitude by the adjacent sides of a parallelogram
- [ ] The combined effect of the two intersecting forces can be shown as one single force
- [ ] The parallelogram of forces can not be drawn to scale

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

Two cables are attached to a bracket as shown in the figure below.

Determine the resultant force acting on the bracket if the force in the horizontal cable is 4.2 kN and that in the inclined cable is 2.4 kN.

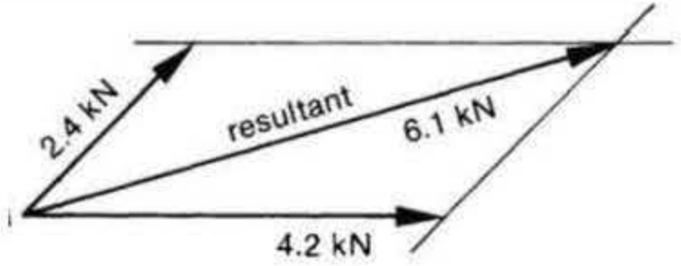


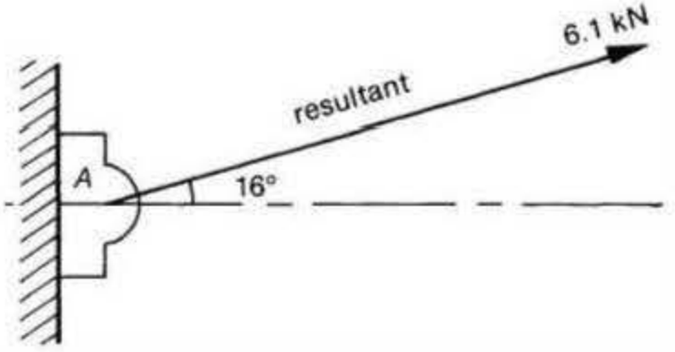
GIVE FEEDBACK

CONTINUE >

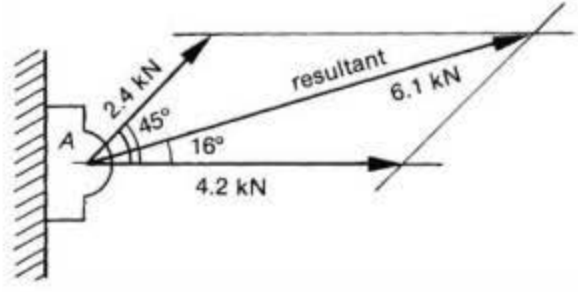
The resultant can be found by constructing the parallelogram of forces, as shown in the figures below, using a suitable scale such as $10\,\mathrm{mm} = 1\,\mathrm{kN}$.

The answer is a force of 6.1 kN acting at 16° to the horizontal.





Note that in a simple example like this, the diagrams can be superimposed to form a combined diagram as shown below.

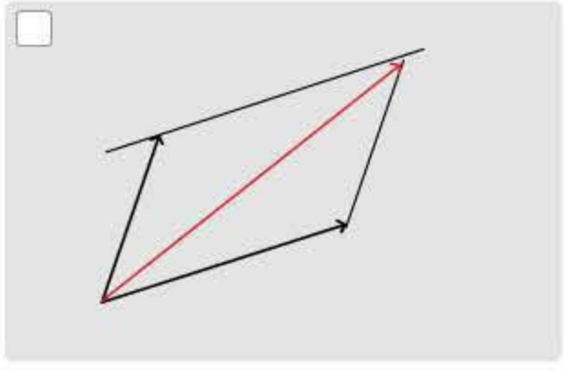


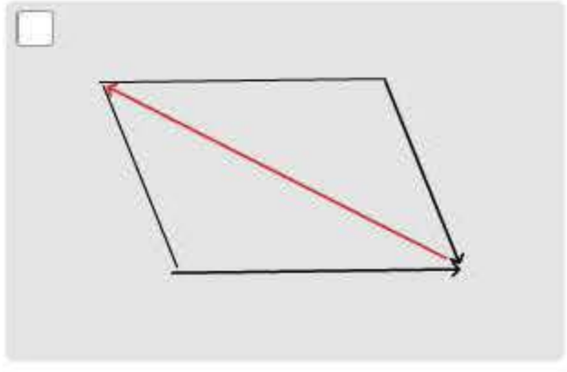
(d)

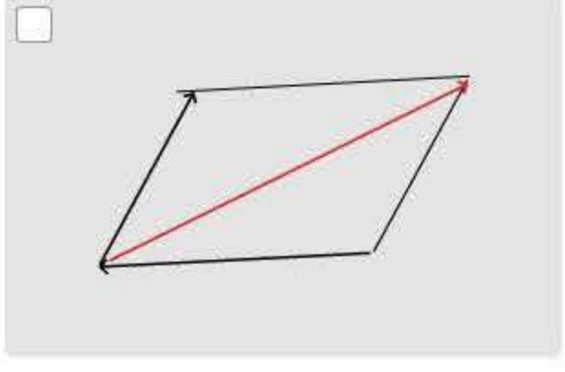
However, as the complexity of force systems increases in other problems, it is more convenient to draw separate force diagrams.

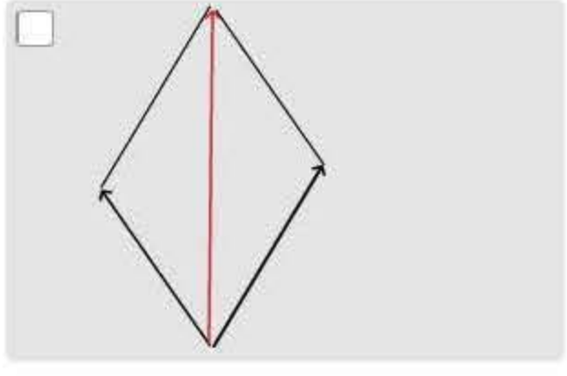
Select the diagrams that show the correct construction of parallelogram of forces.

Check all that apply.









Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

Determine the resultant of the two forces acting on point A:

Click the correct answer.

1 N ←

1 N →

7 N →

7 N ←

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

Type your answer in the box.

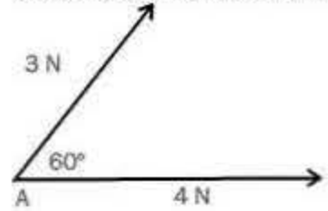
Two cranes are attempting to right an overturned truck by each applying a pull of 50 kN. The two cables form an angle of 30° between each other. The resultant force on the truck is _____ kN.

(Give your answer correct to one decimal place.)
(Hint: Produce the parallelogram of forces.)

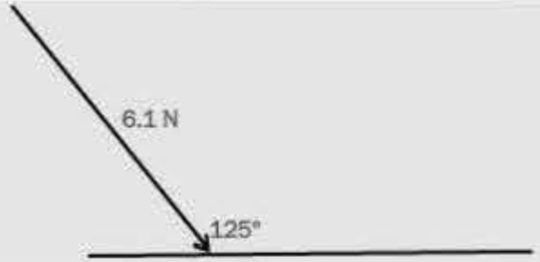
Do you know the answer?

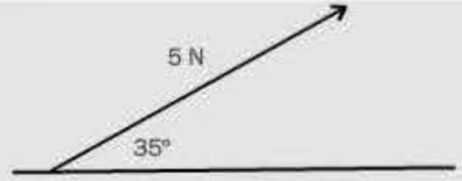
I KNOW IT | THINK SO | UNSURE | NO IDEA

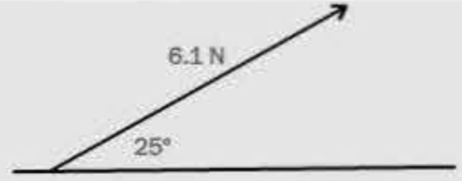
Determine the resultant of the two forces acting on point A:



Click the correct answer.







The resolution of a given force

It was shown how two forces could be combined into a single resultant force. The reverse problem, called resolution of a force into components, is the separation of a single force into two component forces acting in different directions on the same point.

In many engineering problems, the two components into which a single force must be resolved are at right angles to each other. Such components are called rectangular components of a force, as the parallelogram of forces becomes a rectangle.

Problems involving the resolution of a force into rectangular components can either be solved graphically by constructing a rectangle of forces or mathematically by using trigonometric relationships.

GIVE FEEDBACK

OK

Type your answer in the box.

The resolution of a force is the _____ of a single force into _____ component forces acting in _____ directions on the same point.

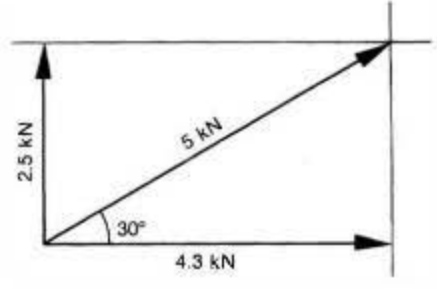
Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

Resolve a given force into two components using the graphical method

A force of 5 kN is acting up and to the right at 30° to the horizontal. Determine its horizontal and vertical components.

Using the graphical method, draw the parallelogram, i.e. rectangle of forces, to scale, as in the figure below.



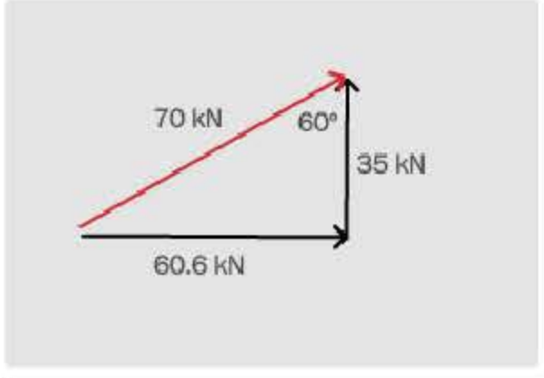
The horizontal component is 4.3 kN to the right and the vertical component is 2.5 kN upwards.

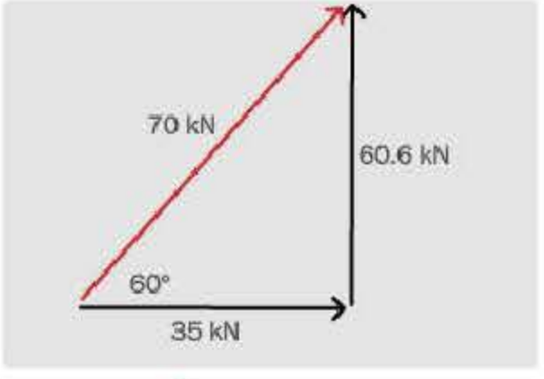
GIVE FEEDBACK

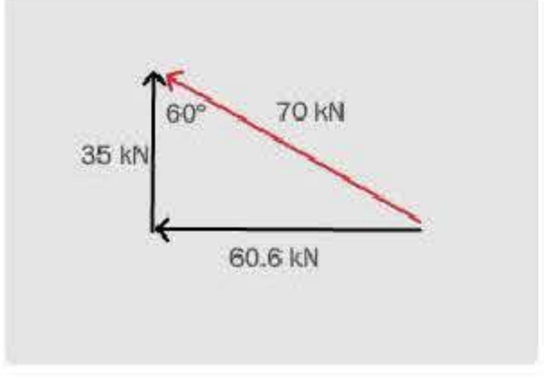
OK

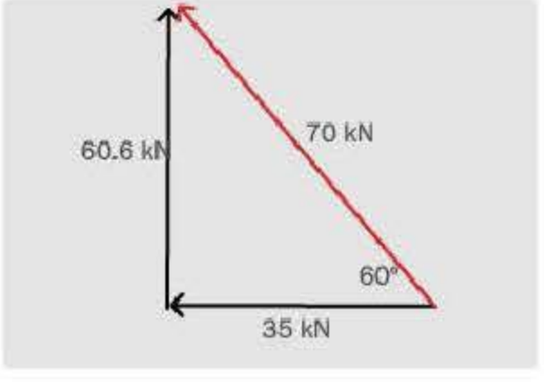
A force of 70 kN is acting up and to the left at 60° to the horizontal. Select the correct diagram showing the resolved horizontal and vertical components.

Click the correct answer.









Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

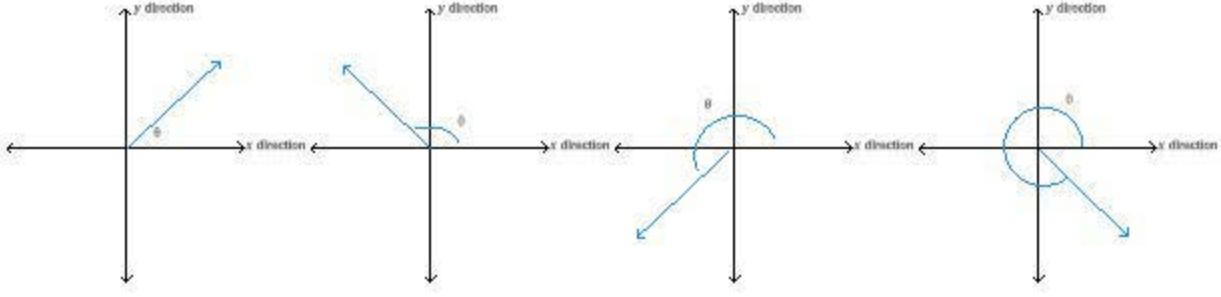
Formulas for resolving of a force into rectangular components

The relationships between a force F and its rectangular components in the mutually perpendicular x and y directions, F_x and F_y, are:

$$F_x = F \cos \theta \text{ and } F_y = F \sin \theta$$

where θ is the angle between the force and the positive x direction.

θ (theta) is a letter of the Greek alphabet often used to represent angular measurement.



GIVE FEEDBACK

OK

Select the correct formulas for resolving of a force into rectangular components in the mutually perpendicular x and y directions, F_x and F_y.

Check all that apply.

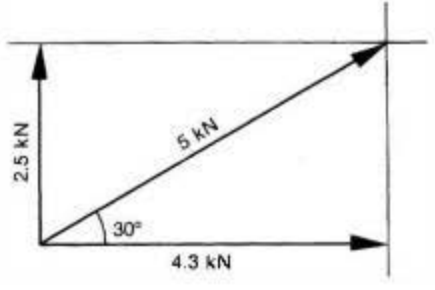
- [ ] $F_x = F \cos \theta$
- [ ] $F_y = F \sin \theta$
- [ ] $F_x = F \csc \theta$
- [ ] $F_x = F \tan \theta$
- [ ] $F_x = F \sin \theta \cos \theta$
- [ ] $F_y = F \sec \theta$

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

A force of 5 kN is acting up and to the right at 30° to the horizontal. Determine its horizontal and vertical components.

Using the mathematical method, sketch a diagram but not necessarily to scale, as shown below.



GIVE FEEDBACK

CONTINUE >

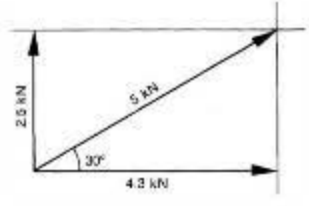
The relationships between a force F and its rectangular components in the mutually perpendicular x and y directions, F_x and F_y, are:

$$F_x = F \cos \theta \text{ and } F_y = F \sin \theta$$

where θ is the angle between the force and the positive x direction.

From the geometry of the triangles involved:

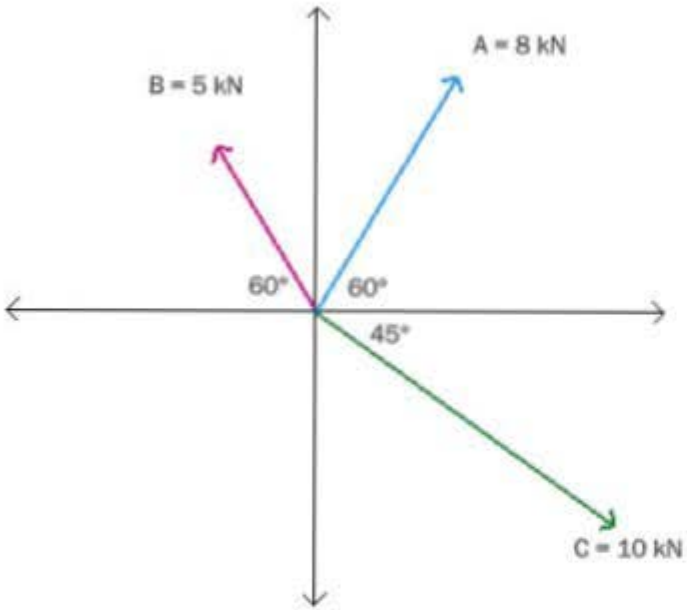
the horizontal component is:	the vertical component is:
$F_x = 5\ \text{kN} \cdot \cos 30°$	$F_y = 5\ \text{kN} \cdot \sin 30°$
$= 5\ \text{kN} \cdot 0.866$	$= 5\ \text{kN} \cdot 0.5$
$= 4.33\ \text{kN}$ →	$= 2.5\ \text{kN}$ ↑



< BACK GIVE FEEDBACK OK

Type your answer in the box.

Resolve the three given forces mathematically and state your answers correct to two decimal places:



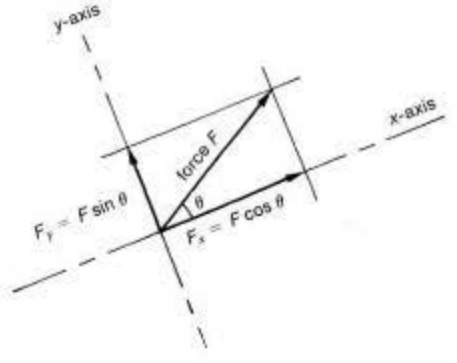
Force	Magnitude	*x* component	*y* component
A	8 kN	kN	6.93 kN
B	5 kN	kN	4.33 kN
C	10 kN	7.07 kN	kN

Formula for combining two forces perpendicular to each other into a resultant force

If the two components F_x and F_y are known, the force itself and the angle it makes with the x direction can be calculated from:

$$F = \sqrt{F_x^2 + F_y^2} \qquad \tan\theta = \frac{F_y}{F_x}$$

The x and y directions are usually horizontal and vertical but they may also be chosen in any two mutually perpendicular directions, as shown below.



GIVE FEEDBACK

OK

Select the correct formula for determining the angle between rectangular component forces in the mutually perpendicular x and y directions, F_x and F_y.

Click the correct answer.

$\tan\theta = \frac{F_y}{F_x}$

$\tan\theta = \frac{F_x}{F_y}$

$\sin\theta = \frac{F_x}{F_y}$

$\cos\theta = \frac{F_x}{F_y}$

$\sin\theta = \frac{F_y}{F_x}$

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

Select the correct formula for determining the resultant force F by combining rectangular components in the mutually perpendicular x and y directions, F_x and F_y.

Click the correct answer.

$F = \sqrt{(F_x)^2 + (F_y)^2}$

$F_x = \sqrt{(F)^2 + (F_y)^2}$

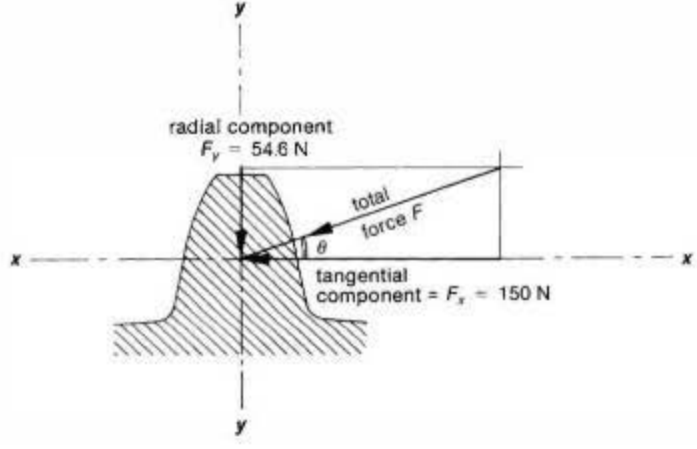
$F_y = \sqrt{(F_x)^2 + (F)^2}$

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

Example

If the components of the force acting on a gear tooth are 54.6 N in the radial direction and 150 N in the tangential direction, determine the total force and the angle between the force and tangential direction.



GIVE FEEDBACK

CONTINUE >

Solution

Total force:

$$\begin{aligned} F &= \sqrt{F_x^2 + F_y^2} \\ &= \sqrt{150^2 + 54.6^2} \\ &= 159.6\ \text{N} \end{aligned}$$

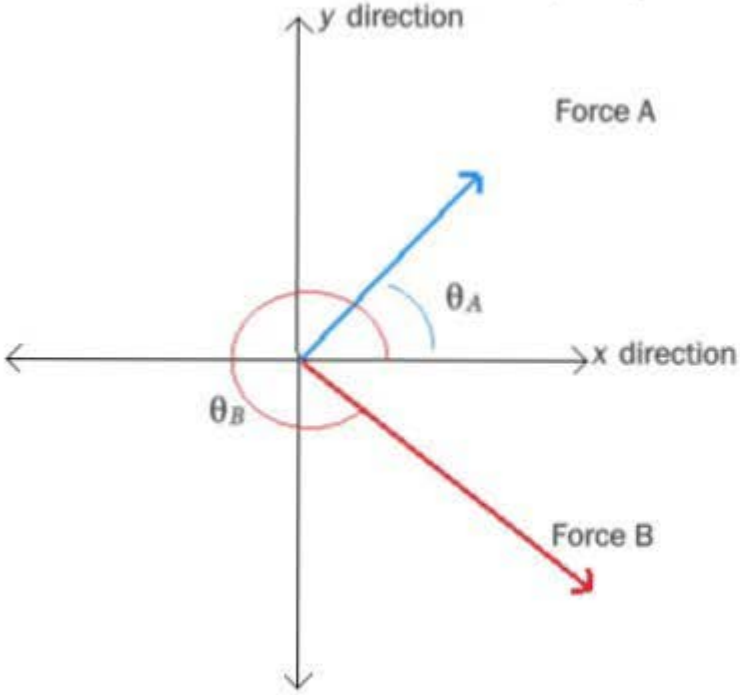
Angle:

$$\begin{aligned} \tan\theta &= \frac{F_y}{F_x} \\ &= \frac{54.6}{150} \\ &= 0.364 \end{aligned}$$

$$\text{therefore } \theta = 20°$$

Type your answer in the box.

Determine the total resultant force and the angle between with the positive horizontal and force A, B.
Fill in the correct values (to two decimal places).



Force	Angle	Magnitude	x component	y component
A	°	kN	9 kN	7 kN
B	°	kN	15 kN	-12 kN

Using the force triangle and the force polygon in graphical addition of forces

In many engineering problems there are systems of forces consisting of more than two forces.

If a resultant of such a system is required, it is possible to apply the parallelogram of forces principle to find the resultant of any two forces in the system, then combine that resultant with another force, and then repeat the procedure until all forces have been included.

The construction required is complicated, involving many construction lines.

The solution can be simplified by introducing the triangle of forces rule and then extending this rule to the polygon of forces method.

In summary, the force triangle rule states that by arranging given forces in a tip-to-tail fashion, taking into account the scaled magnitude and direction of the forces, the resultant of the two forces is found by connecting the tail of one with the tip of the other.

The method of force polygon is the repeated applications of the force triangle rule.

Both methods are used for finding resultants of force systems involving more than two forces.

Both force triangles and force polygons show the true direction and magnitude of the resultant when drawn to scale.

GIVE FEEDBACK

OK

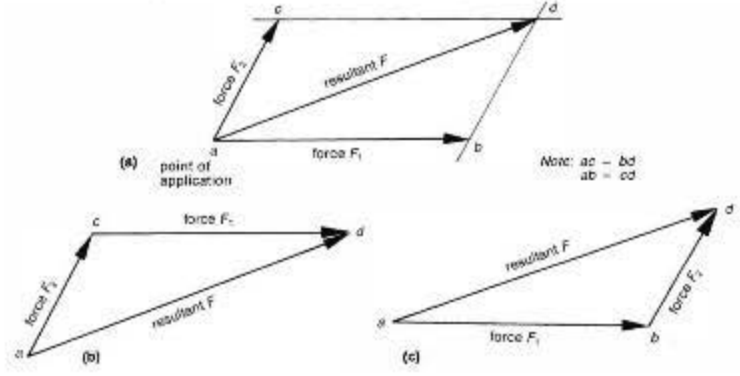
Which of the following statements are true for the force triangle rule and the polygon of forces method?

Check all that apply.

- [ ] The force triangle rule states that by arranging given forces in a tip-to-tail fashion, taking into account the scaled magnitude and direction of the forces, the resultant of the two forces is found by connecting the tail of one with the tip of the other
- [ ] The force triangle and the parallelogram of forces can be drawn together
- [ ] The method of force polygon is used for finding resultants of force systems involving more than two forces
- [ ] The method of force polygon is the repeated applications of the force triangle rule
- [ ] A constructed force triangle or force polygon will look identical to the initial diagram
- [ ] Force triangles and force polygons show the true direction and magnitude of the resultant when drawn to scale

Do you know the answer?

The **triangle of forces rule** (or force triangle rule) is derived simply from the parallelogram principle. When two forces are added by the parallelogram method, the opposite sides of the parallelogram are always equal, and any one of the two opposite sides can represent a force in magnitude, resulting in two possible triangles of forces.



The force triangle rule states that by arranging given forces F_1 and F_2 in a tip-to-tail fashion, taking into account the scaled magnitude and direction of the forces, the resultant of the two forces is found by connecting the tail of one with the tip of the other.

GIVE FEEDBACK

CONTINUE >

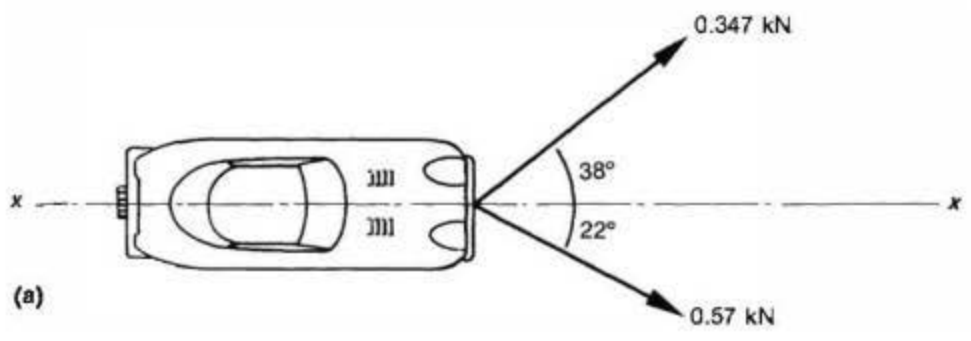
Although closely related, the parallelogram of forces and the triangle of forces differ in one very important respect: the parallelogram of forces shows all given and resultant forces as passing through a common point, the actual point of application of the forces.

In this respect, the parallelogram is a geometrical representation of a fundamental principle showing true relationships between all forces. In a triangle of forces, one of the forces does not pass through the point of application.

The triangle construction can only be regarded as a graphical rule or method for determining the magnitude and direction of the resultant force. As such, the triangle of forces should always be drawn as a separate force diagram and not superimposed on the diagram showing the actual layout of forces in relation to the point of application.

Example

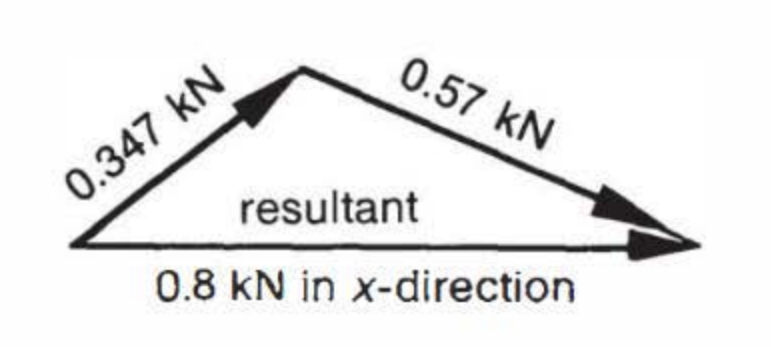
A damaged vehicle is being pulled by two ropes as shown below. Determine the resultant force in magnitude and direction using the triangle of forces rule.



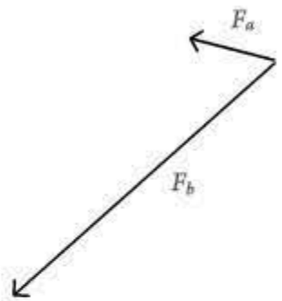
Solution

To solve the problem, construct the triangle of forces according to the rule and scale-off the magnitude and direction (angle).

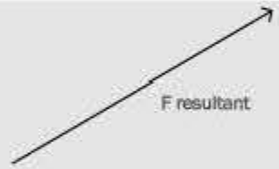
The answer is 0.8 kN in the x direction, acting to the right.

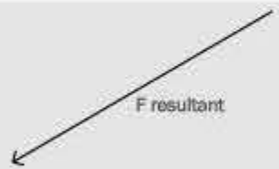


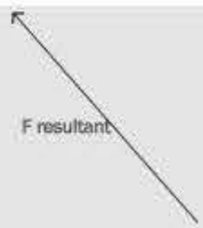
Which of the following shows the correct resultant by using the constructing triangle of forces?



Click the correct answer.





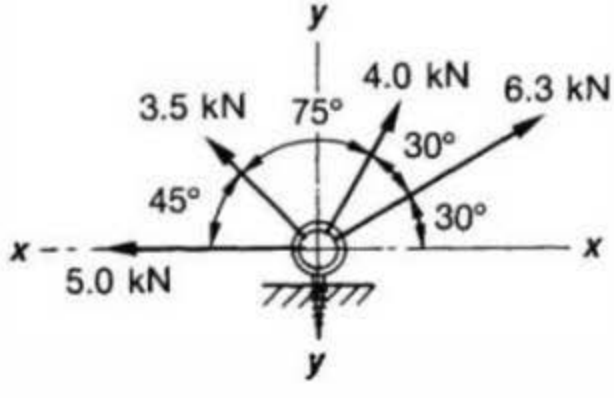


The rule or method for finding resultants of force systems involving more than two forces consists of repeated applications of the force triangle rule to successive pairs of forces until all the given forces are reduced to a single resultant force.

This is called the **polygon of forces method.**

Example

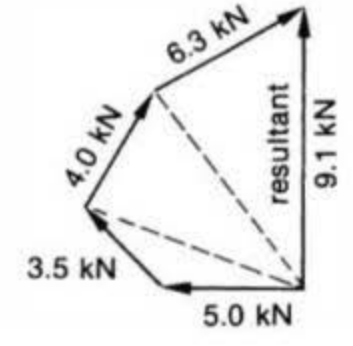
Determine the resultant force on the eye bolt used to anchor four guy wires as shown in the figure below.



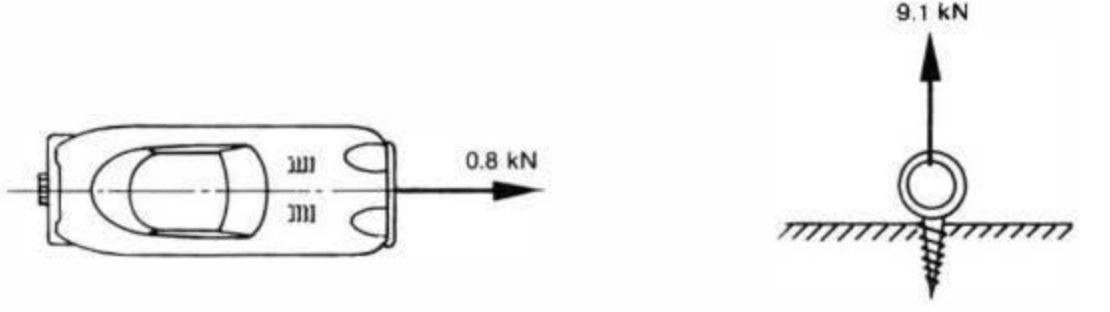
Solution

Construct the polygon of forces by successive addition of forces, as shown in here. The answer is a vertical resultant force of 9.1 kN.

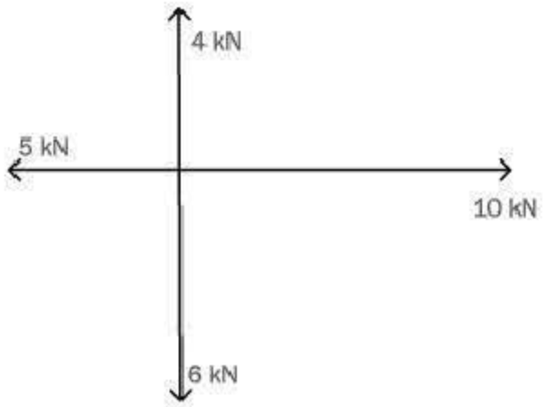
Note that the results of intermediate addition steps shown by dotted lines are usually omitted; only the outline of the force polygon is needed.



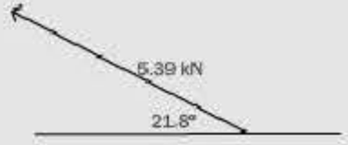
The answers themselves are what are of real physical significance. This should not be obscured by the method or construction used to obtain an answer. Try to visualise the answers in tangible physical terms rather than seeing the method or construction used to obtain the answers as the end in itself.

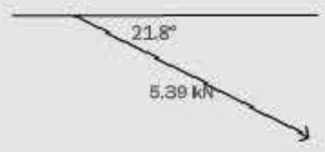


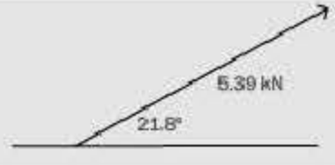
Which of the following shows the correct magnitude and direction of the resultant by using the constructing polygon of forces?



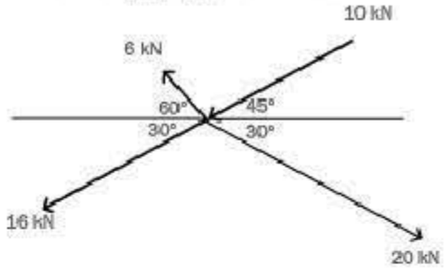
Click the correct answer.



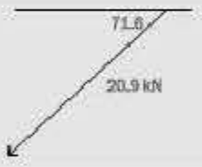


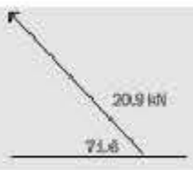


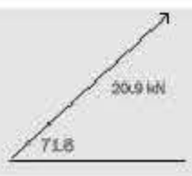
Which of the following shows the correct magnitude and direction of the resultant by using the constructing polygon of forces?



Click the correct answer.







Steps for the mathematical addition of forces

Addition of forces, i.e. solving for the resultant of a system of forces, can also be achieved mathematically by summing their x and y components. The method of solution consists of several steps as follows:

Resolve given forces into x and y components (usually horizontal and vertical) using $F_x = F\cos\theta$ and $F_y = F\sin\theta$, where θ is the acute angle between each force and the x axis (horizontal axis).

Assign positive and negative signs to each component according to the usual mathematical sign convention, i.e. to the right—positive; to the left—negative; upwards—positive; downwards—negative.

Σ is a mathematical sign meaning 'the sum of', pronounced 'sigma'. It is a letter of the Greek alphabet.

Add all x components, ΣF_y, taking into account the positive and negative signs, then add all y components, ΣF_y, taking signs into account.

The two sums can now be used to determine the resultant force using: $F = \sqrt{(\Sigma F_x)^2 + (\Sigma F_y)^2}$

Determine the angle the resultant makes with the x direction using:

$$\tan\theta = \frac{\Sigma F_y}{\Sigma F_x}$$

In summary, this method involves resolving forces into rectangular components (steps 1 and 2), reducing all components to a single force in each of the two directions x and y (step 3), and adding these two remaining forces into the resultant (steps 4 and 5).
A table for recording all intermediate results is useful.

GIVE FEEDBACK

OK

Rearrange the steps for solving an addition of forces problem in the correct order.

↑↓ **Place these in the proper order.**

Resolve the given forces into x and y components using $F_x = F\cos\theta$ and $F_y = F\sin\theta$

Assign positive and negative signs to each component according to usual sign convention (right and up—positive; left and down—negative)

Add all x components, ΣF_x, and add all y components, ΣF_y

Use the two sums to determine the resultant force using $F = \sqrt{(\Sigma F_x)^2 + (\Sigma F_y)^2}$

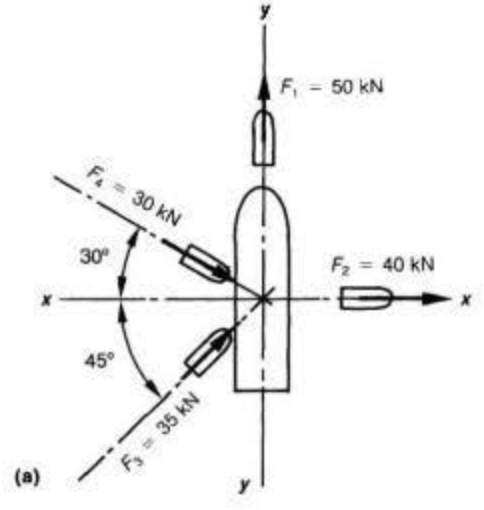
Determine the angle the resultant makes with the x direction using $\tan\theta = \frac{(\Sigma F_y)}{(\Sigma F_x)}$

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

Example

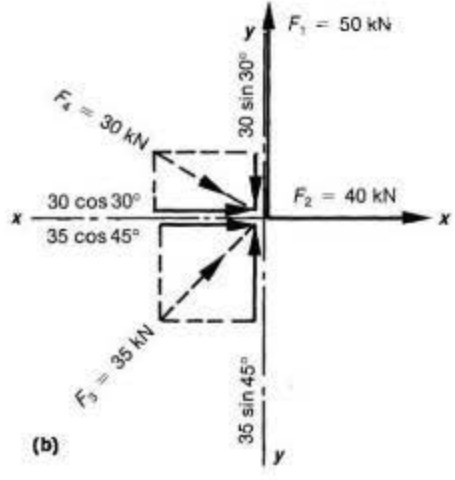
Determine the resultant force acting on the barge due to the combined effort of four tugboats as shown in the following figure.



GIVE FEEDBACK

CONTINUE >

Solution


y
$F_1 = 50$ kN
30 sin 30°
$F_4 = 30$ kN
30 cos 30°
$F_2 = 40$ kN
x
x
35 cos 45°
$F_3 = 35$ kN
35 sin 45°
y
(b)

The results are tabulated below.

Force	Magnitude	x component	y component
F_1	50	0	50.0
F_2	40	40.0	0
F_3	35	24.7	24.7
F_4	30	26.0	−15.0
		$\Sigma F_x = 90.7$	$\Sigma F_y = 59.7$

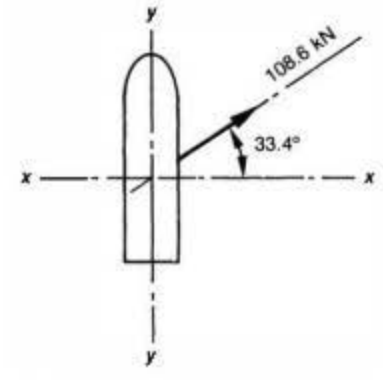
Resultant:

$$F = \sqrt{90.7^2 + 59.7^2}$$
$$= 108.6 \text{ kN}$$

Angle:

$$\tan \theta = \frac{59.7}{90.7}$$
$$= 0.658$$
$$\text{therefore } \theta = 33.4°$$

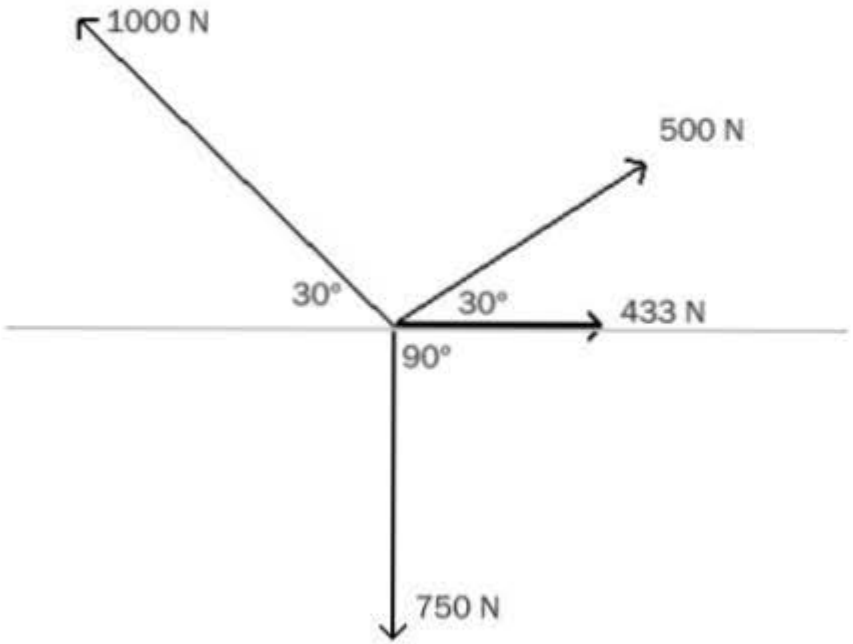
The resultant force is shown below.



Finally, it is always a good idea to cross-check the solution using an independent alternative method. A mathematical solution can be verified graphically and vice versa.

Type your answer in the box.

Evaluate the magnitude and direction of the resultant with mathematical addition in the following diagram. (State your answer correct to the nearest kN and degree.)

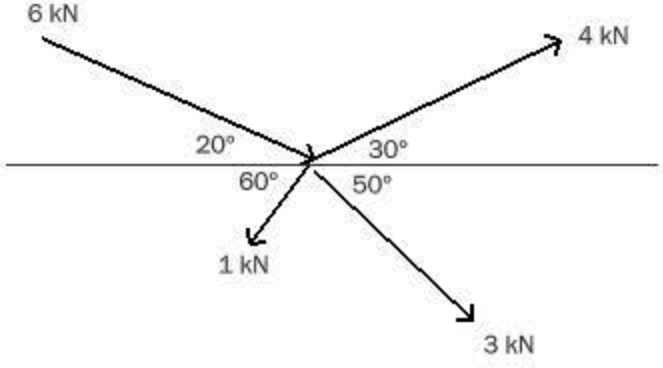


The magnitude of the resultant force is _____ kN. The angle between the resultant force and the positive horizontal is _____ degrees.

Do you know the answer?

Type your answer in the box.

Evaluate the magnitude and direction of the resultant with mathematical addition in the following diagram. (State your answer correct to the nearest kN and degree.)



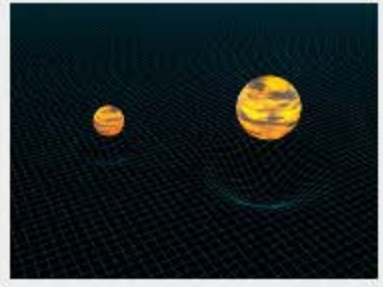
The magnitude of the resultant force is _____ kN. The angle between the resultant force and the positive horizontal is _____ degrees.

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

The law of universal gravitation

Gravity is one of the most common physical phenomena seen in nature; it manifests itself as a force of mutual attraction between masses.



Newton's law of universal gravitation states that the force of gravitational attraction (F_g) between two bodies having masses m_1 and m_2 separated by a distance d is given by:

$$F_g = G\frac{m_1 m_2}{d^2}$$

Historically our understanding of the law of universal gravitation was a result of many centuries of astronomical observations culminating in the work of Johannes Kepler (1571–1630), who discovered important regularities in the motion of the planets, lending support to the Copernican heliocentric theory of the solar system.

GIVE FEEDBACK

OK

Which of the following equations correctly reflects Newton's law of universal gravitation?

Click the correct answer.

$F_g = G\frac{(m_1 m_2)}{d^2}$

$F_g = \frac{(m_1 m_2)}{G}d$

$F_g = \frac{G}{d^2}$

$F_g = -mg$

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

The value of the universal gravitational constant

It is important to understand that the constant G, known as the **universal gravitational constant,** has a numerical value which is the same for any pair of bodies, regardless of their masses or the distance separating them.

The actual value of G was measured experimentally by Henry Cavendish in 1798. Significant improvements in the accuracy of the measurement were achieved in the 19th and 20th centuries.

The present accepted value, determined at the United States National Bureau of Standards, is:

$$G = 66.7 \times 10^{-12} \frac{\text{N.m}^2}{\text{kg}^2}$$

GIVE FEEDBACK

OK

What is the value of universal gravitational constant G?

Click the correct answer.

- $66.7 \times 10^{-12}\,\mathrm{N} \cdot \frac{\mathrm{m}^2}{\mathrm{kg}^2}$
- $9.81\,\mathrm{N} \cdot \mathrm{kg}^2$
- $3.14159 \times 10^{-12}\,\mathrm{N} \cdot \frac{\mathrm{m}^2}{\mathrm{kg}^2}$
- 42

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

1. Determine the force of mutual attraction between the following pairs of bodies.

The Earth and the Moon, given the mass of Earth as $5.97 \times 10^{24}\,\text{kg}$, the mass of the Moon as $73.7 \times 10^{21}\,\text{kg}$ and the distance between them as $0.38 \times 10^{6}\,\text{km}$:

$$F_g = 66.7 \times 10^{-12} \frac{\text{N.m}^2}{\text{kg}^2} \cdot \frac{5.97 \times 10^{24}\,\text{kg} \cdot 73.7 \times 10^{21}\,\text{kg}}{(0.38 \times 10^{9}\,\text{m})^2}$$
$$= 2.03 \times 10^{21}\,\text{N}$$

This is the huge pull between the Earth and the Moon which keeps the Moon in its orbit.

GIVE FEEDBACK

CONTINUE >

2. Determine the force of mutual attraction between the following pairs of bodies.

Two ships, 30 000 t each, at a centre-to-centre distance of 50 m:

$$F_g = 66.7 \times 10^{-12} \frac{\text{N.m}^2}{\text{kg}^2} \cdot \frac{30 \times 10^6\,\text{kg} \cdot 30 \times 10^6\,\text{kg}}{(50\,\text{m})^2}$$
$$= 24\,\text{N}$$

In comparison with other forces acting on the ships, a force of 24 N is insignificant.

3. Determine the force of mutual attraction between the following pairs of bodies.

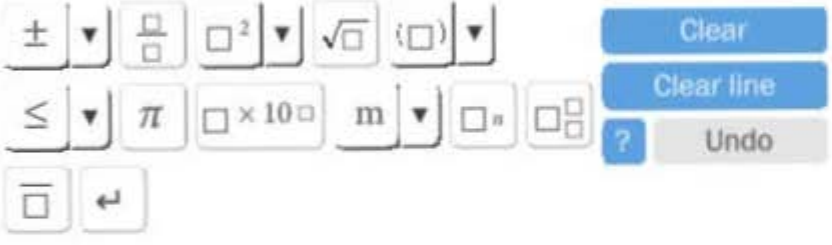
Two 1 kg masses at a distance of 1 m:

$$F_g = 66.7 \times 10^{-12} \frac{\text{N.m}^2}{\text{kg}^2} \cdot \frac{1\,\text{kg} \cdot 1\,\text{kg}}{(1\,\text{m})^2}$$

This is a tiny force which is of no particular interest to an engineer.

Determine the force of attraction between the Sun and the Earth, given that the mass of the Sun is 1.99×10^{30}kg, that of the Earth is 5.97×10^{24}kg and the distance between them is 1.5×10^{8}km.

(State your answer in scientific notation correct to two decimal places.)



Click and type your answer here. Show your work.

CHALLENGE SUBMIT SHOW ANSWER

INSTRUCTIONS

- You must show intermediate steps for full credit, one on each line.
- Write your final answer on the last line.
- The computer will check all your work in detail when you click "Submit".

Hint Each hint will reduce the credit received for this question

The uses and limitations of the gravitational constant in practical engineering calculations

Engineers are concerned with structures and machines which are located on, or very near, the surface of the Earth, i.e. at nearly constant distance from the centre of the Earth, equal to its mean radius of 6370 km.

It may appear at this point that the law of universal gravitation is of no particular practical use to engineers, since forces of attraction between objects, even as large as ships, are very small indeed.

However, the understanding of the law is necessary for developing the concept of weight. This is important in calculating the weight of structures and machines.

GIVE FEEDBACK

OK

Which of the following statements are true about universal gravitation?

Check all that apply.

- [ ] The law of universal gravitation is of no particular practical use to an engineer
- [ ] The forces of attraction between objects on Earth are too small to calculate
- [ ] Understanding of the law of universal gravitation is necessary for developing the concept of weight
- [ ] The law of universal gravitation is only useful in astrophysics

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

If this distance is taken as constant for all such objects, the law of universal gravitation can be reduced to a special case applicable at or near the Earth's surface as follows:

$$F_g = G\frac{m_e \cdot m_o}{r_e^2}$$

where:
m_e is the mass of the Earth $= 5.97 \times 10^{24}\,\text{kg}$
r is the mean radius of the Earth $= 6.37 \times 10^{6}\,\text{m}$
m_o is the mass of a given object

GIVE FEEDBACK

CONTINUE >

Substitution and combining of constants yields:

$$F_g = 66.7 \times 10^{-12} \frac{\text{N.m}^2}{\text{kg}^2} \cdot \frac{5.97 \times 10^{24}\ \text{kg} \cdot m_o\ \text{kg}}{(6.37 \times 10^6\ \text{m})^2}$$
$$= 9.81\ \text{N/kg} \cdot m_o\ \text{kg}$$

The new constant we have obtained is called the **local gravitational constant** (symbol g). In science and engineering, the force of gravity exerted by the Earth on an object is often referred to as the **weight of the object**, F_w, given by:

$$F_w = m\,g$$

where m is the mass of the object and:

$$g = 9.81\ \mathrm{N/kg}$$

Which of the following statements are true about weight?

Check all that apply.

- [ ] The weight of an object will be different when it is on the Moon
- [ ] Weight of an object is defined as the force of gravity exerted by the Earth on such an object
- [ ] It is the same as mass
- [ ] Weight is expressed in newtons
- [ ] Mass and weight are both expressed in kilograms

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

The SI unit of weight

Being a force, weight is measured in units of force, i.e. newtons.
In this regard, the common usage of the word 'weight' is not equivalent to mass or quantity.

In engineering, mass is a measure of quantity expressed in kilograms and weight is a measure of gravitational force expressed in newtons.

GIVE FEEDBACK

OK

Type your answer in the box.

The SI unit of weight is _____. The symbol is _____.

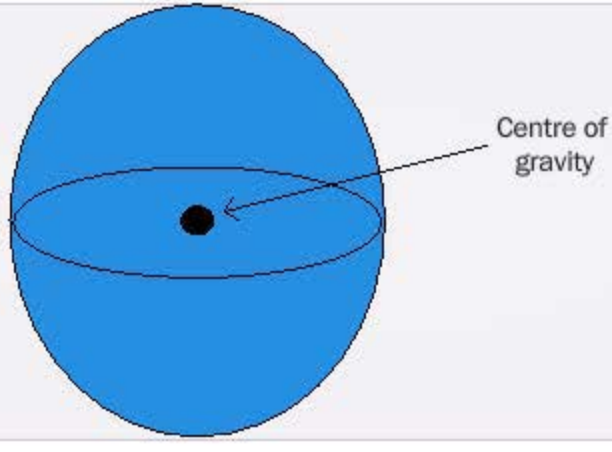
Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

Centre of gravity

The force of gravity on an object, or weight, is always acting towards the centre of the Earth, i.e. vertically downwards, and is applied to the object at the centre of its mass distribution known as its **centre of gravity**.

When the mass of an object is distributed uniformly throughout its volume, the centre of gravity coincides with the geometrical centre of the shape, e.g. the centre of gravity of a uniform solid sphere is at its geometrical centre.



GIVE FEEDBACK

OK

Which of the following statements are true about the centre of gravity?

Check all that apply.

- [ ] The centre of gravity is the centre of an object's mass distribution
- [ ] The centre of gravity of an object will always be the centre of the object
- [ ] The centre of gravity will coincide with the geometrical centre as long as the object is symmetrical in shape
- [ ] The centre of gravity of a uniform solid sphere is at its geometrical centre

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

Example

A man has a mass of 79 kg. What is his weight?

GIVE FEEDBACK

CONTINUE >

Example

A man has a mass of 79 kg. What is his weight?

Solution

$$\begin{aligned} F_w &= m\,g \\ &= 79\ \text{kg} \cdot 9.81\ \text{N/kg} \\ &= 775\ \text{N} \end{aligned}$$

Example

What is the force in a cable supporting a load of 1.5 tonnes?

Example

What is the force in a cable supporting a load of 1.5 tonnes?

Solution

$$
\begin{aligned}
F &= F_w \\
&= m\,g \\
&= 1{,}500\ \text{kg} \cdot 9.81\ \text{N/kg} \\
&= 14{,}715\ \text{N} \\
&= 14.7\ \text{kN}
\end{aligned}
$$

The weight of a kilogram mass is:

Click the correct answer.

- 9.81 N
- 9 N
- 1 kg
- 10 N

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

Determine the weight of a truck which has a mass of 2.3 tonnes. (State your answer correct to the nearest newton.)

+ − · ÷ $\frac{\square}{\square}$ $\square^2$ $\sqrt{\square}$ Clear

$(\square)$ ▼ ≤ ▼ π N ▼ $\overline{\square}$? Undo

Click and type your answer here

CHALLENGE SUBMIT SHOW ANSWER

Determine the weight of a 50 g egg. (State your answer correct to four decimal places.)

+ − · ÷ $\frac{\square}{\square}$ $\square^2$ $\sqrt{\square}$ Clear

$(\square)$ ▼ ≤ ▼ π N ▼ $\overline{\square}$? Undo

Click and type your answer here

CHALLENGE SUBMIT SHOW ANSWER

Calculate the weight of a brick of mass 4 kg. (State you answer correct to two decimal places.)

+ − · ÷ $\frac{\square}{\square}$ $\square^2$ $\sqrt{\square}$ Clear Clear line

$(\square)$ ▾ ≤ ▾ π ft ▾ $\overline{\square}$ ↵ ? Undo

Click and type your answer here. Show your work.

CHALLENGE SUBMIT SHOW ANSWER

INSTRUCTIONS

- You must show intermediate steps for full credit, one on each line.
- Write your final answer on the last line.
- The computer will check all your work in detail when you click "Submit".

Hint Each hint will reduce the credit received for this question

The different effects of mass and weight depending on the object's location

In general the value of the local gravitational constant g was assumed to be the same for all places on the Earth's surface. However, this is true only if the distance to the centre of the Earth is the same for all locations, which is not strictly correct.

Because the Earth is slightly ellipsoidal in shape and not a perfect sphere, there is a small gradual variation in g with latitude.

These values are average values only because there are other local influences owing to the nature of the underlying rocks, etc. at different locations along the same latitude.

Gravity varies at different latitudes on Earth.
This table shows the variation of g with latitude at sea level.

Gravity also varies with altitude above sea level.
This table shows the variation of g with altitude for a fixed location with latitude of 45°.

Variation of g with altitude

Altitude (km)	sea level	1	2	5	10	30	100
g (N/kg)	9.806	9.803	9.800	9.791	9.776	9.714	9.598

In engineering practice, an occasional approximation to 9.8 N/kg may be acceptable when dealing with other parameters which are not capable of being measured with a high degree of precision.

The overall average, known as the International Standard value, has been defined as $g = 9.80665\,\mathrm{N/kg}$ at sea level.
The local value for Sydney (Australia) is 9.796 83 N/kg.

GIVE FEEDBACK

OK

The different effects of mass and weight depending on the object's location

In general the value of the local gravitational constant g was assumed to be the same for all places on the Earth's surface. However, this is true only if the distance to the centre of the Earth is the same for all locations, which is not strictly correct.

Because the Earth is slightly ellipsoidal in shape and not a perfect sphere, there is a small gradual variation in g with latitude.

These values are average values only because there are other local influences owing to the nature of the underlying rocks, etc. at different locations along the same latitude.

Variation of g at sea level

Latitude	equator	10°	20°	30°	40°	50°	60°	70°	80°	90°
g (N/kg)	9.780	9.782	9.786	9.793	9.802	9.811	9.819	9.826	9.831	9.832

Gravity also varies with altitude above sea level.
This table shows the variation of g with altitude for a fixed location with latitude of 45°.

Variation of g with altitude

Altitude (km)	sea level	1	2	5	10	30	100
g (N/kg)	9.806	9.803	9.800	9.791	9.776	9.714	9.598

However, the use of the round figure 10 N/kg is strongly discouraged because it tends to give the erroneous impression that the gravitational constant is an exact decimal factor, which it is not. It is suggested that 9.81 N/kg should be used consistently.

It is common practice to use the value of 9.81 N/kg for most engineering calculations. The margin of error involved in using this value instead of the more accurate local value is insignificant, except for very high altitudes.

GIVE FEEDBACK

OK

What is the value of g with a latitude of 45° at 10 km above sea level?

Click the correct answer.

- 9.776
- 9.806
- 9.791
- 9.598

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

What is the value of g with a latitude of $60°$ at sea level?

Click the correct answer.

- 9.819
- 9.811
- 9.826
- 9.831

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

If a body with a mass of 70 kg is taken to the South Pole at sea level, what is the weight of the object?

Clear

Clear line

Undo

Click and type your answer here. Show your work.

CHALLENGE

SUBMIT

SHOW ANSWER

INSTRUCTIONS

- You must show intermediate steps for full credit, one on each line.
- Write your final answer on the last line.
- The computer will check all your work in detail when you click "Submit".

Hint

Each hint will reduce the credit received for this question

Variation of gravity at sea level

Latitude	equator	10°	20°	30°	40°	50°	60°	70°	80°	90°
g (N/kg)	9.780	9.782	9.786	9.793	9.802	9.811	9.819	9.826	9.831	9.832

Variation of gravity with altitude for a latitude of 45°

Altitude (km)	sea level	1	2	5	10	30	100
g (N/kg)	9.806	9.803	9.800	9.791	9.776	9.714	9.598

SMALL MEDIUM LARGE

What is the value of g with a latitude of 45° at 10 km above sea level?

Click the correct answer.

9.776

9.806

9.791

9.598

Do you know the answer?

I KNOW IT THINK SO UNSURE NO IDEA

Variation of gravity at sea level

Latitude	equator	10°	20°	30°	40°	50°	60°	70°	80°	90°
g (N/kg)	9.780	9.782	9.786	9.793	9.802	9.811	9.819	9.826	9.831	9.832

Variation of gravity with altitude for a latitude of 45°

Altitude (km)	sea level	1	2	5	10	30	100
g (N/kg)	9.806	9.803	9.800	9.791	9.776	9.714	9.598

SMALL | MEDIUM | LARGE

What is the value of g with a latitude of 60° at sea level?

Click the correct answer.

- 9.819
- 9.811
- 9.826
- 9.831

Do you know the answer?

I KNOW IT | THINK SO | UNSURE | NO IDEA

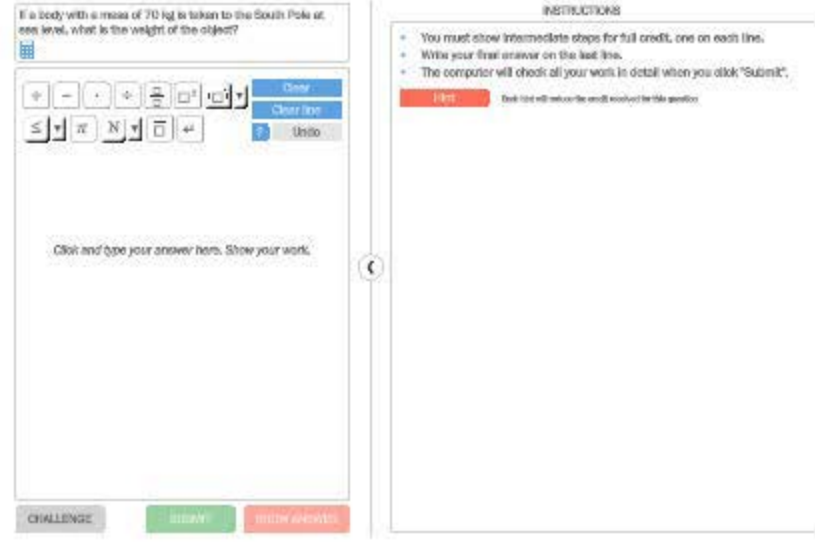
Variation of gravity at sea level

Latitude	equator	10°	20°	30°	40°	50°	60°	70°	80°	90°
g (N/kg)	9.780	9.782	9.786	9.793	9.802	9.811	9.819	9.826	9.831	9.832

Variation of gravity with altitude for a latitude of 45°

Altitude (km)	sea level	1	2	5	10	30	100
g (N/kg)	9.806	9.803	9.800	9.791	9.776	9.714	9.598

SMALL MEDIUM LARGE



Variation of gravity at sea level

Latitude	equator	10°	20°	30°	40°	50°	60°	70°	80°	90°
g (N/kg)	9.780	9.782	9.786	9.793	9.802	9.811	9.819	9.826	9.831	9.832

Variation of gravity with altitude for a latitude of 45°

Altitude (km)	sea level	1	2	5	10	30	100
g (N/kg)	9.806	9.803	9.800	9.791	9.776	9.714	9.598

SMALL MEDIUM LARGE

If a body with a mass of 70 kg is taken to a latitude of 45° at 1 km above sea level, what is the weight of the object?

Clear

?

Undo

Click and type your answer here

CHALLENGE SUBMIT SHOW ANSWER

If a body with a mass of 70 kg is taken to a latitude of $45°$ at 1 km above sea level, what is the weight of the object?

$+$ $-$ $\cdot$ $\div$ $\frac{\square}{\square}$ $\square^2$ $\sqrt{\square}$ Clear

$(\square)$ ▼ $\leq$ ▼ π N ▼ $\overline{\square}$? Undo

Click and type your answer here

CHALLENGE SUBMIT SHOW ANSWER