National 5 Physics

"DYNAMICS"

'Newton's Laws'

Name: ______________________________

This section of the "Dynamics" unit starts by introducing the terms 'mass', 'inertia', 'weight' and 'gravitational field strength'.

The use of the equation W = m g to solve problems involving 'weight', 'mass' and 'gravitational field strength' on earth's surface and in different places in the universe is then explained.

This is followed by the use of 'Newton's first law of motion' and 'balanced forces' to explain 'constant velocity' ('speed'), making reference to 'frictional forces'.

'Terminal velocity' ('speed') and 'free fall'/'weightlessness' are explained.

'Newton's second law of motion' and 'unbalanced forces' are used to explain/determine 'acceleration' where one or more forces are acting in one dimension, using the equation F = m a.

'Newton's third law of motion' is introduced and used to explain motion resulting from a 'reaction force'.

'Newton's second law' and 'third law' are applied to 'space travel', 'rocket launch' and 'rocket landing'.

By the end of this section, you should be able to:

☐ explain the terms 'mass', 'inertia', 'weight' and 'gravitational field strength''

☐ solve problems involving 'weight', 'mass' and 'gravitational field strength' on earth's surface and in different locations in the universe using the equation W = m g

☐ apply Newton's first law of motion and balanced forces to explain constant velocity (or speed), making reference to frictional forces

☐ apply Newton's second law of motion and unbalanced forces to explain and/or determine acceleration where one or more forces are acting in one dimension using the equation F = m a

☐ explain 'free-fall' and 'terminal velocity' in terms of Newton's laws

☐ explain motion resulting from a 'reaction force' in terms of 'Newton's third law'

☐ apply 'Newton's second law' and 'third law' to 'space travel', 'rocket launch' and 'rocket landing'

Mass, Weight and Gravitational Field Strength

Mass

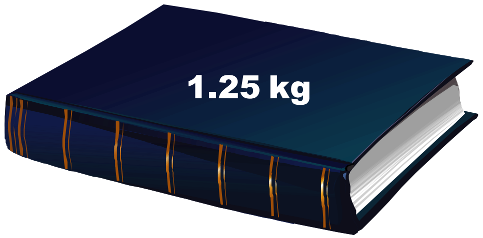
The **mass** of an object is the **amount of material** in the object.

The unit of **mass** is the **k** _ _ _ _ _ _ _ _ (_ _).

PROVIDED NO MATERIAL IS ADDED TO OR REMOVED FROM AN OBJECT, ITS MASS WILL NOT CHANGE ..... NO MATTER WHERE THE OBJECT IS MOVED TO IN THE UNIVERSE.

1) On Earth, a large book book has a mass of 1.25 kg.

What would the mass of the book be if it were:



(a) On the moon? ____________

(b) On mars? ____________

(c) At the edge of the Milky Way galaxy? ____________

(d) On the star Proxima Centauri? ____________

Inertia

The **inertia** of a moving object is a measure of how difficult it is to change the motion of the object ..... the greater the mass of the object, the greater is its inertia.

2) (a) Which moving shopping trolley is more difficult to stop - an **empty** one or a **full** one?: ____________________

(b) Explain why: ____

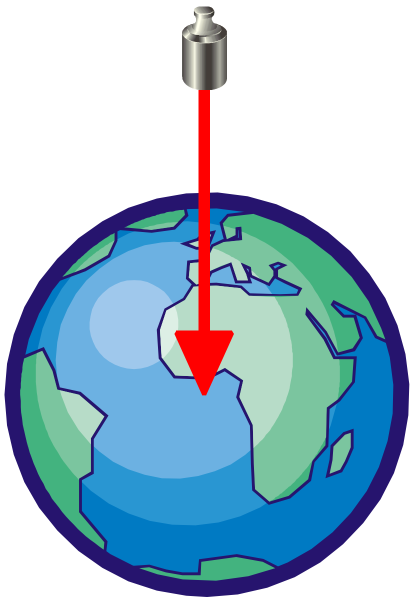
____

Weight and Gravitational Field Strength

All objects attract (pull one another together) - this attraction (pull) is known as the **force of g** _ _ _ _ _ _ _.

Weight is a **force**. It is the **gravitational pull** of the earth (or another planet or moon or star) on an object.

The unit of **weight** is the **n** _ _ _ _ _ _ (__).



The **force of gravity** pulls every object near or on the earth's surface down towards the centre of the earth with a **force** of **9.8 newtons for every kilogram of mass**.

This **downwards force** (**weight**) **per kilogram of mass** is called the **g** _ _ _ _ _ _ _ _ _ _ _ _ _ **f** _ _ _ _ **s** _ _ _ _ _ _ _ _. (Symbol __).

Near the earth's surface, **g = ___ newtons per kilogram** (**N kg^{-1}**).

3) When an object is hung from a **Newton balance**, what quantity does the **force reading** on the **Newton balance** represent?

____

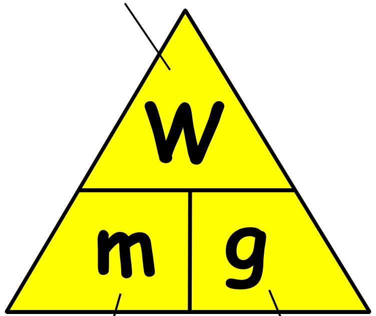
Mass and Weight Calculations (On Earth)

For any object:

weight = mass × gravitational field strength

$$\boxed{W = m\,g}$$

weight
newtons (N)



W =

m =

g =

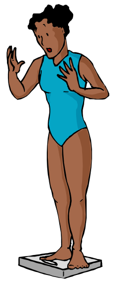
mass
kilograms (kg)

gravitational field strength
newtons per kilogram ($N\ kg^{-1}$)

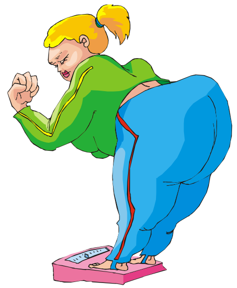
Near earth's surface, $g = 9.8\ N\ kg^{-1}$

4) Each person is standing on a set of scales on the earth's surface.
Calculate the **weight** of each person.


Harry
(mass 80 kg)


Mary
(mass 55 kg)


David
(mass 65 kg)


Bertha
(mass 110 kg)

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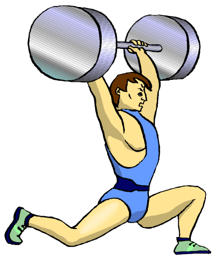
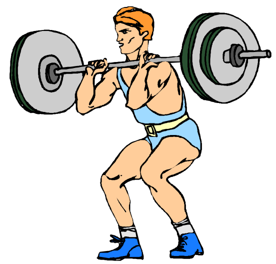
5) Each weightlifter is working out in a gym on the earth's surface.
Calculate the **mass** being lifted by each weightlifter.


Dwayne
(lifting 980 N)


Sonya
(lifting 147 N)


Tanya
(lifting 294 N)


Victor
(lifting 1 568 N)

Mass and Weight Calculations (Not on Earth)

PROVIDED NO MATERIAL IS ADDED TO OR REMOVED FROM AN OBJECT, ITS MASS WILL NOT CHANGE ..... NO MATTER WHERE THE OBJECT IS MOVED TO IN THE UNIVERSE.

ON DIFFERENT PLANETS (OR MOONS OR STARS), THE FORCE OF GRAVITY PULLING DOWN ON EVERY KILOGRAM OF AN OBJECT THAT IS NEAR ITS SURFACE IS DIFFERENT ..... SO THE GRAVITATIONAL FIELD STRENGTH NEAR THE SURFACE OF DIFFERENT PLANETS (OR MOONS OR STARS) IS DIFFERENT.

Some examples of gravitational field strength:

PLACE IN UNIVERSE	gravitational field strength ($N\ kg^{-1}$)
Near surface of earth	9.8
Near surface of the moon	1.6
Near surface of mars	3.8
In deep outer space	0

6) Calculate the **weight** of a 2.5 kg metal block when it is:

(a) Near the surface of earth.

(b) Near the surface of the moon.

(c) Near the surface of mars.

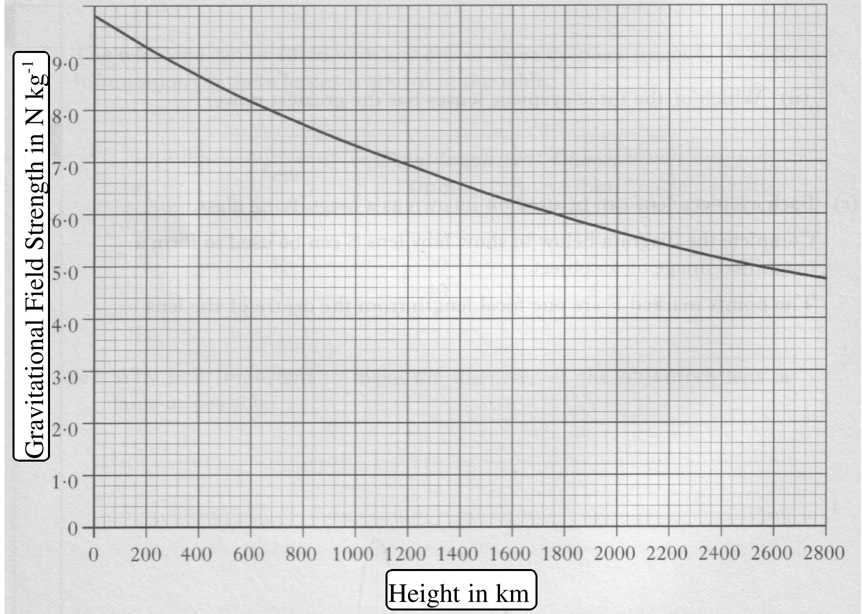
(d) In deep outer space.

Gravitational Field Strength and Distance From a Planet/Moon/Star

As you move further away from the surface of a planet/moon/star, the value for the **gravitational field strength** **decreases**.

This means that the **weight** of an object **decreases** as its distance from a planet/moon/star increases.

7) The graph below shows how the gravitational field strength of the earth decreases as you move further away from its surface:



Use the graph to help you calculate the **weight** of a 15 kg object when it is at each of the following heights above the earth's surface.

(a) 200 km

(b) 1 400 km

(c) 2 200 km

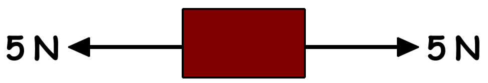
Balanced and Unbalanced Forces

Force is a **vector** quantity
- it has ***magnitude*** (***size***) and ***direction***.

Balanced Forces

If the forces acting on an object are **equal in size** but **act in opposite directions**, the forces are said to be **b** _ _ _ _ _ _ _ _.

For example:

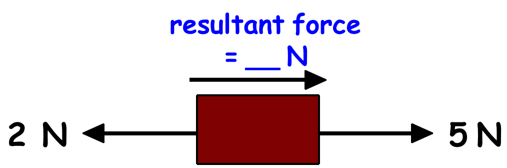


The forces **cancel out**.
They are equivalent to **no force at all**.
We say: **"The resultant force is zero"**.

Unbalanced Forces

If the forces acting on an object are **<u>not</u> equal in size**, the forces are said to be **u** _ _ _ _ _ _ _ _ _ _.

For example:

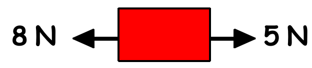


The forces **do not cancel out**.
We could replace the forces with **<u>one</u> force** (called a **resultant** force) which would have exactly the same affect on the object.

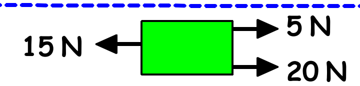
For the forces shown in the diagram above, we can say:
"The resultant force is __ N to the ________".

8) In each case, calculate the **size** of the **<u>resultant</u> force** and state any **direction**. Tick the correct box to show whether the forces acting on the object are **balanced** or **unbalanced**.

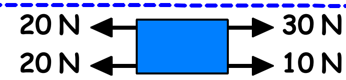
☐ balanced forces ☐ unbalanced forces



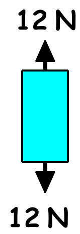
☐ balanced forces ☐ unbalanced forces



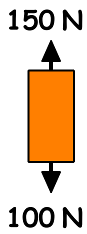
☐ balanced forces ☐ unbalanced forces



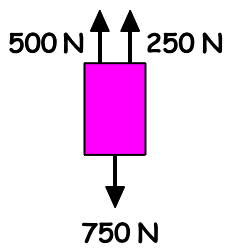
☐ balanced forces ☐ unbalanced forces



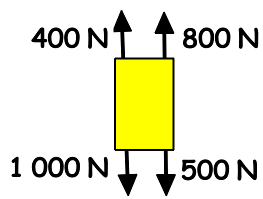
☐ balanced forces ☐ unbalanced forces



☐ balanced forces ☐ unbalanced forces



☐ balanced forces ☐ unbalanced forces



☐ balanced forces ☐ unbalanced forces

Newton's First Law of Motion

If the **forces** acting on an object are **balanced** (or **no forces act**), the object's **motion** remains the same.

The object either:

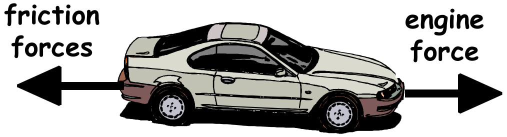
- remains **s** _ _ _ _ _ _ _ _ _ _ **or**
- continues to move at **c** _ _ _ _ _ _ _ **s** _ _ _ _ in a **s** _ _ _ _ _ _ _ **l** _ _ _.

If the forces acting on an object are **unbalanced**, the object:

- **a** _ _ _ _ _ _ _ _ _ _ _ in the direction of the **u** _ _ _ _ _ _ _ _ _ **f** _ _ _ _.

For example:

The diagram shows the forces acting on a car in the horizontal direction:



- The car is stationary at a set of traffic lights.

The horizontal forces acting on it are _______________.
The engine force and friction forces have the _________ size.

- As the traffic lights change to green, the car accelerates forwards.

The horizontal forces acting on it **are now** _________________.
The engine force is ___________ than the friction forces.

- After a few seconds, the car reaches a constant speed (known as its **t** _ _ _ _ _ _ _ speed).

The horizontal forces acting on it **are now** _____________ **again.**
(During these few seconds, the size of the friction forces ___________ until they are the _______ size as the engine force).

9) The diagram shows the horizontal forces acting on a motorbike during a race.

How does the size of these forces compare:

(a) Just before the start of the race when the motorbike is **not moving**? ____

____

(b) One second after the start of the race when the motorbike is **accelerating forwards**? ____

____

(c) A few seconds later when the motorbike has reached a **constant** (**terminal**) **speed**? ____

____

(d) Just after the finish of the race when the motorbike is **decelerating**? ____

____

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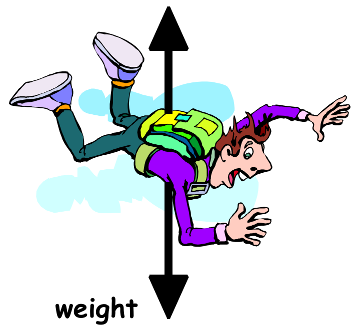
10) The vertical forces acting on a skydiver are shown in the diagram.



(a) As soon as the skydiver jumps from an aeroplane, he **accelerates downwards**. Explain why:

____

____

____

____

____

(b) After a few seconds, the skydiver reaches a **constant** (**terminal**) **speed**. Explain why:

____

____

____

____

Terminal Speed (or Velocity)

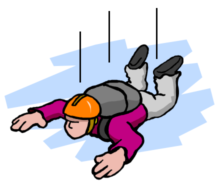
An object accelerates through a gas or a liquid when an **unbalanced force** acts on the object ..... Newton's First Law of Motion.

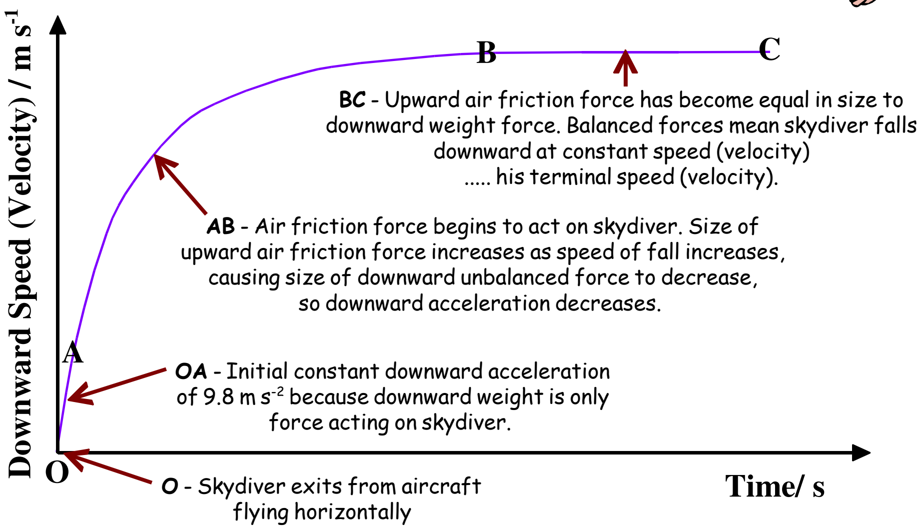
For a very short time at the start of the acceleration period, the **friction force** exerted by the gas/liquid on the object is negligible (zero)..... so the object's acceleration is **constant**.

As the speed of the accelerating object increases, the **friction force** exerted by the gas/liquid on the object increases in size ..... this means that the size of the **unbalanced force** acting on the object decreases, so the size of the object's acceleration **decreases**.

The **friction force** exerted by the gas/liquid on the object continues to increase until the **friction force** has the same size as the object's **driving force** (or **weight**, for a falling object) ..... the forces acting on the object are now **balanced**, so the object travels at a **constant speed** (or **velocity**) in a straight line - its **terminal speed** (or **velocity**).

The line graph below shows (and explains) how the downward speed (velocity) of a skydiver changes from the instant they exit from an aircraft flying horizontally [TIME = 0 s].



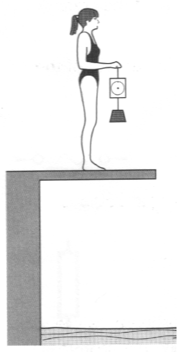


Free Fall and Weightlessness

Any object which is falling **"freely"** towards the Earth's surface is said to be in **"free fall"**.

Objects in **free fall** "***appear***" to be **weightless** - although they still have **weight** (since they are being acted upon by the earth's gravitational field.)

For example:



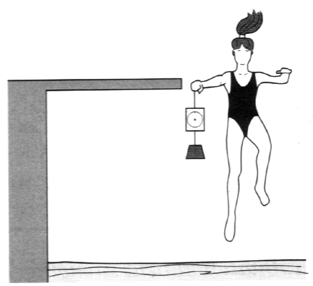
1) Kerry is standing still on a diving board.

In her right hand, she is holding a force meter with a 3 kg mass hanging from it.

Due to its **weight**, the mass exerts a downward force on the force meter.

11) Calculate the size of the **downward force** (**weight**) the mass exerts on the force meter.

2) Kerry jumps off the diving board, still holding the force meter with the 3 kg mass hanging from it.

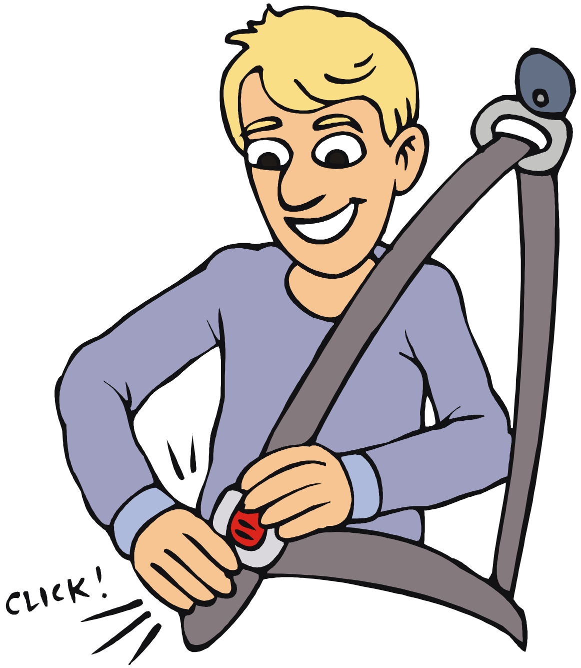


Both the **force meter** and the **3 kg mass** are now in **f _ _ _ f _ _ _** - they are both accelerating downwards towards the earth at the same rate of ____ **m s^{-2}**.

Because the **force meter** and the **3 kg mass** are falling at the same rate, the **mass** does not exert a **d _ _ _ _ _ _ _ f _ _ _ _** on the **force meter** - so the reading on the **force meter** is ___ **N**. (The **3 kg mass** "*appears*" to be **w _ _ _ _ _ _ _ _ _** as it falls "**freely**".

Seat Belts

Seat belts are a vital **safety feature** in road vehicles. Every year, thousands of people's lives are saved because, during a vehicle crash, they were wearing a **seat belt**.



12) Explain, in terms of **forces** (**Newton's First Law of Motion**), how a **seat belt** works:

____

____

____

____

____

____

____

____

____

____

Newton's Second Law of Motion

Acceleration is the change in an object's **speed** (or **velocity**) in **1 second**.

An object **accelerates** (or **decelerates**) when an **unbalanced force** acts on it.

> The **acceleration** of the object is directly proportional to the **size** of the **unbalanced force** acting on it and inversely proportional to the **mass** of the object.

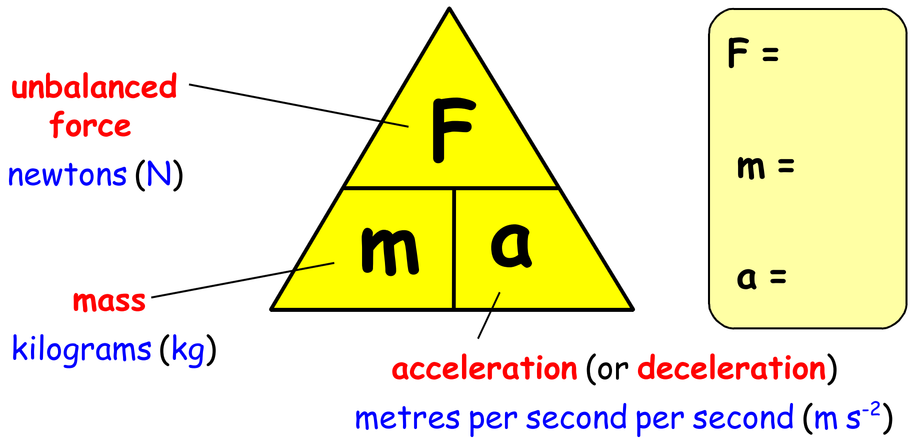
This means that:

- if you increase the size of the **unbalanced force** (but keep the mass the same), the **acceleration** ________________
- if you increase the **mass** of the object (but keep the unbalanced force the same), the **acceleration** ________________.

Acceleration, **unbalanced force** and **mass** are related by the formula:

unbalanced force = mass x acceleration

$$F = ma$$

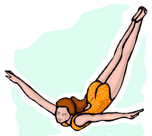


F =

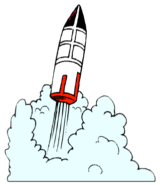
m =

a =

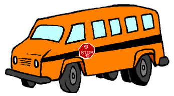
Basic F = ma Calculations



13) Daisy the diver has a mass of 50 kg. After jumping from a diving board, she accelerates downwards towards a swimming pool at 9.8 m s^{-2}. Calculate the size of the **unbalanced force** acting on Daisy.



14) Calculate the size of the **unbalanced force** acting on a rocket of mass 5 000 kg if it accelerates upwards from the ground at 0.8 m s^{-2}.



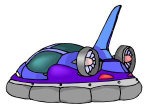
15) A minibus of mass 2 500 kg accelerates at 0.75 m s^{-2}. Calculate the size of the **unbalanced force** acting on the minibus.

16) A 10 000 kg truck accelerates at 0.2 m s^{-2}. Calculate the size of the **unbalanced force** acting on the truck.

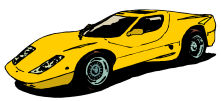
17) Sally the snow boarder accelerates at 0.5 m s^{-2} when an unbalanced force of 30 N acts on her. Calculate the combined **mass** of Sally and her snow board.

18) When an unbalanced force of 588 N acts on a skydiver, he accelerates towards the ground at 9.8 m s^{-2}. Calculate the **mass** of the skydiver and his equipment.

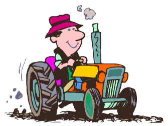
19) A speed skater accelerates at 1.5 m s^{-2} when an unbalanced force of 96 N acts on him. Calculate the **mass** of the speed skater.



20) A mini hovercraft accelerates at 1.6 m s^{-2} when an unbalanced force of 1 840 N acts on it. Calculate the **mass** of the hovercraft.

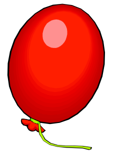


21) Calculate the **acceleration** of a car of mass 1 500 kg when it is acted upon by an unbalanced force of 4 500 N.



22) A tractor and its driver have a combined mass of 1 700 kg. An unbalanced force of 2 040 N drives the tractor forward. Calculate the tractor's **acceleration**.

23) An unbalanced force of 91 N acts on Simon and his skateboard which have a combined mass of 65 kg. Calculate the **acceleration** of Simon and his skateboard.



24) A balloon of mass 0.001 kg accelerates upwards when acted upon by an unbalanced force of 0.002 N. Calculate the **acceleration** of the balloon.

F = ma Calculations Where More Than One Force Is Acting

If more than one force is acting on an object, it is necessary to determine the size and direction of the unbalanced force acting on the object before its acceleration can be determined.

Example: The diagram shows the horizontal forces acting on a motorbike and rider:

Determine:

(a) The **size** and **direction** of the **unbalanced force** acting on the motorbike and rider.

(b) The **size** and **direction** of the motorbike and rider's **acceleration**.

ANSWER

(a) Unbalanced force = 1 500 N - 800 N

= 700 N to the left

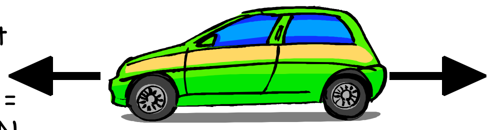
(b) $a = \frac{F}{m} = \frac{700}{250}$

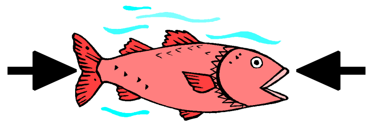
$= 2.8\ \mathrm{m\,s^{-2}}$ to the left

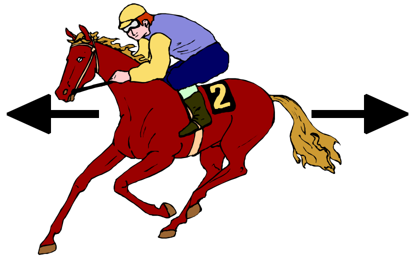
25) In each case, determine:

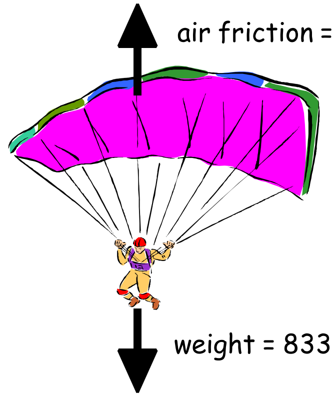
(a) the **size** and **direction** of the **unbalanced force** acting on the object;

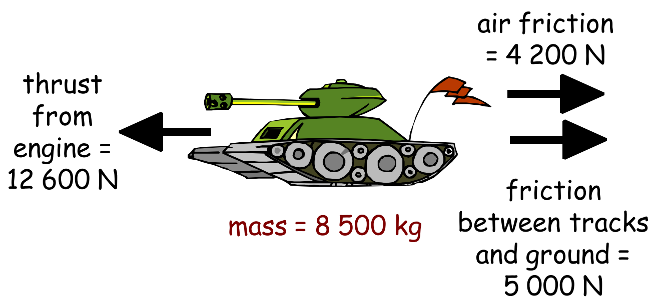
(b) the **size** and **direction** of the object's **acceleration**.

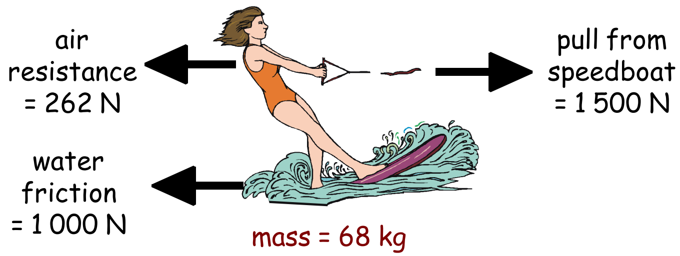


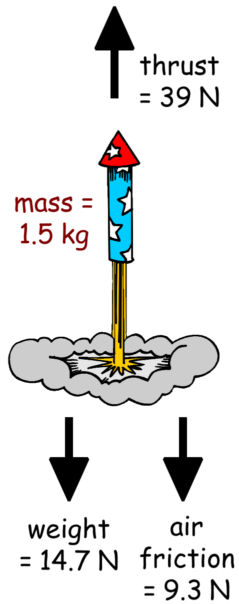


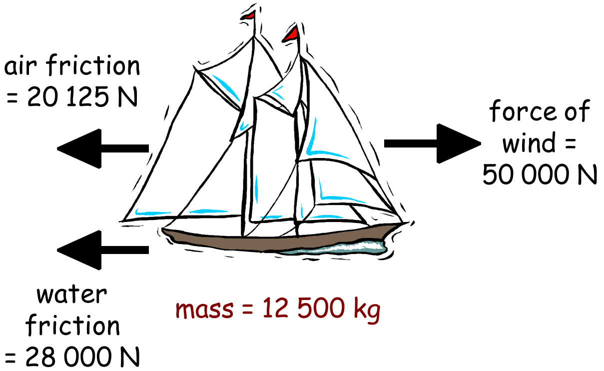


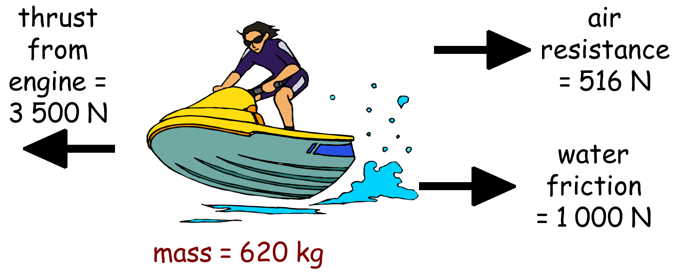


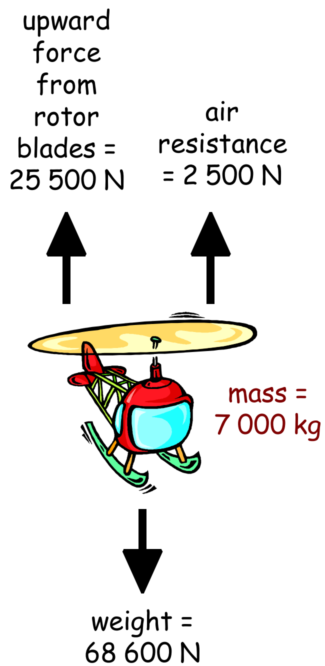

thrust from engine = 12 600 N
air friction = 4 200 N
friction between tracks and ground = 5 000 N
mass = 8 500 kg


air resistance = 262 N
water friction = 1 000 N
pull from speedboat = 1 500 N
mass = 68 kg

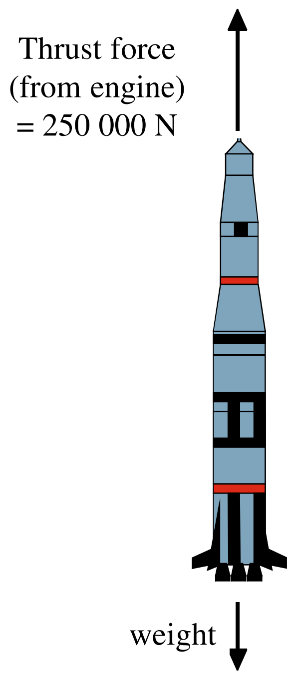

thrust = 39 N
mass = 1.5 kg
weight = 14.7 N
air friction = 9.3 N


air friction = 20 125 N
force of wind = 50 000 N
water friction = 28 000 N
mass = 12 500 kg


thrust from engine = 3 500 N
air resistance = 516 N
water friction = 1 000 N
mass = 620 kg


upward force from rotor blades = 25 500 N
air resistance = 2 500 N
mass = 7 000 kg
weight = 68 600 N

F = ma Calculations Involving Rocket Launch



Example: The diagram shows the vertical forces acting on a rocket of mass 10 000 kg as it is launched vertically from the earth's surface, where $g = 9.8\ \text{N kg}^{-1}$. (Air friction has been ignored).

Determine:

(a) The **weight** of the rocket.

(b) The **size** and **direction** of the **unbalanced force** acting on the rocket.

(c) The **size** and **direction** of the rocket's **acceleration**.

ANSWER

(a) $W = mg$

$= 10\,000 \times 9.8$

$= 98\,000\ \text{N}$

(b) Unbalanced force = 250 000 N - 98 000 N

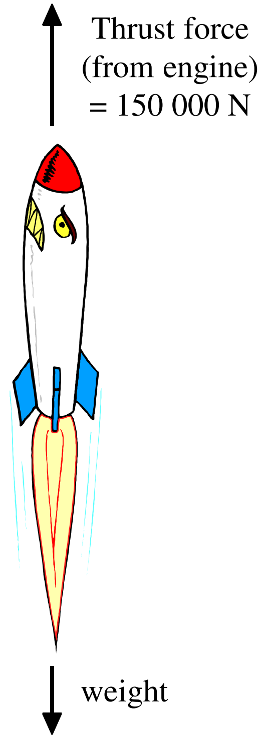
= 152 000 N upwards

(c) $a = \dfrac{F}{m}$

$= \dfrac{152\,000}{10\,000}$

$= 15.2\ \text{m s}^{-2}$ upwards

26) The diagram shows the vertical forces acting on a rocket of mass 12 000 kg as it is launched vertically from the earth's surface, where $g = 9.8\ \text{N kg}^{-1}$. (Air friction has been ignored).



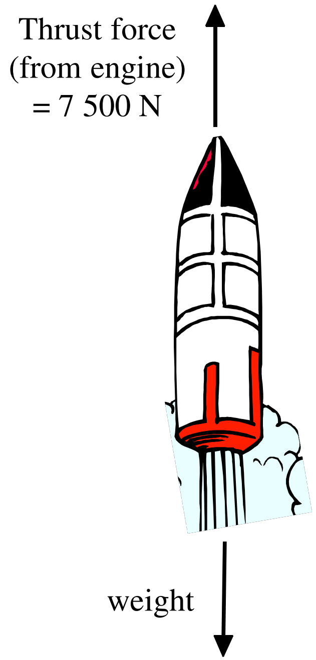
Determine:

(a) The **weight** of the rocket.

(b) The size and direction of the **unbalanced force** acting on the rocket as it is launched.

(c) The size and direction of the rocket's **acceleration** as it is launched.

F = ma Calculations Involving Rocket Landing



Example: The diagram shows the vertical forces acting on a rocket of mass 5 000 kg as it lands vertically on the moon's surface, where g = 1.6 N kg^{-1}.
(Assume there is no air friction on the moon).

Determine:

(a) The **weight** of the rocket.

(b) The **size** and **direction** of the **unbalanced force** acting on the rocket.

(c) The **size** and **direction** of the rocket's **acceleration**.

ANSWER

(a) W = mg
= 5 000 × 1.6
= 8 000 N

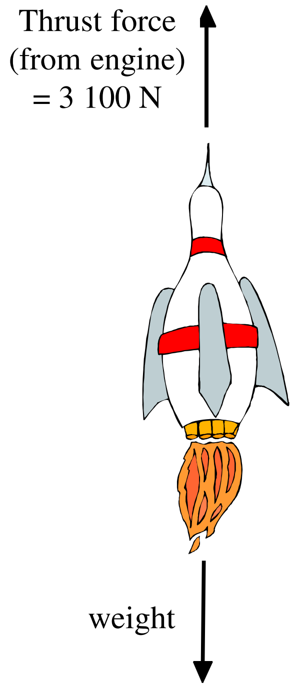
(b) Unbalanced force = 8 000 N - 7 500 N
= 500 N downwards

(c) $a = \frac{F}{m}$

$= \frac{500}{5\,000}$

= 0.1 m s^{-2} downwards

27) The diagram shows the vertical forces acting on a rocket of mass 2 000 kg as it lands vertically on the moon's surface, where g = 1.6 N kg^{-1}.
(Assume there is no air friction on the moon).



Determine:

(a) The **weight** of the rocket.

(b) The size and direction of the **unbalanced force** acting on the rocket as it is landing.

(c) The size and direction of the rocket's **acceleration** as it is landing.

NOTE

For a rocket/spacecraft to land with minimum impact, at a constant speed, the upward thrust force from the engine should be equal in size to the downward weight + air friction forces.

[BALANCED FORCES ⟷ CONSTANT SPEED]

Space Travel - Forces in Outer Space and Motion

Large parts of outer space are a **vacuum**
- there are no air (or other) particles present.

Therefore, when a spacecraft travels through outer space, there is no **air friction** acting on it ..... if its engine is switched **off**, **no forces** will be acting on it.

This means the spacecraft will travel at
c _ _ _ _ _ _ _ _ **speed** in a **s** _ _ _ _ _ _ _ _ **line**.

If the spacecraft engine is switched **on**, this will create an **u** _ _ _ _ _ _ _ _ _ _ **force**, so the spacecraft will **a** _ _ _ _ _ _ _ _ _ _ in the direction of the **u** _ _ _ _ _ _ _ _ _ _ **force**.

28) A spacecraft is travelling through outer space.
Its engine is switched **off**.

(a) Describe and explain the motion of the spacecraft:

____

____

(b) The spacecraft's engine is now switched **on**.
Describe and explain the spacecraft's motion:

____

____

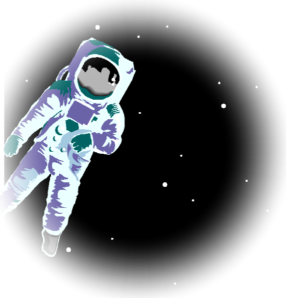
29) An astronaut is travelling at constant speed through outer space towards her space capsule.

(a) Describe the forces acting on her:

____

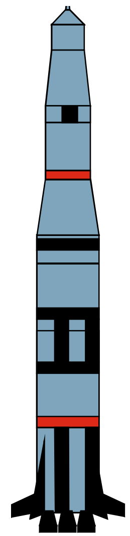
(b) The space capsule is accelerating towards the astronaut.

Describe the forces acting on it: ________________



30) A rocket is launched vertically upwards from the earth's surface. During launch, three forces act on the rocket: its **weight**, the **thrust force** from its engine and **air friction**. .

(a) Show the **direction** of each of these forces on the diagram, using arrows.
Label each force.



(b) At the instant the rocket is launched, it **accelerates upwards**.

Explain why, in terms of the **forces** acting on the rocket.

____

____

____

____

(c) As the rocket travels into outer space, its acceleration increases.

Suggest **one** reason why:

____

____

____

(d) Once the rocket reaches outer space, its engine is switched off.

(i) The forces acting on the rocket become **zero**. Explain why:

____

____

____

(ii) Describe the motion of the rocket in outer space:

____

____

____

Notes

Newton's Third Law (Newton Pairs)

Forces occur in pairs - Newton pairs - the "action" and the "reaction".
If object A exerts a force on object B, then object B exerts an equal force in the opposite direction on object A.

PUPILS OFTEN CONFUSE BALANCED/UNBALANCED FORCES WITH NEWTON PAIRS.

YOU MUST LEARN THAT:

- **BALANCED/UNBALANCED FORCES ACT ON THE S _ _ _ OBJECT.**
- **NEWTON PAIRS ACT ON D _ _ _ _ _ _ _ _ _ OBJECTS.**

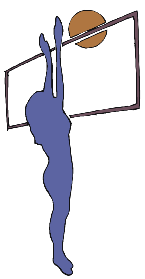
31) Six **NEWTON PAIRS** are shown in the diagrams below.
Complete each diagram to identify the "action" and "reaction" forces:

ACTION
Force of brush on floor.
REACTION
____
____
____

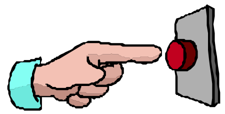
ACTION
Force of goalkeeper gloves on football.
REACTION
____
____
____

ACTION
Force of drumstick on drum.
REACTION
____
____
____

ACTION
____
____
____
REACTION
Force of football on boot.



ACTION
____
____
____
REACTION
Force of volleyball on hand.



ACTION
____
____
____
REACTION
Force of button on finger.

Rocket Propulsion

Rocket propulsion can be explained in terms of "Newton pairs":

The **rocket engine** produces **exhaust gases**.

The **rocket engine** pushes the **exhaust gases** (the "propellant") **b** _ _ _ _ _ _ _ _ _
- this is the **a** _ _ _ _ _ _ **force**.

At the same time, the **exhaust gases** push the **rocket engine** (and therefore the rocket) **f** _ _ _ _ _ _ _ _
- this is the **r** _ _ _ _ _ _ _ _ **force**.

32) Complete the diagram below to show the "action" and "reaction" forces:

ACTION

R _ _ _ _ _ _ **e** _ _ _ _ _ _
pushes
e _ _ _ _ _ _ _ **g** _ _ _ _
b _ _ _ _ _ _ _ _ _ _.

REACTION

E _ _ _ _ _ _ _ **g** _ _ _ _
push
r _ _ _ _ _ _ **e** _ _ _ _ _ _
f _ _ _ _ _ _ _ _ .

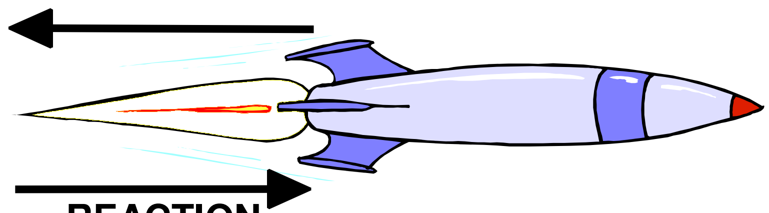
33) Complete the diagram by describing the "action" and "reaction" forces causing the rocket to be propelled forward:

ACTION

____

____

____



REACTION

____

____

____

34) On his back, an astronaut wears a 'jet pack'. This contains a small rocket engine which, when fired, emits exhaust gases away from the astronaut's back.

Label the diagram with "arrows" and "words" to explain how the 'jet pack' can propel the astronaut forwards through space.

Notes