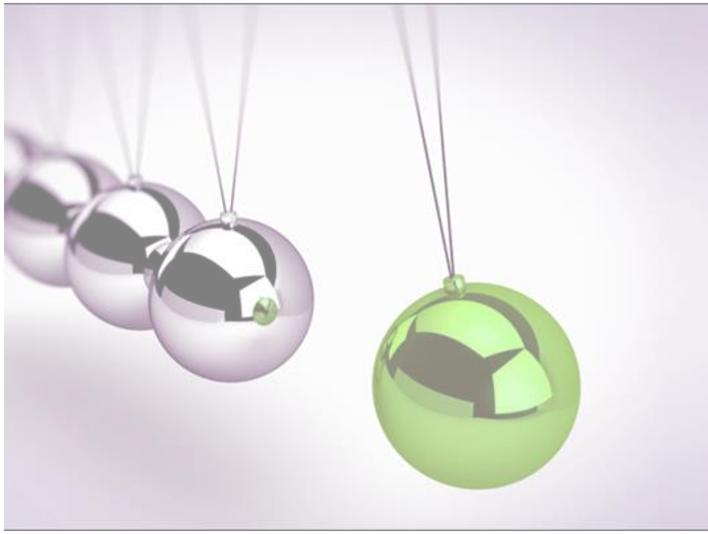
Mechanics

2015 EdExcel A Level Physics
Topic 2

Force and Motion



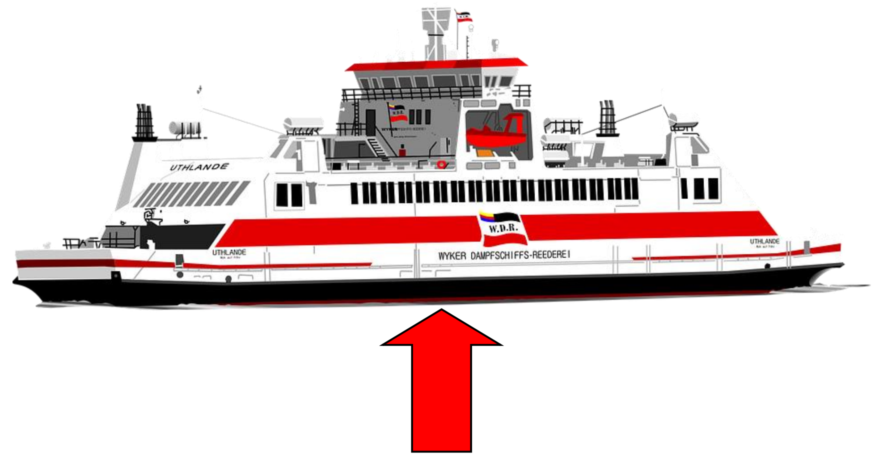
Force and Motion

25/10/2017

Introduction to Forces

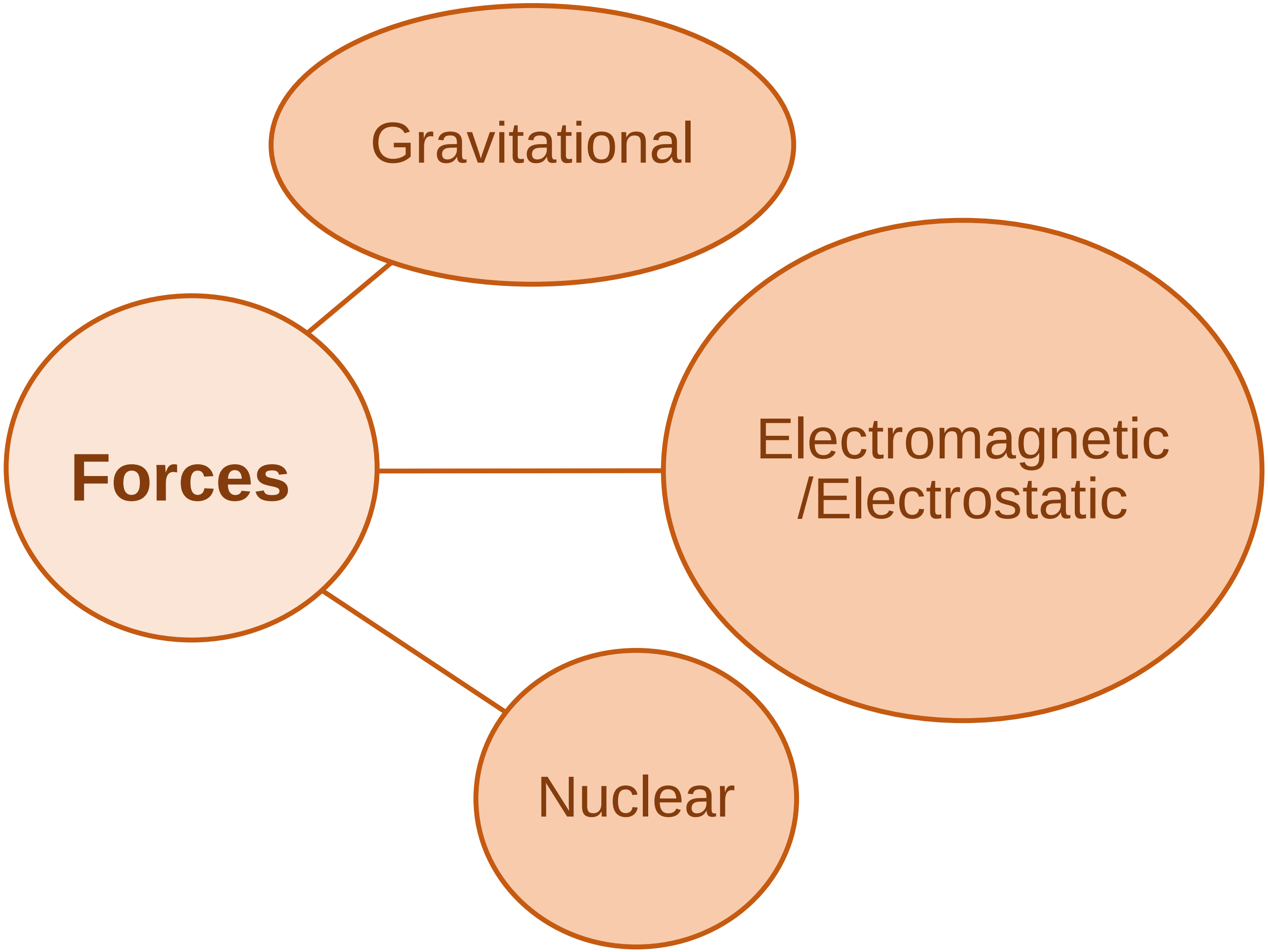
A force is the effect that may produce a change in the motion state, the size, or the shape of a body.Some common examples:

Friction – *a contact force that acts against anything moving*



Upthrust – *keeps things afloat*

Types of Forces



Revision questions

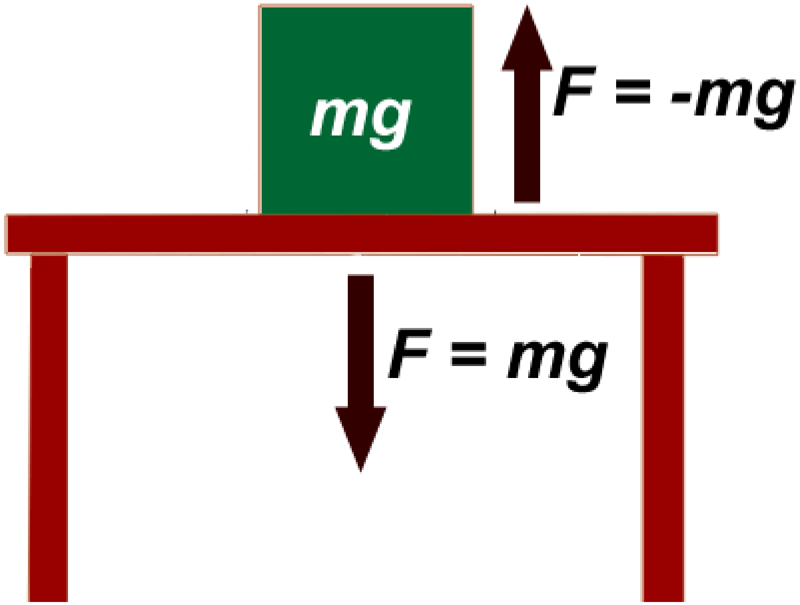
1) A force of 1000N is applied to push a mass of 500kg. How quickly does it accelerate?
2) A force of 3000N acts on a car to make it accelerate by $1.5ms^{-2}$. How heavy is the car?
3) A car accelerates at a rate of $5ms^{-2}$. If it weighs 500kg how much driving force is the engine applying?
4) A force of 10N is applied by a boy while lifting a 20kg mass. How much does it accelerate by?

Newton’s First Law

“The Law of Inertia”

An object at rest tends to remain at rest, and an object in motion tends to remain in motion at constant velocity (with the same speed and in the same direction) unless acted upon by a net force.

Objects at Rest



An object remains at rest because the forces acting on it are balanced; not because there are NO forces acting upon it

The downward force (mg) of gravity is balanced by an upward force of the table (-mg).

A c c e l e r a t i o n

Acceleration is the rate of change in velocity:

- A change in speed (magnitude)
- A change in direction
- A change in both magnitude (speed) and direction

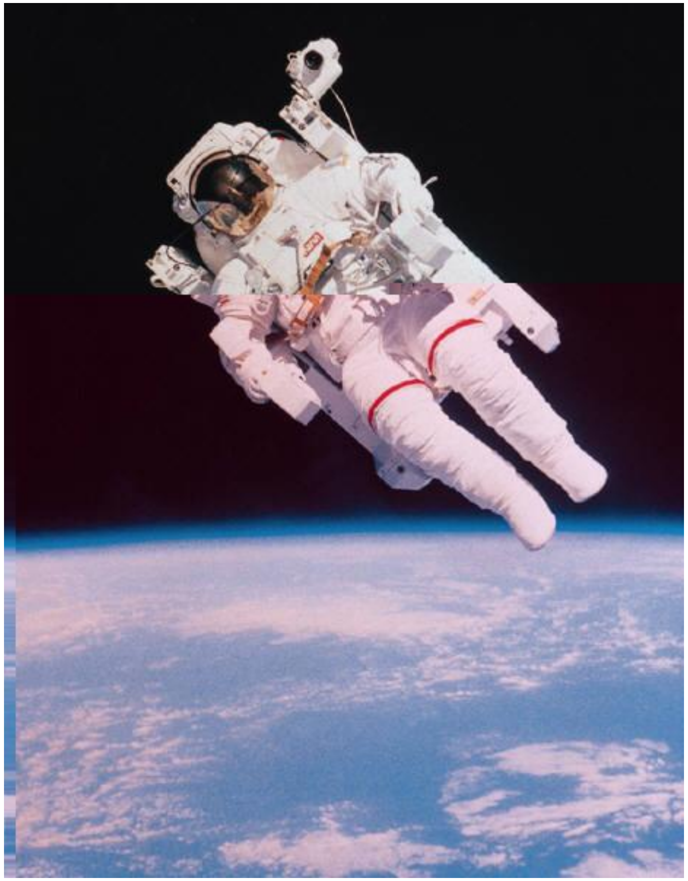
Newton's First Law - Restated

The velocity of an object remains unchanged unless acted upon by a net force.

or….

An object will experience acceleration if acted upon by a net force.

Inertia Example 1

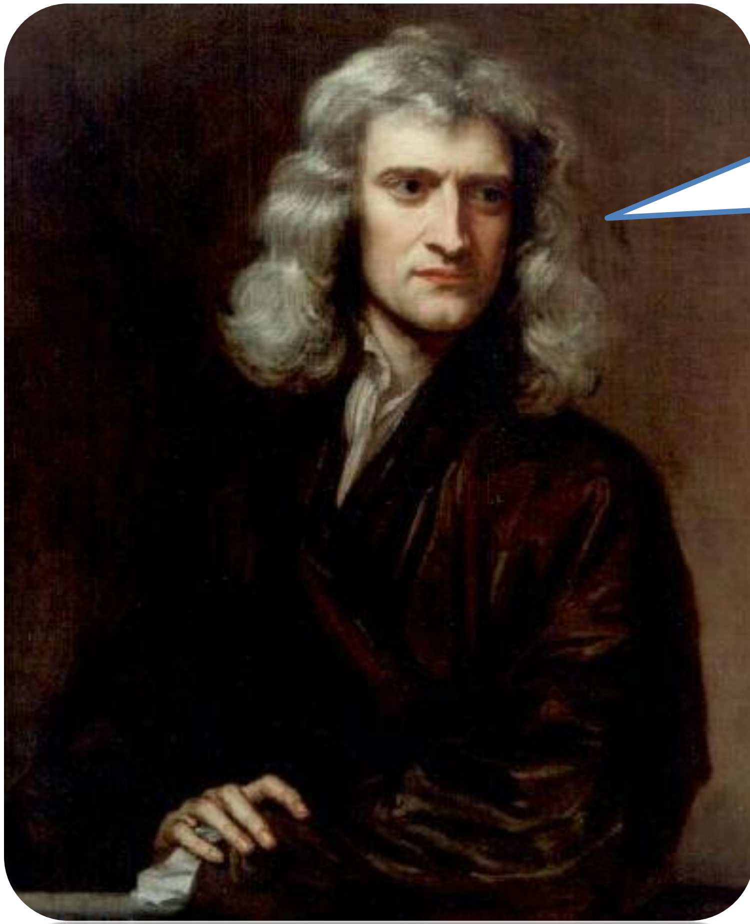


An astronaut in outer space will continue drifting in the same direction at the same speed indefinitely until acted upon by an outside force

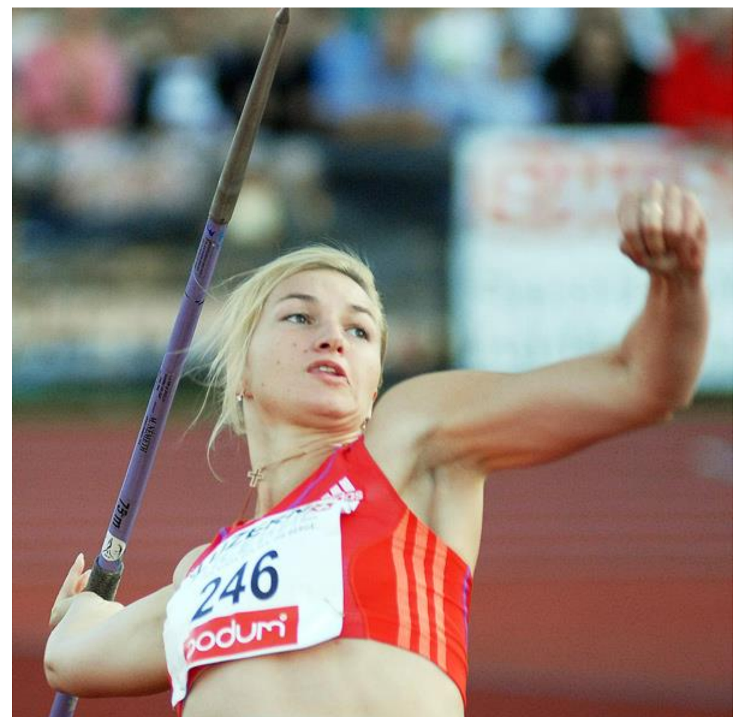
Inertia Example 2

If you're driving at 100 Kmph and have an accident, your car may come to a stop in an instant, while your body is still moving at 100 Kmph. Without a seatbelt, your inertia could carry you through the windshield.

Newton’s Second Law



$$F = m \times a$$



The Second Law of Motion

Force equals mass times acceleration (F_{net} = ma): The net force on an object is equal to the mass of the object multiplied by its acceleration."

Units of Force

m = mass = kilogram (kg)

a = acceleration = m/s^2

F_{net} = force = ma = $\frac{kg \cdot m}{s^{-2}}$

= Newton (N)

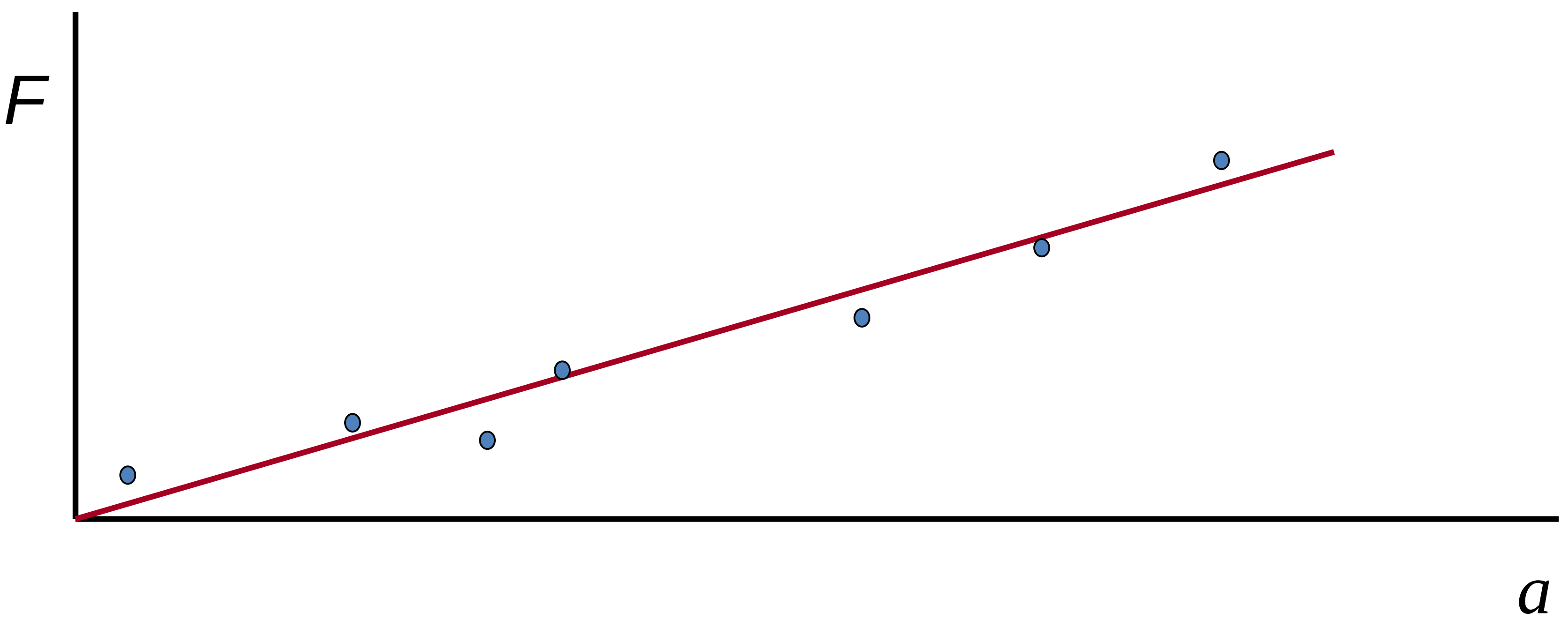
{F_{net}} is sometimes written as {ΣF}

Newton's 2nd Law: $\boldsymbol{F}_{net} = m\,\boldsymbol{a}$

- The acceleration of an object is directly proportion to the net force acting on it
- For a given mass, if F_{net} doubles, triples, etc., so does <u>a</u>.
- The acceleration of an object is inversely proportion to its mass($a = F_{net}/m$).
- For a given $\boldsymbol{F}_{net}$, if <u>m</u> doubles, <u>***a***</u> is cut in half.
- $\boldsymbol{F}_{net}$ and ***a*** are vectors; m is a scalar.
- $\boldsymbol{F}_{net}$ and ***a*** always point in the same direction.
- The 1st law is really a special case of the 2nd law (if net force is zero, so is acceleration).

Graph of $\mathbf{F}_{net}$ vs. a

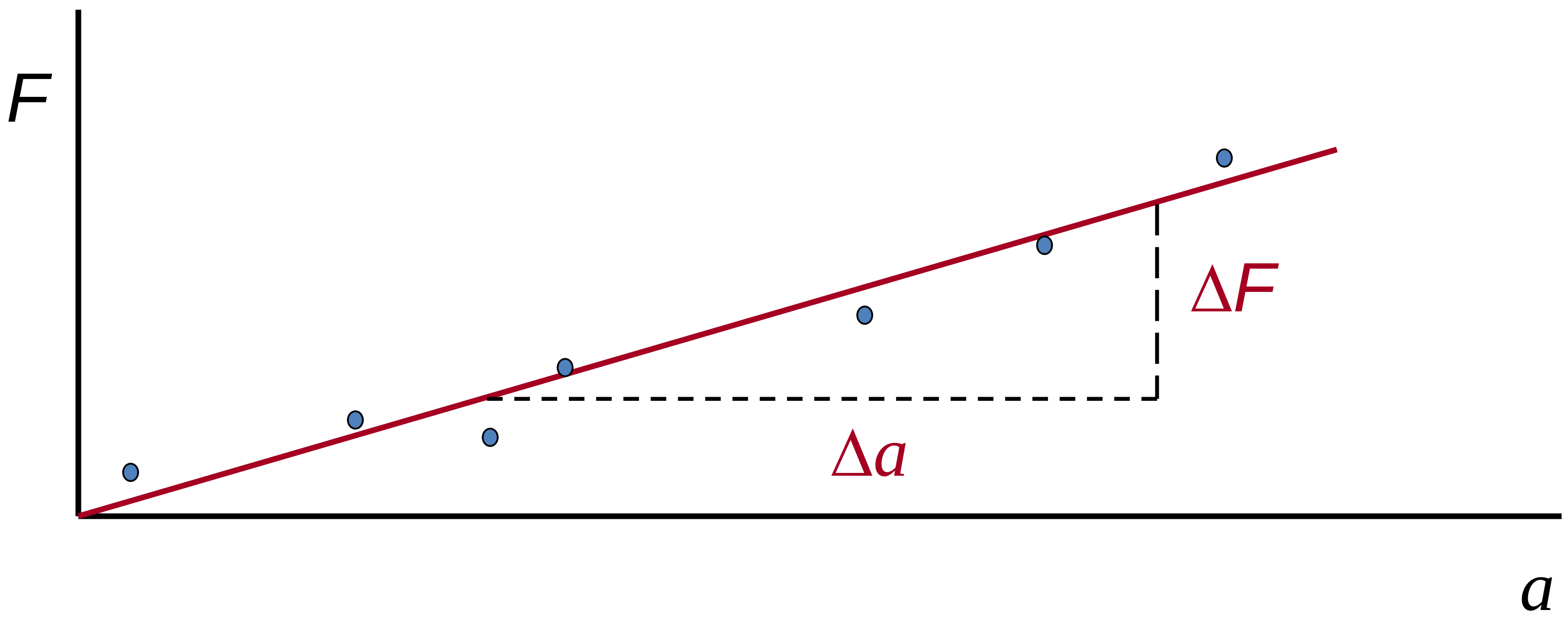
In the lab various known forces are applied—one at a time, to the same mass—and the corresponding accelerations are measured. The data are plotted. Since $\mathbf{F}_{net}$ and a are directly proportional, the relationship is linear.



Mass = Slope

Since gradient = ΔF / Δa, the gradient is equal to the mass.

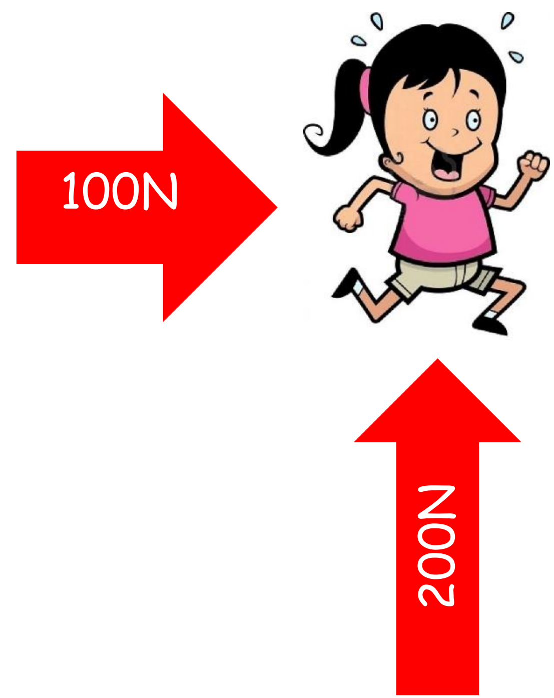
so [m = ΔF / Δa]



F=m x a questions

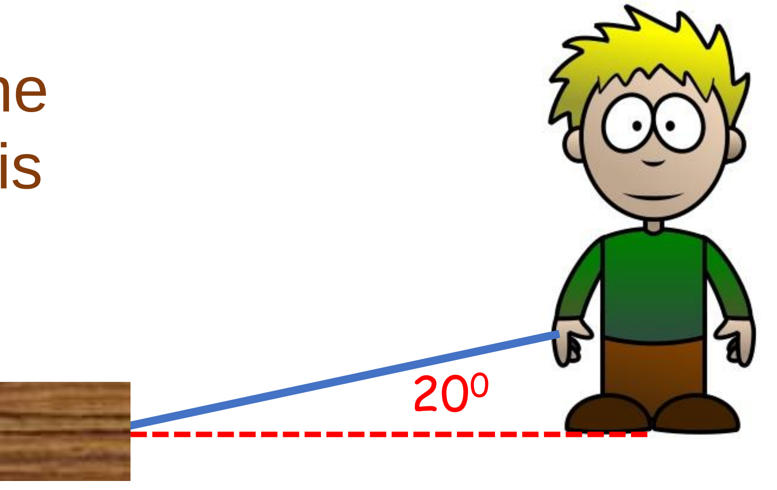
1. This car has a mass of 1500kg. The engine exerts a driving force of 6000N and a frictional force of 3000N acts against it. What is its acceleration?

2. This body has a mass of 60kg and is acted on by the forces shown. What will its acceleration be and at which angle (to the vertical)?



Resolving Force Vectors

This guy is dragging a 2kg box along the ground with a force of 23N. The block is stuck in a groove and can't move upwards. If the block accelerates from rest to $2ms^{-1}$ in 5s calculate:



1) The block's acceleration

2) The size of the resultant force on the block

3) The size of the frictional force on the block

Weight vs. Mass

Earth's Gravitational Field Strength is 9.81 Nkg^{-1}. In other words, a 1kg mass is pulled downwards by a force of 9.81N.

Weight = Mass x Gravitational Field Strength

(in N) *(in kg)* *(in Nkg^{-1})*

1) What is the weight on Earth of a book with mass 2kg?
2) What is the weight on Earth of an apple with mass 100g?
3) Matt weighs 700N on the Earth. What is his mass?
4) On the moon the gravitational field strength is 1.6Nkg^{-1}. What will Matt weigh if he stands on the moon?

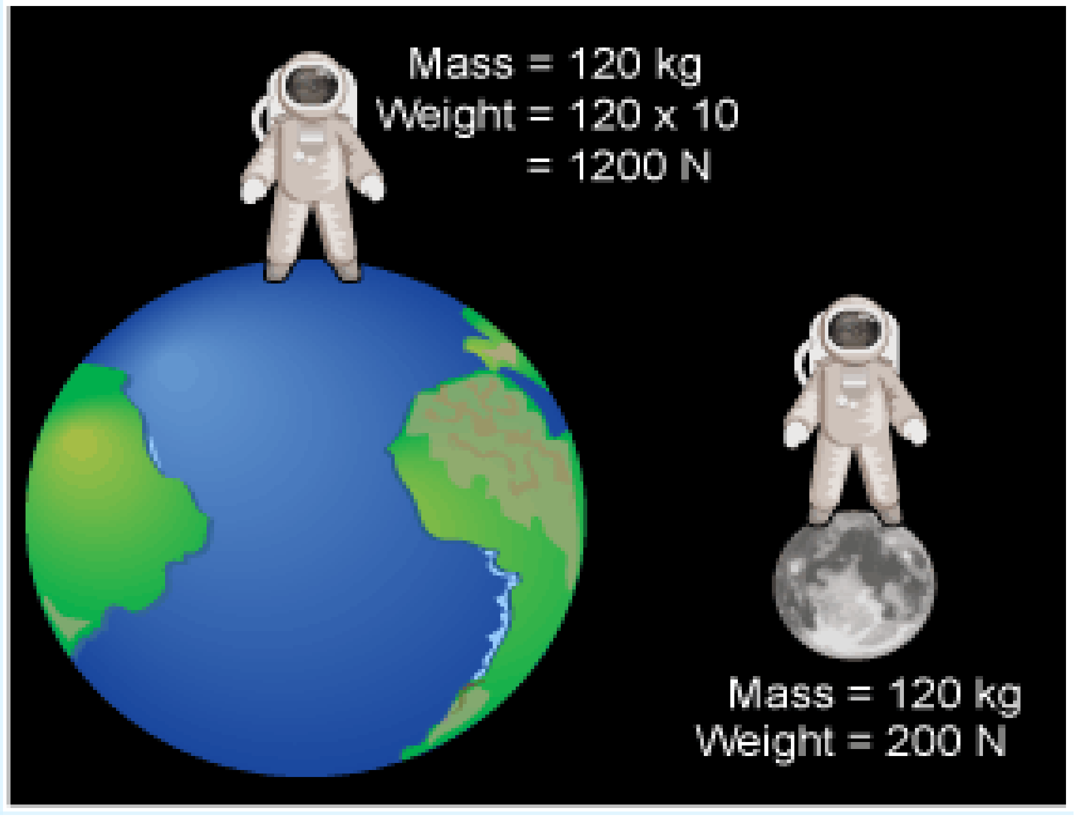
Mass and Weight

- Mass measures the amount of matter in an object, it's a scalar quantity.

- Weight is the force of gravity on a body, it's a vector quantity, it points toward the centre of Earth.

Weight = mass × acceleration due to gravity (this follows directly from *F* = *m a*).

Mass and Weight (cont.)



On the moon, your mass would be the same, but your weight would be less, this is because the gravity of the moon is less than the gravity of Earth.

$g_{moon} \approx 1/6\ g_{earth} \approx 1.6\ m/s^2$

→ W(on moon) ≈ 1/6 W(on earth)

Gravitational Fields

Recall the equation:

Weight = mass x gravitational field strength W = mg

This equation related mass to weight. Mass is a scalar quantity but weight, being a force, is a vector.

Notice that g has two names and units:

The gravitational field strength g = 9.81 Nkg^{-1}

The acceleration due to gravity g = 9.81 ms^{-2}

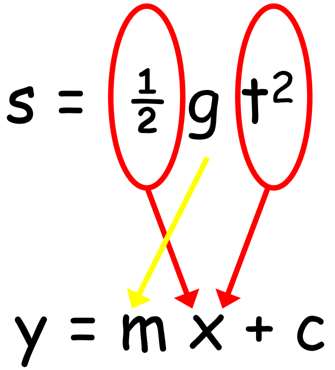
Core Practical - Measuring g

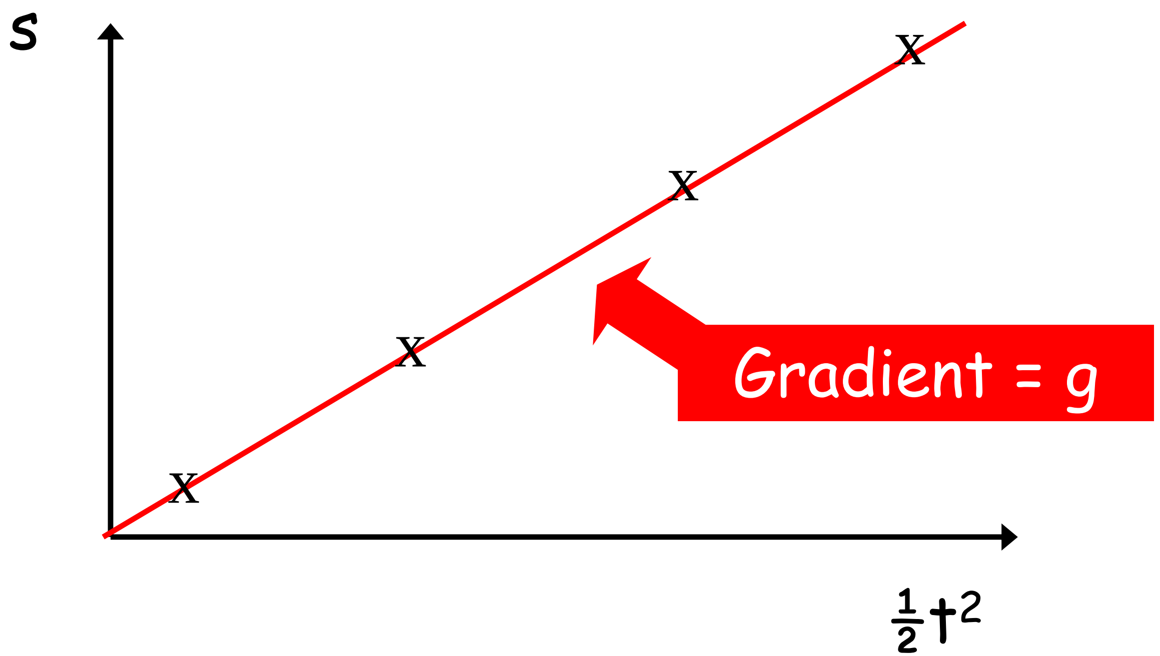
Consider the equation $s = ut + \frac{1}{2}at^2$…

If we consider a ball being dropped then u=0, so $s = \frac{1}{2}at^2$

We also know that a = g, therefore…

$$s = \frac{1}{2}gt^2$$

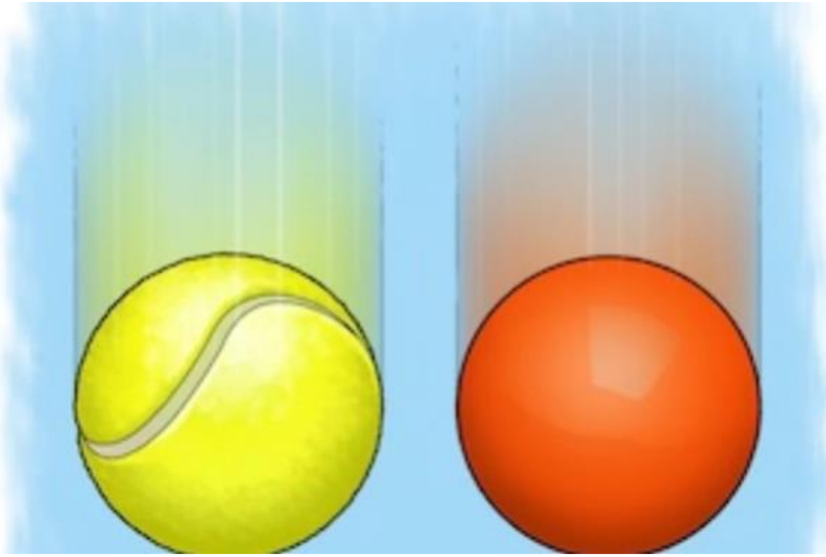




Acceleration due to Gravity

When objects fall through the air on Earth they will:

- Accelerate at a constant rate initially a=g
- Acceleration decreases as drag builds up a<g
- Eventually a constant speed it reached (terminal velocity) a=0

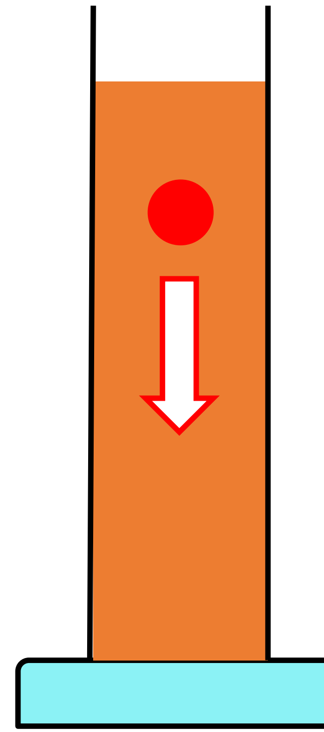


Terminal Velocity

Consider a ball falling through a liquid:

Some questions to consider:

1) What forces are acting on the ball?
2) How do those forces change when the ball gets faster?
3) Will the ball keep getting faster? Explain your answer in terms of forces



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Terminal Velocity

Consider a skydiver:

1) At the start of his jump the air resistance is ________ so he ________ downwards.

2) As his speed increases his air resistance will ________

3) Eventually the air resistance will be big enough to ________ the skydiver's weight. At this point the forces are balanced so his speed becomes _________ - this is called TERMINAL VELOCITY

Words – increase, small, constant, balance, accelerates

Terminal Velocity

Consider a skydiver:

1) At the start of his jump the air resistance is small so he accelerates downwards.

2) As his speed increases his air resistance will increase

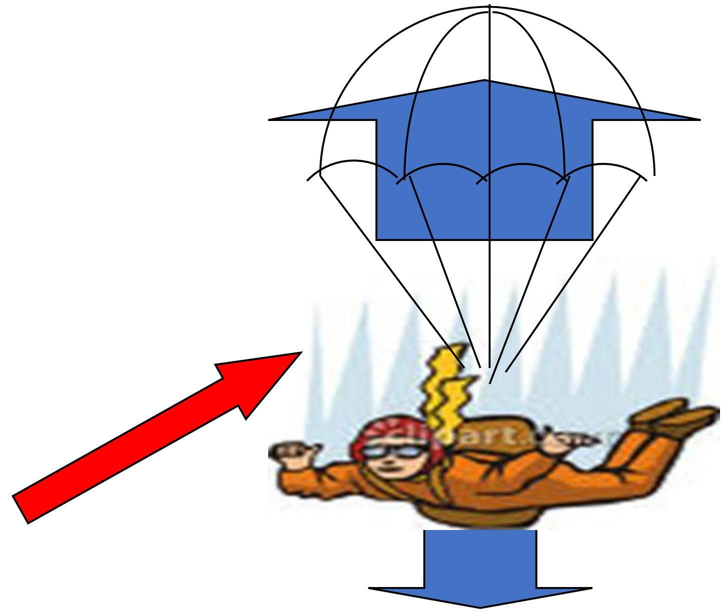
3) Eventually the air resistance will be big enough to balance the skydiver's weight. At this point the forces are balanced so his speed becomes constant - this is called TERMINAL VELOCITY

Words – increase, small, constant, balance, accelerates

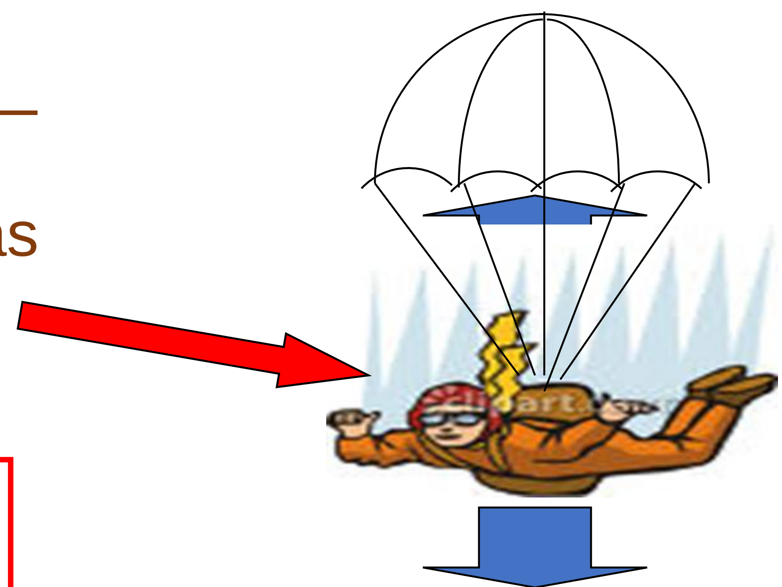
Terminal Velocity

Consider a skydiver:

4) When he opens his parachute the air resistance suddenly ________, causing him to start _____ ____.



5) Because he is slowing down his air resistance will _______ again until it balances his _________. The skydiver has now reached a new, lower ________ _______.

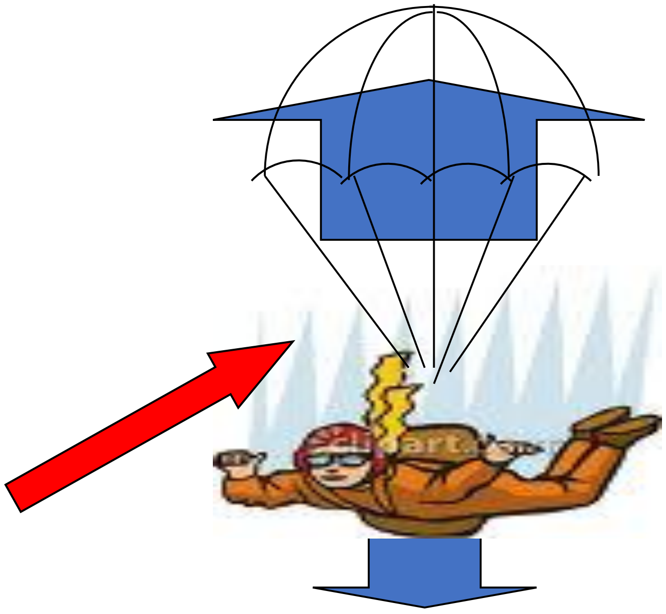


Words – slowing down, decrease, increases, terminal velocity, weight

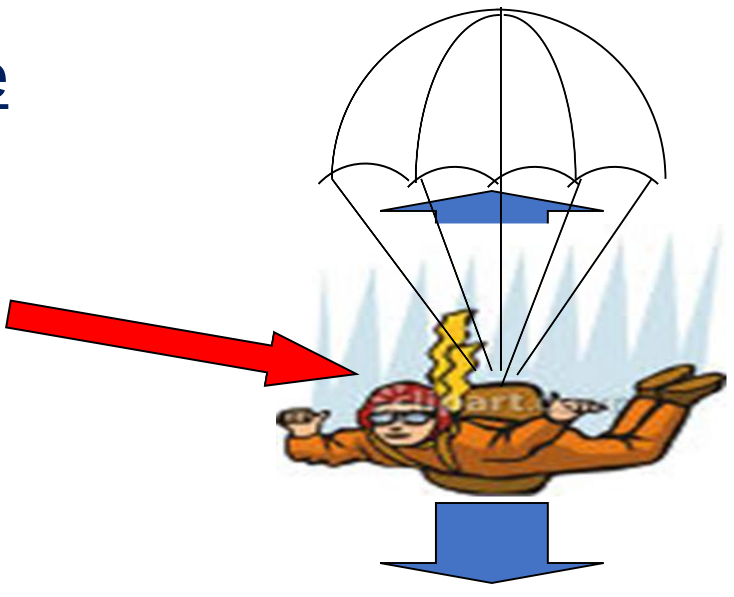
Terminal Velocity

Consider a skydiver:

4) When he opens his parachute the air resistance suddenly increases, causing him to start slowing down.



5) Because he is slowing down his air resistance will decrease again until it balances his weight. The skydiver has now reached a new, lower terminal velocity.



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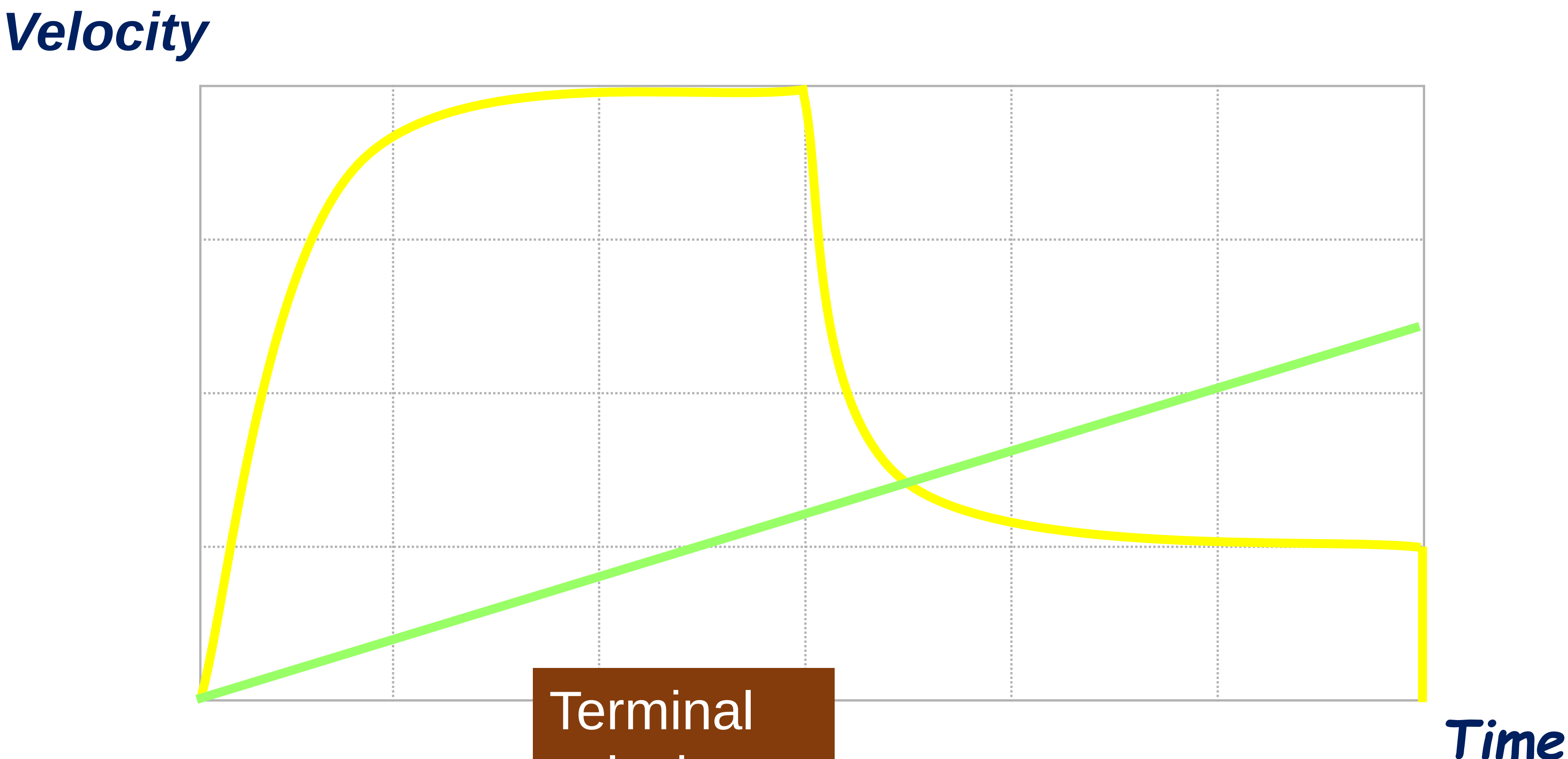
Labelling a Velocity-time graph



Terminal velocity reached…

On the Moon

Parachute opens – diver slows down

Speed increases…

New, lower terminal velocity reached

Diver hits the ground

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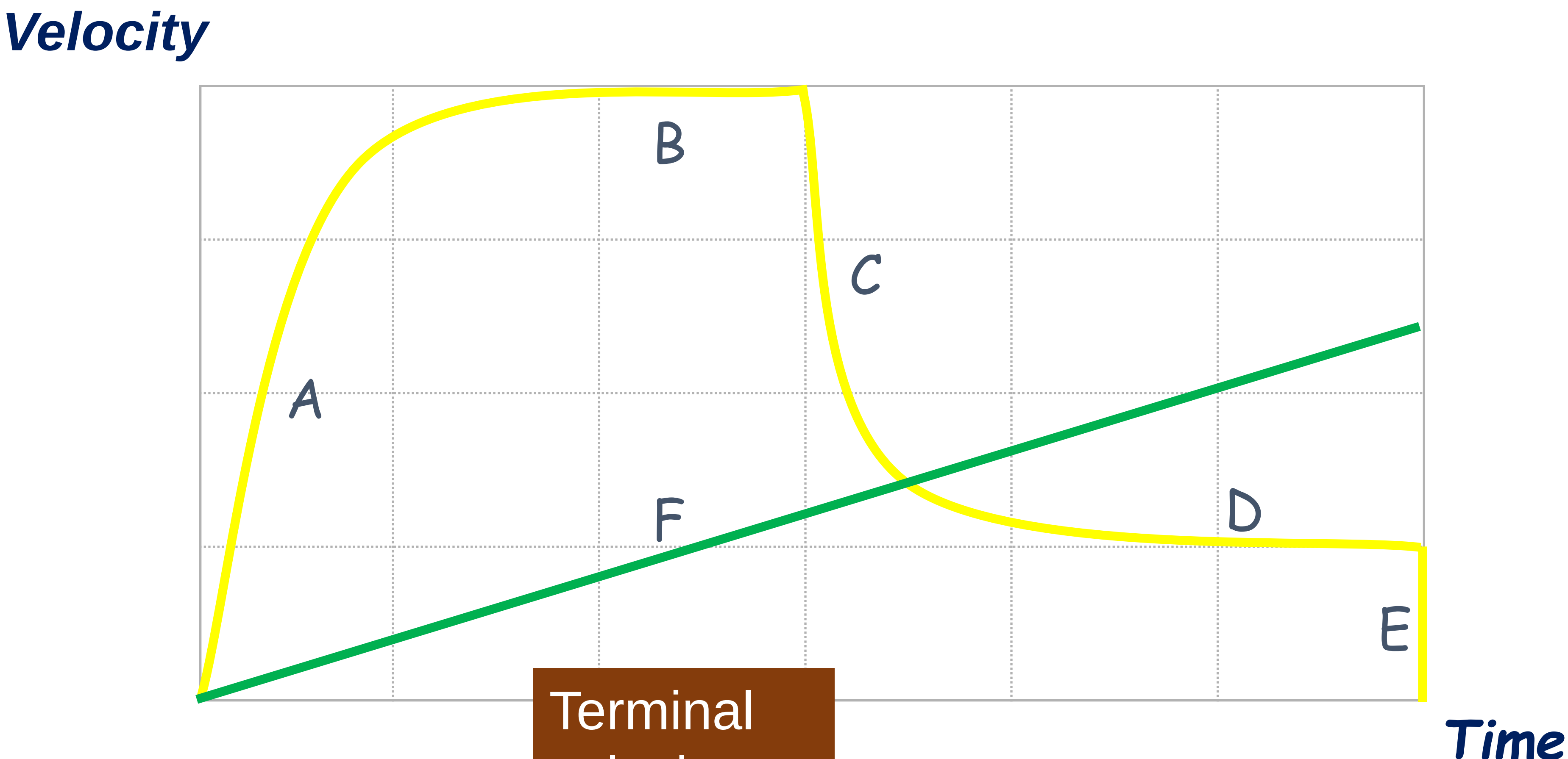
Labelling a Velocity-time graph for a skydiver



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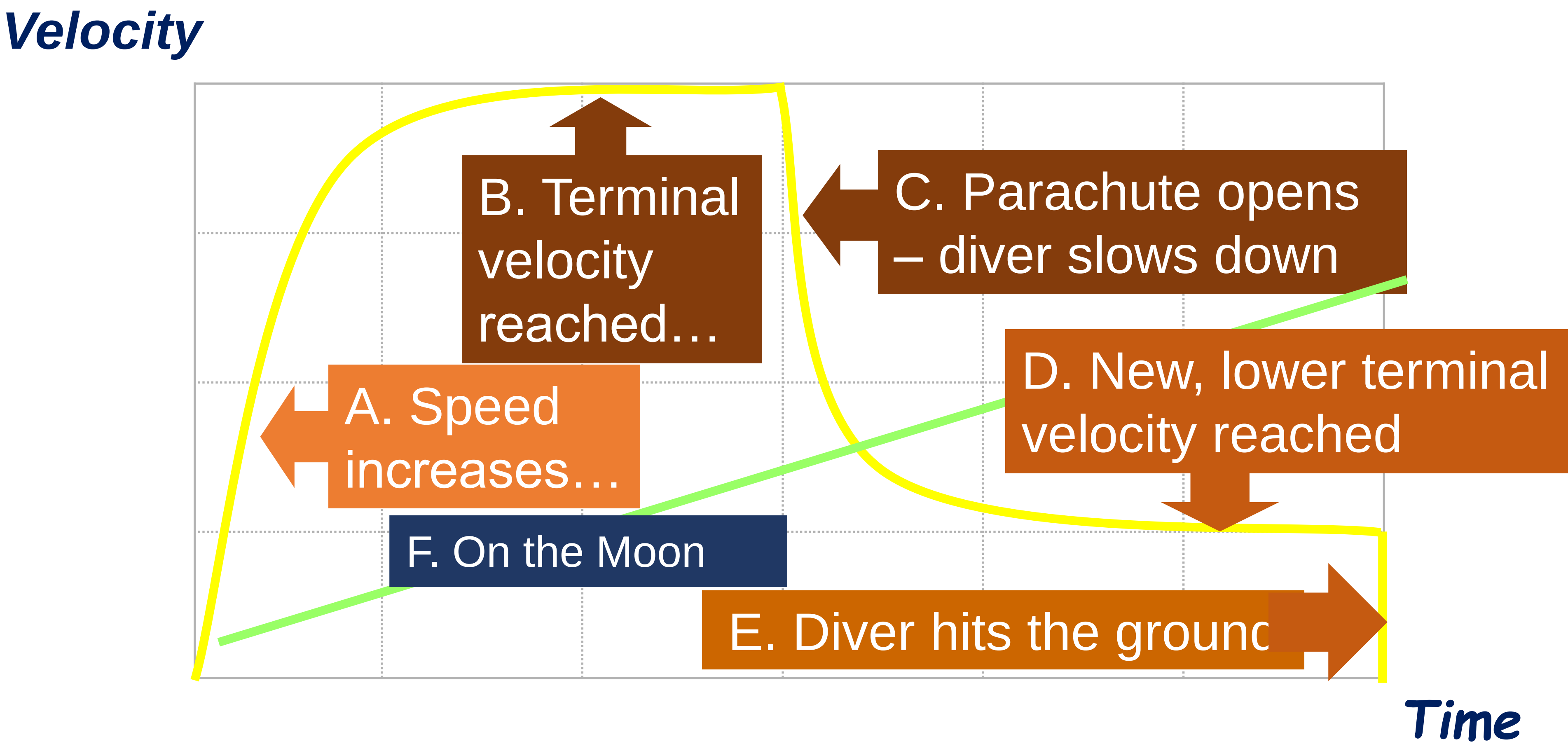
Labelling a Velocity-time graph



Forces & Motion

To solve motion problems involving forces:

1. Find the net force (by combining vectors).
2. Calculate acceleration (using: $\mathbf{F_{net} = m \times a}$).
3. Use equations of motion:

$a = (v - u)/t$ or

$v = u + a t$

$s = ut + \frac{1}{2} a t2$

$V^2 = u^2 + 2 a s$

$s = \frac{1}{2} (v2 + v1) t$

(t = time of motion)

(v = final velocity)

(u= initial velocity)

(s = displacement travelled by object)

(a = acceleration)

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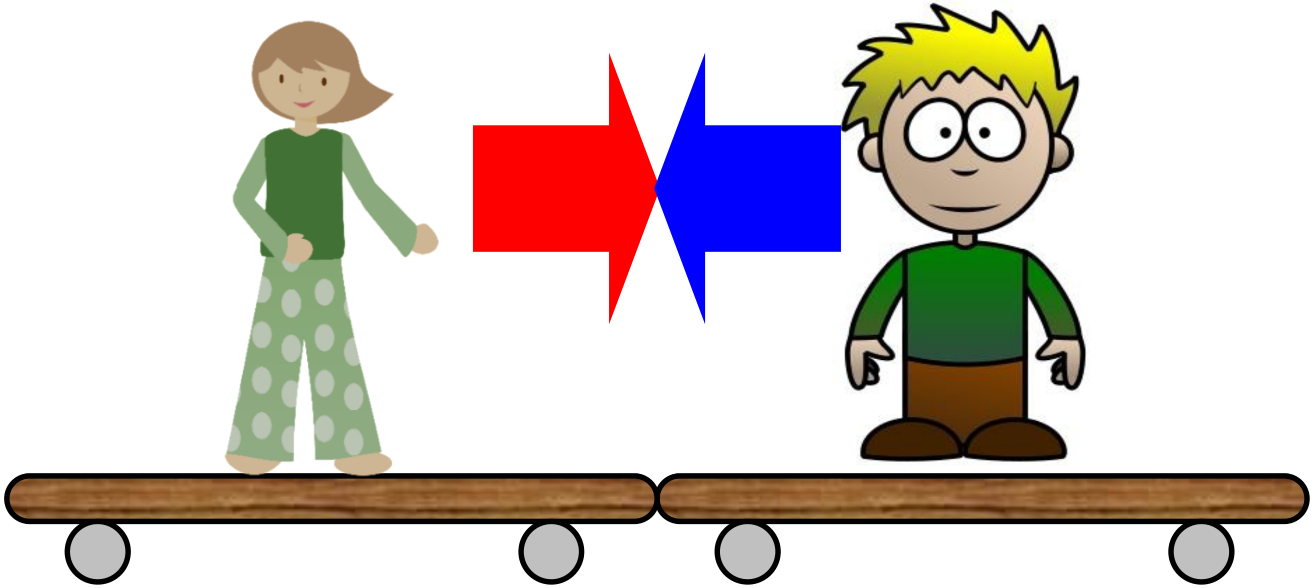
Newton's 3rd Law of Motion

When body A exerts a force on body B, body B exerts an equal and opposite force on body A.

My third law predicts that when the girl pushes to the right, she will move to the left as well



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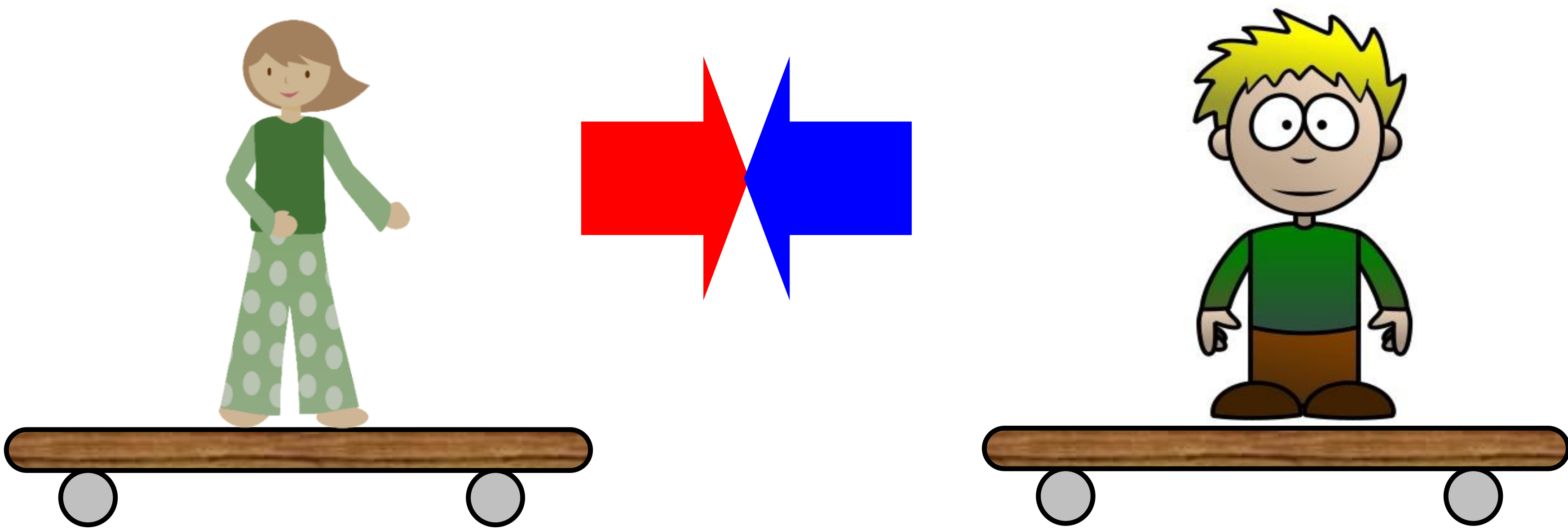
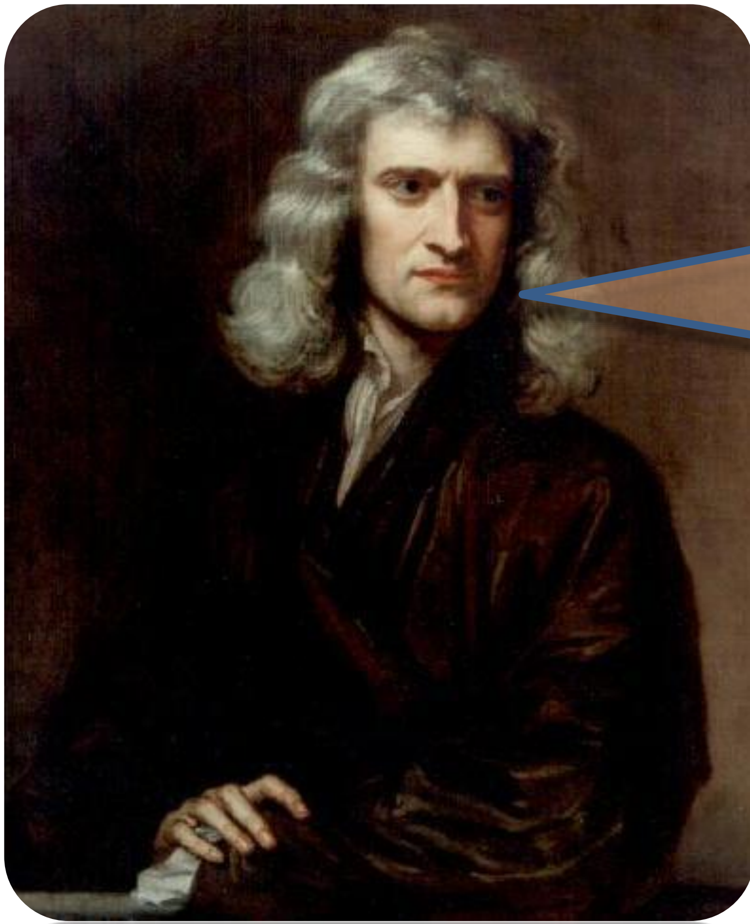
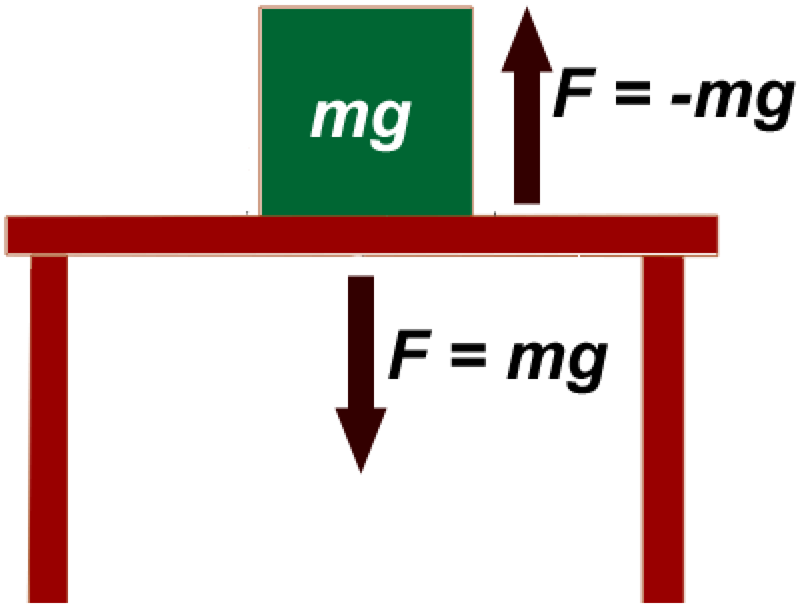


Newton’s Third Law



"Every action has an equal and opposite reaction"

The 3^{rd} Law Restated



Forces always occur in pairs. If object A exerts a force F on object B, then object B exerts an equal and opposite force –F on object A.

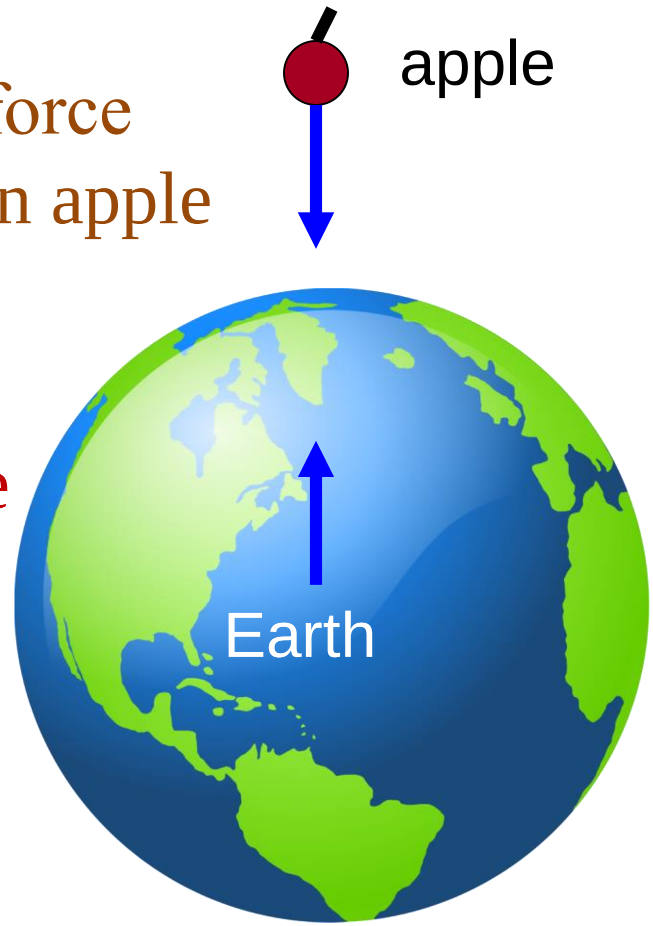
Action – Reaction examples:

- If you hit a tennis ball with a racquet, the force on the ball due to the racquet is the same as the force on the racquet due to the ball, except in the opposite direction.
- If you fire a rifle, the bullet pushes the rifle backwards just as hard as the rifle pushes the bullet forwards.
- If you drop an apple, the apple pulls on the Earth upwards just as hard as the Earth pulls on the apple downwards.

Earth and Apple

How could the forces on the tennis ball, apple, and bullet, be the same as on the racquet, Earth, and rifle? The 3rd Law says they must be, the effects are different because of the 2nd Law!

e.g. Apple's weight = force exerted by Earth on apple = 5 N



Force exerted by apple on Earth = 5 N

Earth and apple (cont.)

F(from Earth on apple) = **F**(from apple on Earth) in magnitude

$$m\,\mathbf{a} = \mathbf{M}\,a$$

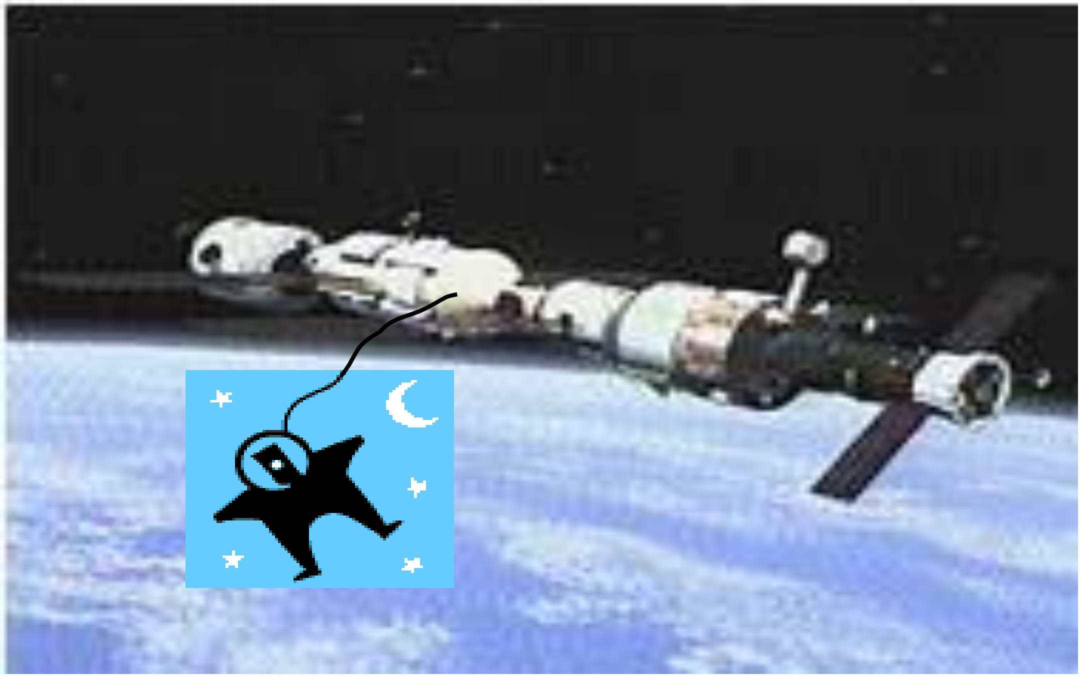
Apple's little mass

Apple's big acceleration

Earth's big mass

Earth's little acceleration

Examples: 1. Lost in Space



Suppose an International Space Station astronaut is on a spacewalk when her tether snaps. What would happen if she pushes the Space Station away from her?

2. Swimming

Due to the 3rd Law, when you swim you push the water (blue), and it pushes you back just as hard (red) in the forward direction. The water around your body also produces a drag force-resistance- (green) on you, pushing you in the backward direction. If the green and red cancel out, you don't accelerate (2nd Law) and maintain a constant velocity.

Note: The blue vector is a force on the water, not the on swimmer! Only the green and red vectors act on the swimmer.

Newton's Laws recap

1st Law: "If the forces acting on an object are balanced then that object is either stationary or moving with constant speed"

2nd Law: "The resultant force is proportional to the object's rate of change of momentum"

3rd Law: "Every force has an equal and opposite reaction"

Free body force diagrams

Consider a man standing on a table on the Earth:

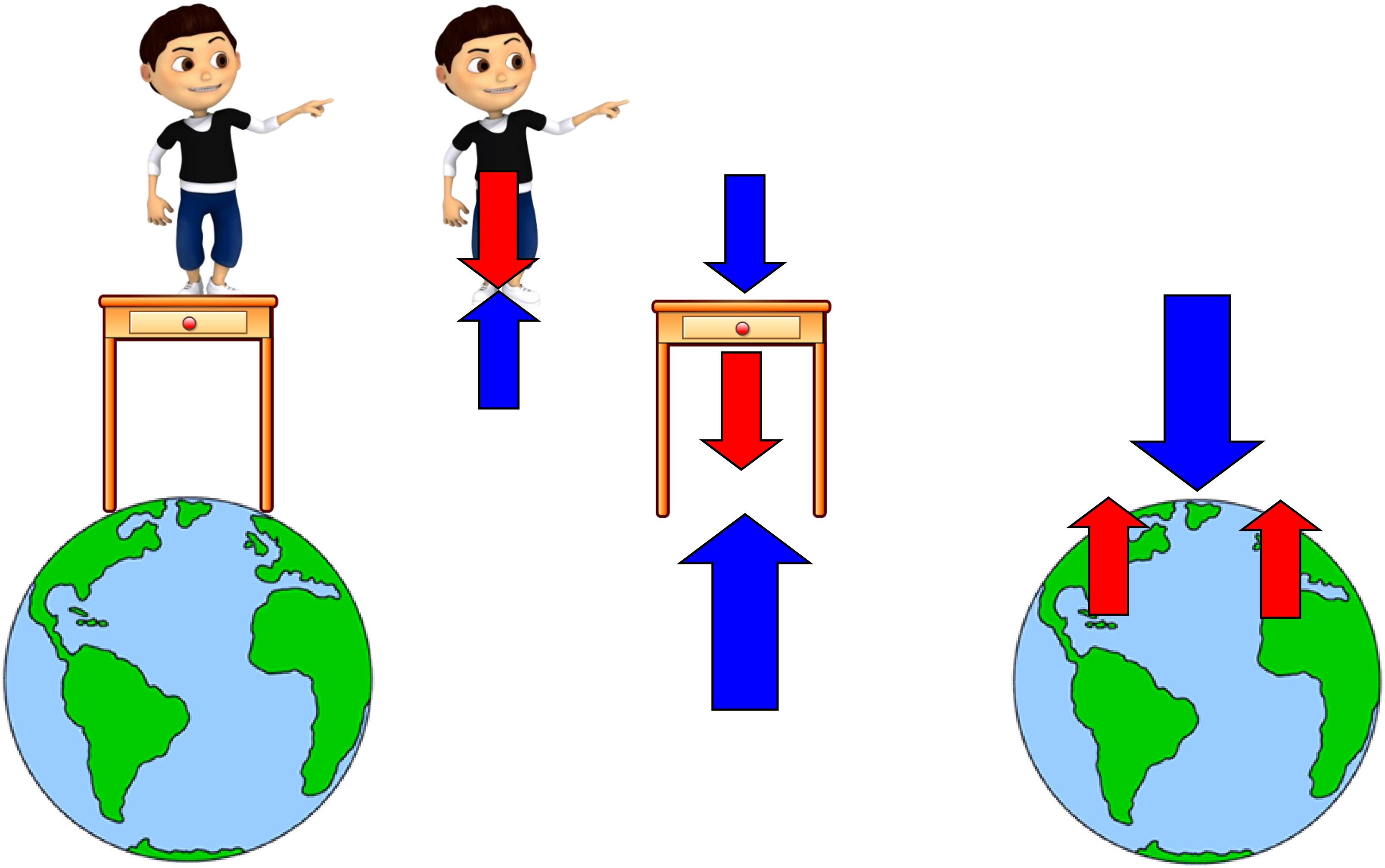
Free body force diagrams show all the forces acting on **one object**

Sketch free body force diagrams for

- **The Man**
- **The table**
- **The Earth**

Free body force diagrams

Consider a man standing on a table on the Earth:



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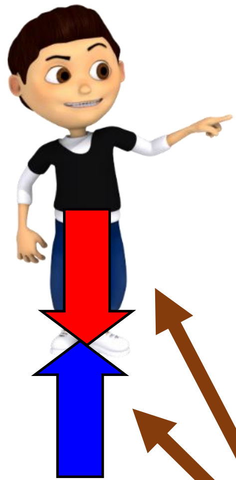
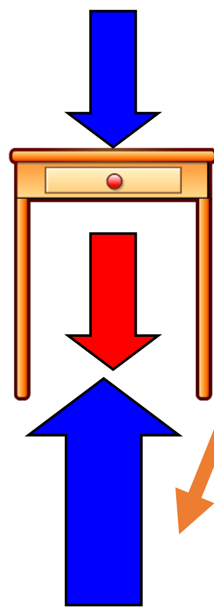
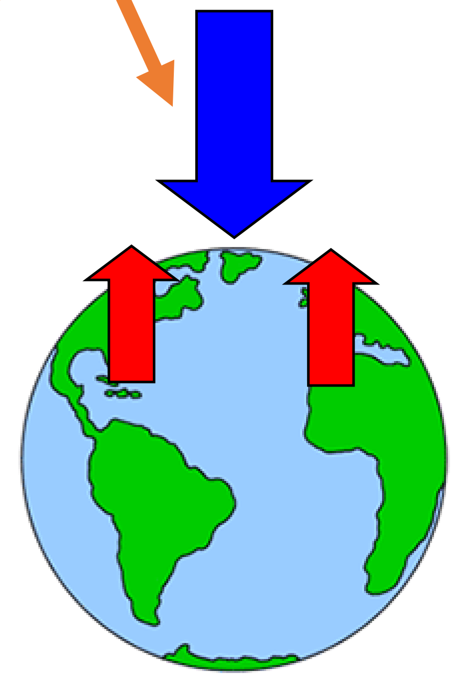
Newton 1 vs. Newton 3



These two forces are acting on different bodies, they're both the same type and they are always equal and opposite – this is a "Newton III pair of forces".

These two forces are acting on the same body, they're two different types of force and the man is in equilibrium as long as the forces balance – this is a "Newton I pair of forces".



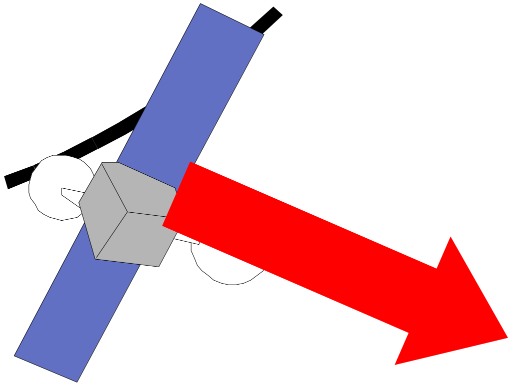


Summary of Newton 1 vs. Newton 3

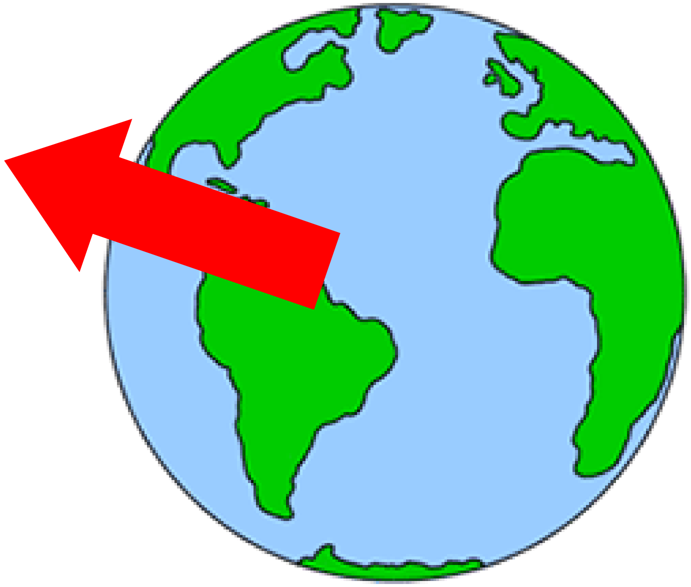
Newton I	Newton III
A law about the forces on one object	A law about the forces on two objects
Concerns any number of forces	Always concerns one pair of forces only
The forces can be any types	Both forces are the same type
If there are two forces and the body is in equilibrium the forces are equal and opposite	The two forces are ALWAYS equal and opposite

Free Body Force Diagrams

For the satellite:



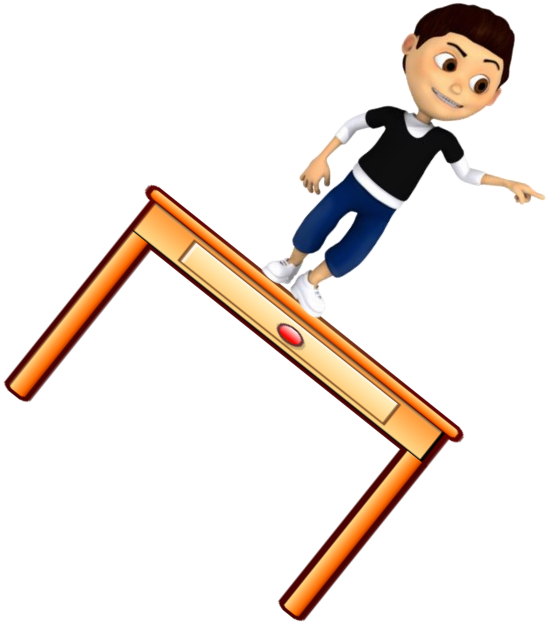
For the Earth:



Is this a Newton 1 or Newton 3 example? Why?

Free body force diagrams

Consider a man on a sloping table:



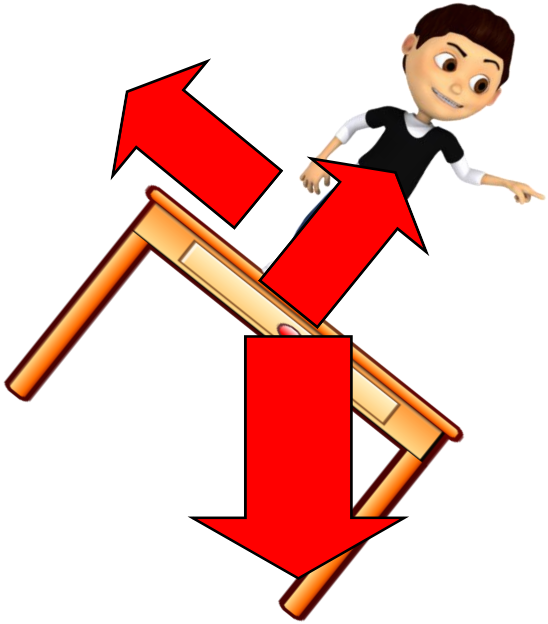
He is not moving

What forces are acting on him?

Sketch a free body force diagram

Free body force diagrams

Consider a man on a sloping table:



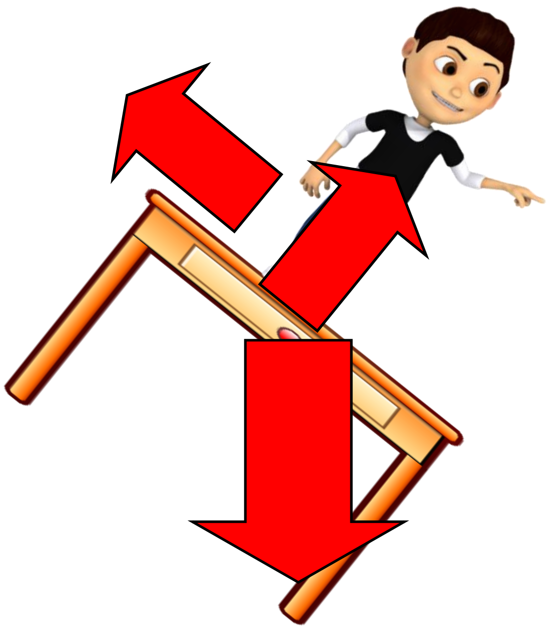
Reaction (a contact force) is ALWAYS perpendicular to the surface.

Friction (a tangential contact force) ALWAYS acts against motion.

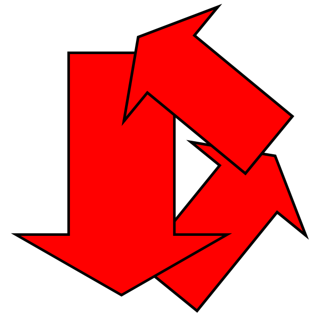
Let's combine the forces…

Free body force diagrams

Consider a man on a sloping table:



If the vectors combine to give a closed triangle, there is no resultant force



Resultant force is zero, so no acceleration

Free body force diagrams

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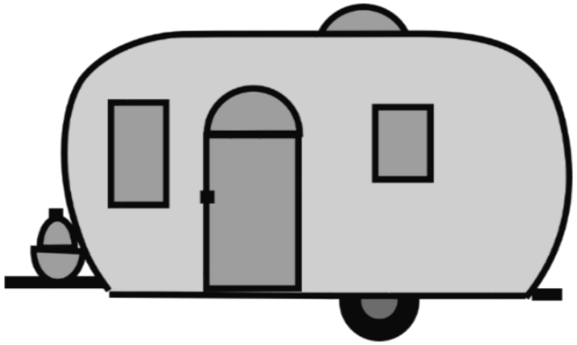
1. Draw a free body force diagram for a ladder against a wall.

2. A car pulls a caravan along the A1. Draw a free body force diagram for the caravan.



3. Draw a free body force diagram for a car driving on the M6 motorway.