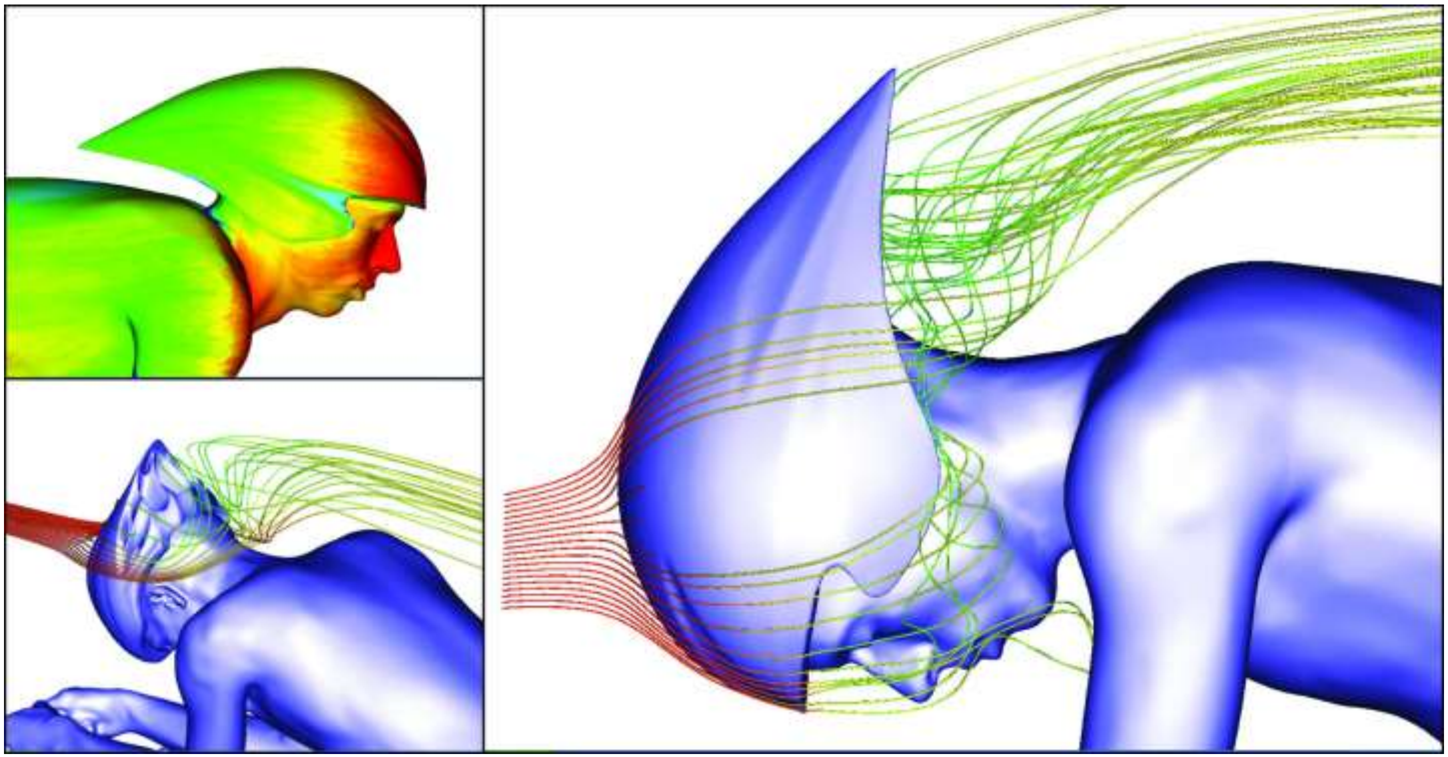
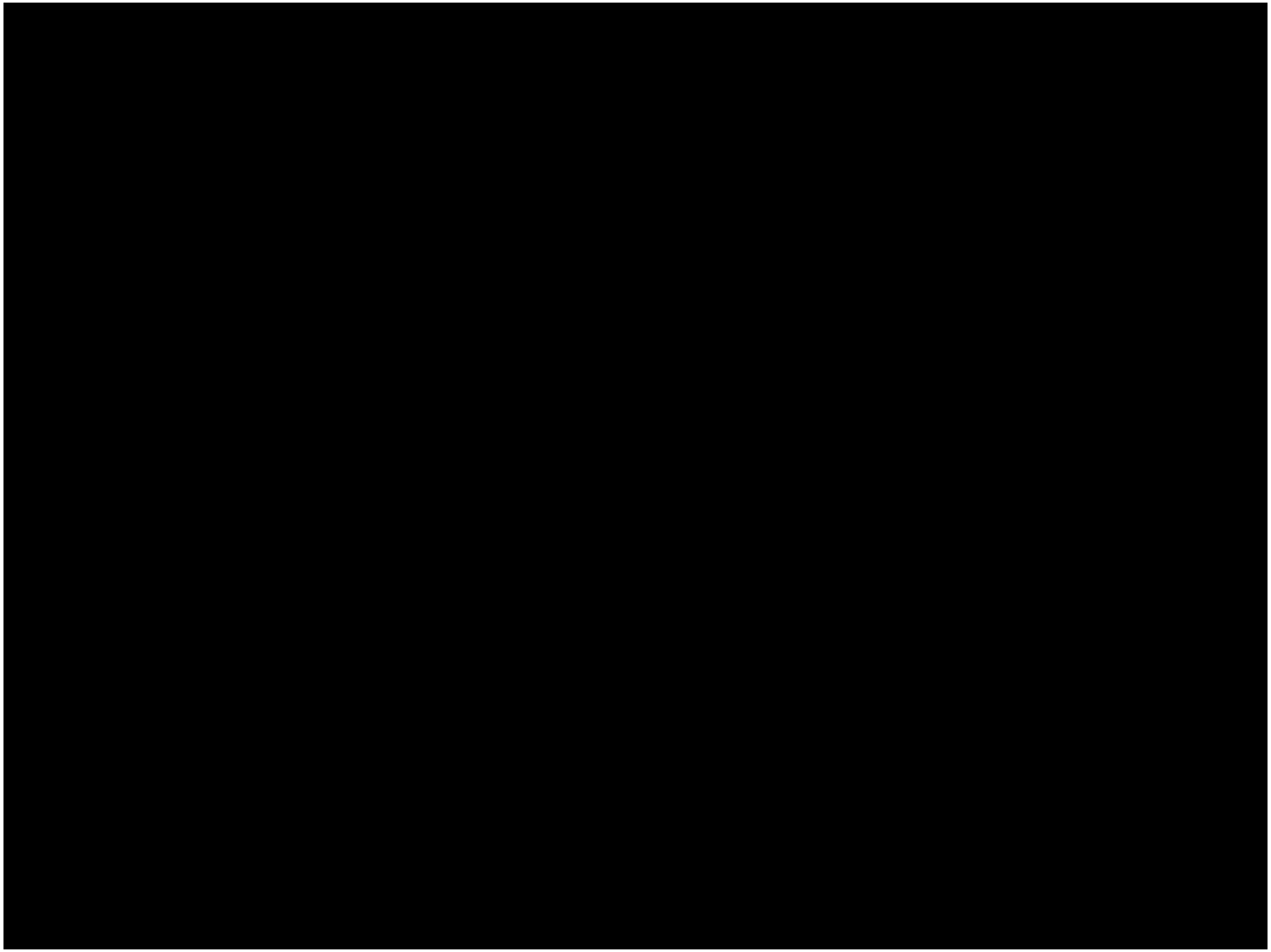
FUNDAMENTALS OF BIOMENCHANICS



STARTER:

What are the five components of biomechanics?



Learning Objectives

Define the terms:

- Biomechanics
- Kinetics
- Kinematics

Outline the different types of motion

Compare distance to displacement

Biomechanics: applications of mechanics to the human body and sporting implements, and studies forces on (and caused by) the human body and subsequent result of those forces

- **Kinematics**: study of motion (change in position) of a body or object
  - **Linear motion**: in a straight line
  - **Curvilinear motion**: in a curve
  - **Angular (rotational) motion**: around an axis
  - **General motion**: linear and angular motion together
- **Kinetics**: forces involved in the movement of an object or body
  - **Linear kinetics**: force, gravity, mass and weight
  - **Angular kinetics**: torque (moments), levers

NOW COPY THIS INTO YOUR WORKBOOK!

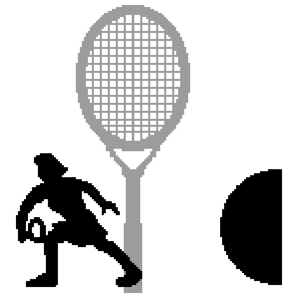
Motion - Linear

When a body moves in a straight line with all its parts moving the same DISTANCE, DIRECTION, and SPEED

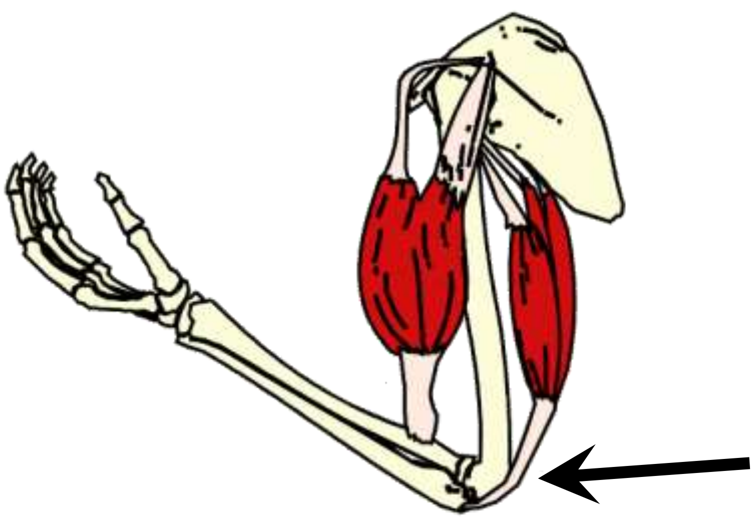
Everything is moving in the same direction at the same speed

SPORTING EXAMPLE = <u>THE BOB SLEIGH (TOBOGGAN)</u>

Motion - Angular



When a body or part of a body moves in a circle or part of a circle about a point (the axis of rotation).



Axis of rotation

Circular motion about a point. i.e. The elbow being fixed when the forearm moves in a half circle in a tennis serve

SPORTING EXAMPLE = BENDING YOUR ARM IN A TENNIS SERVE

Motion – General

General = Angular +Linear

General motion is a combination of Linear and Angular motion

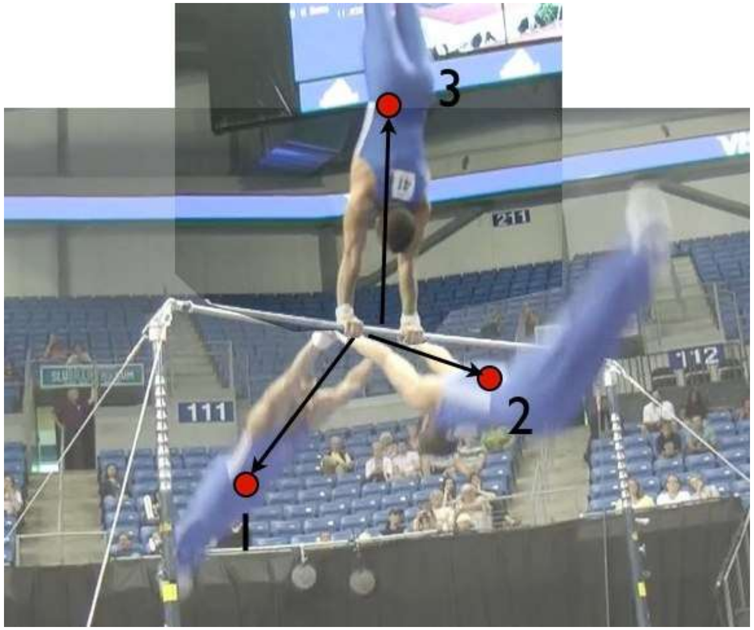
Sporting examples

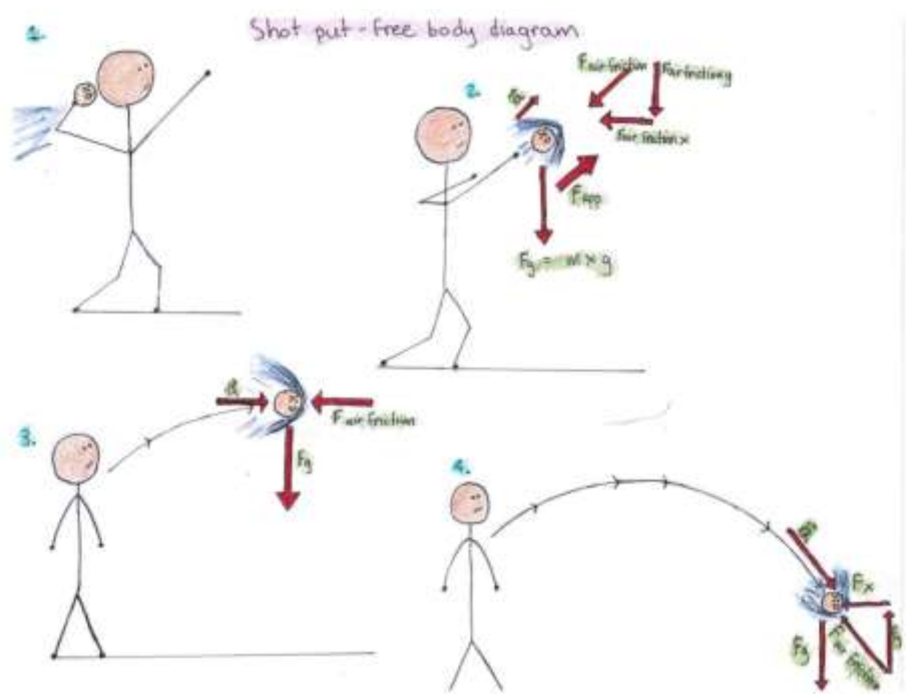
- Javelin
- Wheel chair athletics
- Swimming
- Running

Can you add these examples to your flow diagram?!

Group Activity:

Guess the type of motion!





Scalars and Vectors

A scalar quantity has only magnitude.

A vector quantity has both magnitude and direction.

PAIRS ACTIVITY:

Sort the following quantities into vector and scalar quantities

- velocity
- accelaration
- length
- lift
- drag
- mass
- density
- volume
- pressure
- weight
- energy
- momentum
- force
- power
- work
- speed

Scalars and Vectors

A **scalar quantity** has only **magnitude.**

A **vector quantity** has both **magnitude** and **direction.**

Scalar Quantities

length, area, volume
speed
mass, density
pressure
temperature
energy, entropy
work, power

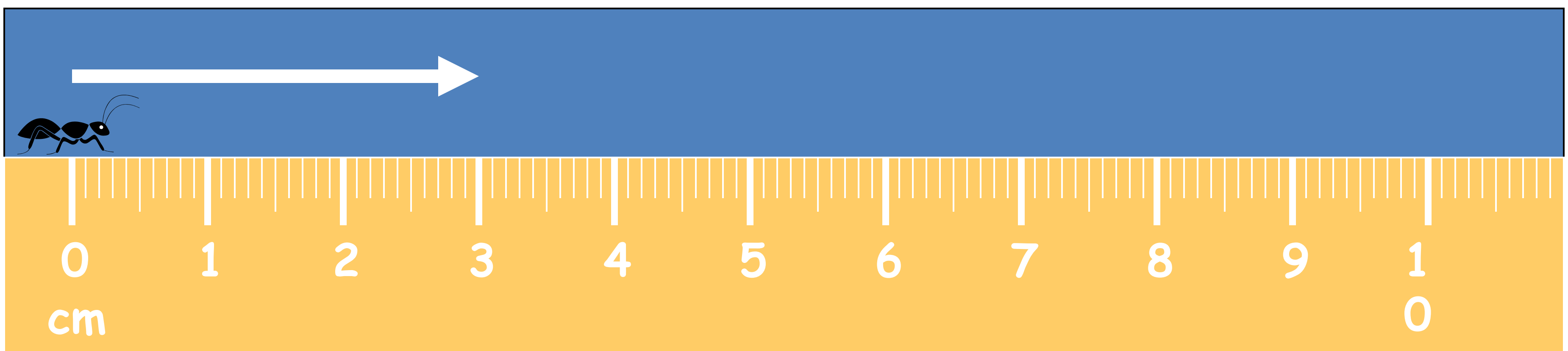
Vector Quantities

displacement, direction
velocity
acceleration
momentum
force
lift , drag , thrust
weight

NOW COPY THIS INTO YOUR WORKBOOK!

Distance

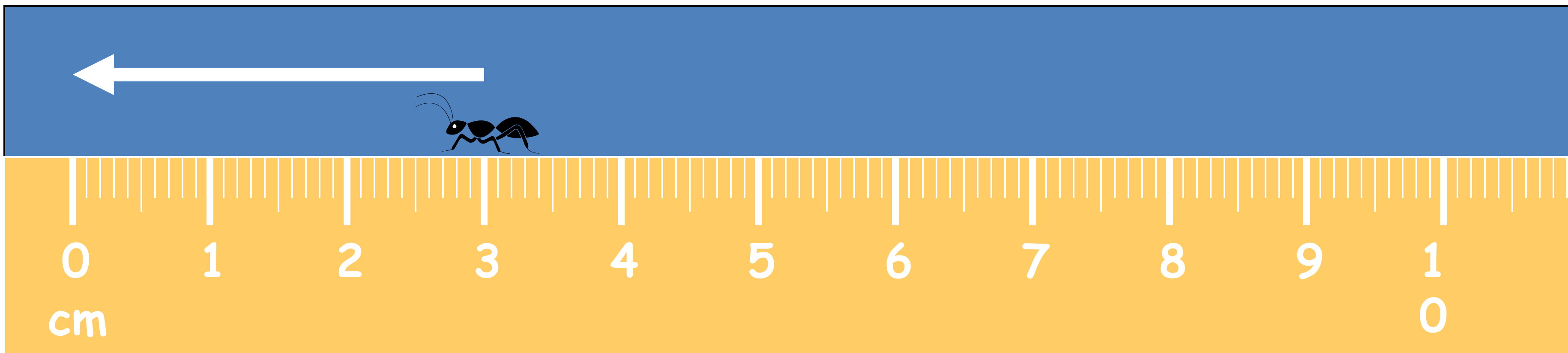
- **Distance (d) – how far an object travels**.
  - Does *not* depend on direction.
- Imagine an ant crawling along a ruler.



- What *distance* did the ant travel?
  - d = 3 cm

Distance

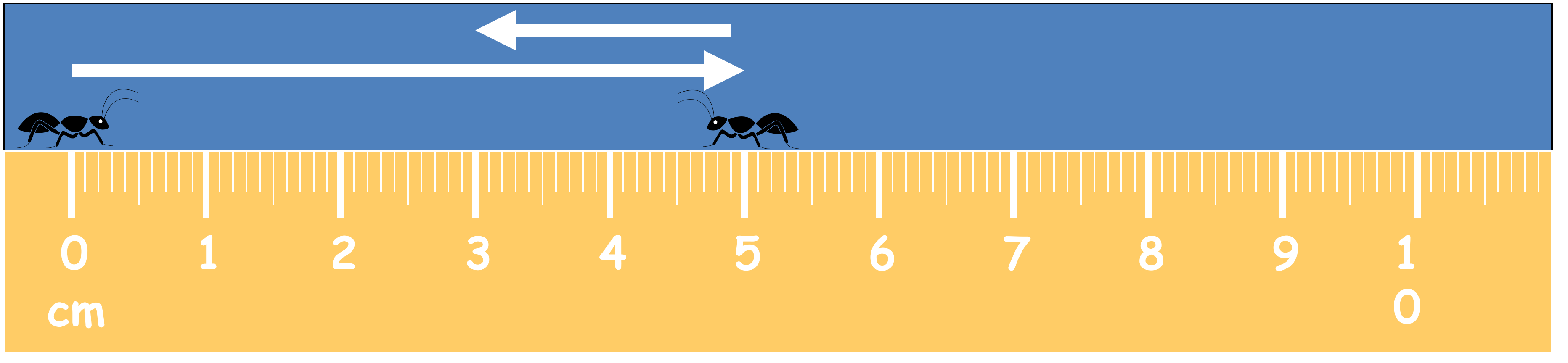
- Distance does not depend on direction.
- Here's our intrepid ant explorer again.



- Now what distance did the ant travel?
  - d = 3 cm
- Does his direction change the answer?

Distance

- Distance does not depend on direction.
- Let's follow the ant again.



- What distance did the ant walk this time?
- d = 7 cm

Displacement

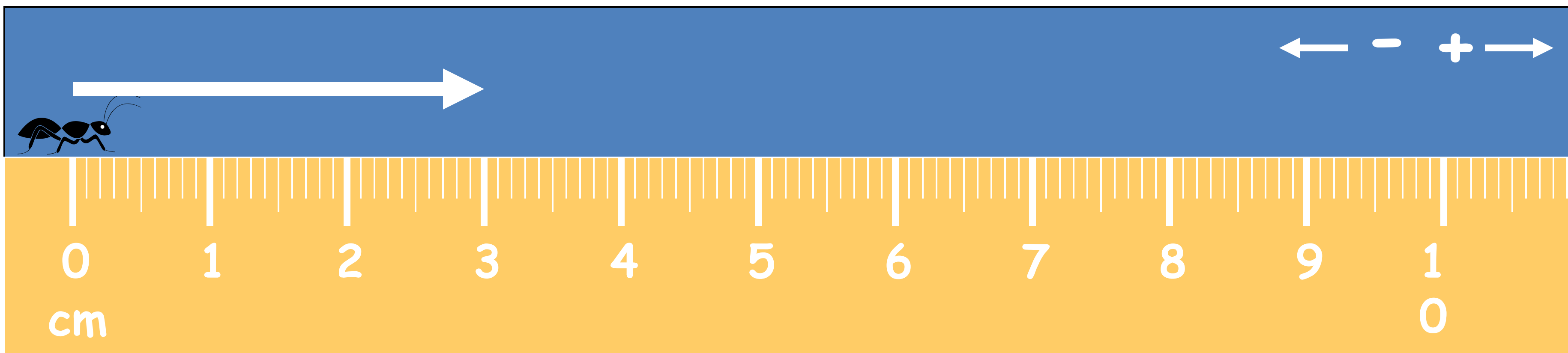
- **Displacement (Δx) – difference between an object's final position and its starting position.**
  - ***Does* depend on direction.**
- Displacement = final position – initial position
- $\Delta x = x_{final} - x_{initial}$
- In order to define displacement, we need directions.
- Examples of directions:
  - + and –
  - N, S, E, W
  - Angles

Displacement vs. Distance

- Example of distance:
  - The ant walked 3 cm.
- Example of displacement:
  - The ant walked 3 cm EAST.
- An object's distance traveled and its displacement aren't always the same!

Displacement

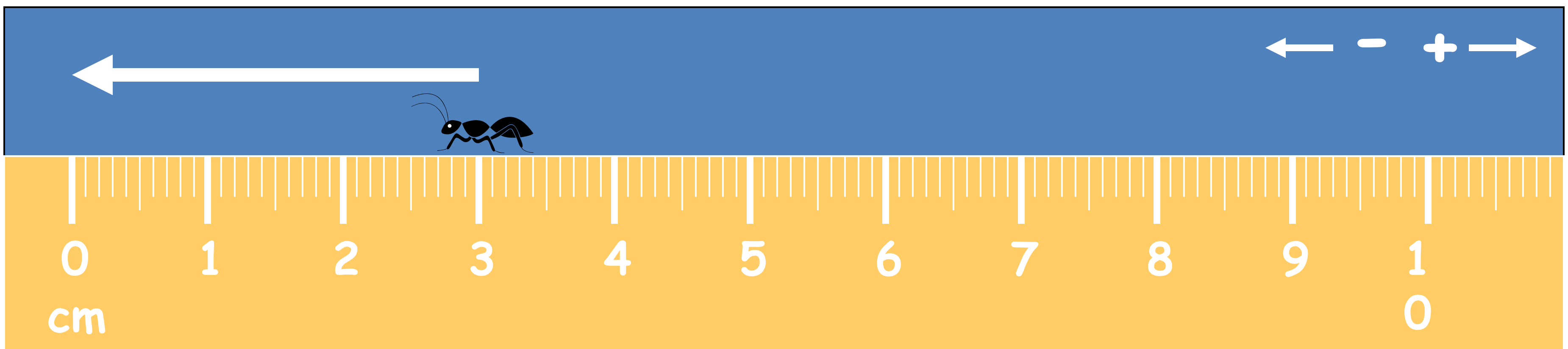
- Let's revisit our ant, and this time we'll find his displacement.



- Distance: 3 cm
- Displacement: +3 cm
  - The positive gives the ant a direction!

Displacement

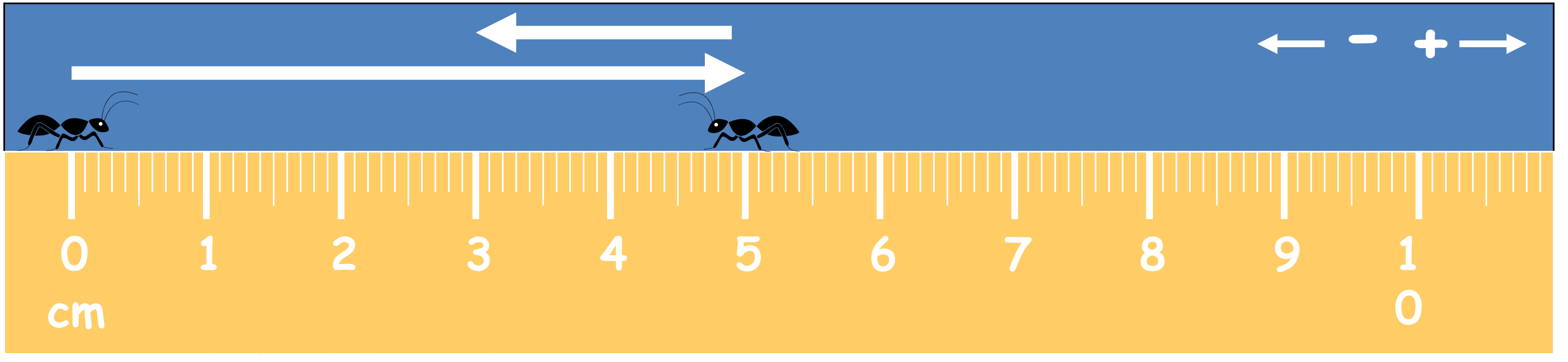
- Find the ant's displacement again.
  - Remember, displacement has direction!



- Distance: 3 cm
- Displacement: -3 cm

Displacement

- Find the distance and displacement of the ant.

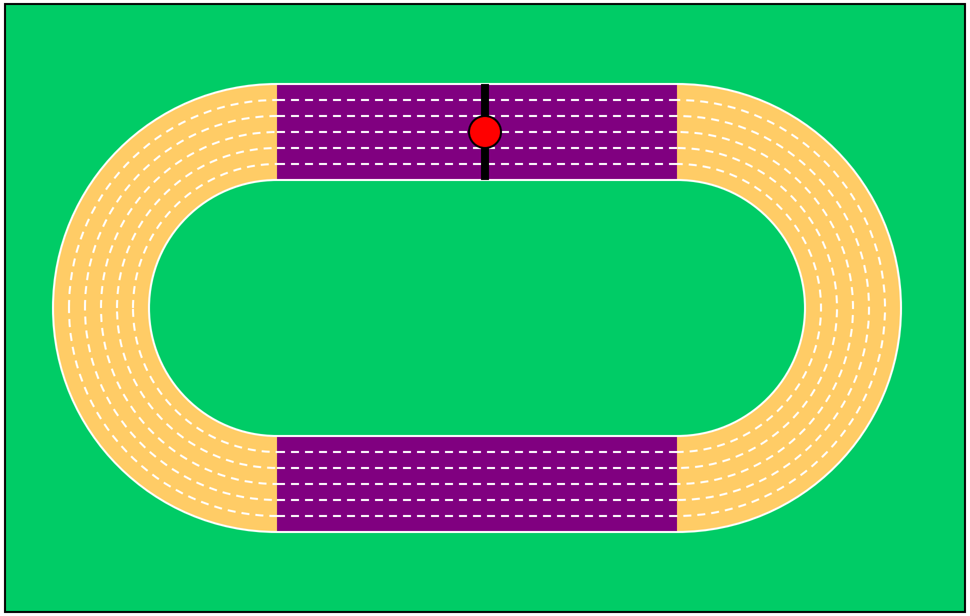


- Displacement: +3 cm

GROUP THOUGHT:

Displacement vs. Distance

- An athlete runs around a track that is 100 meters long three times, then stops.
  - What is the athlete's distance and displacement?

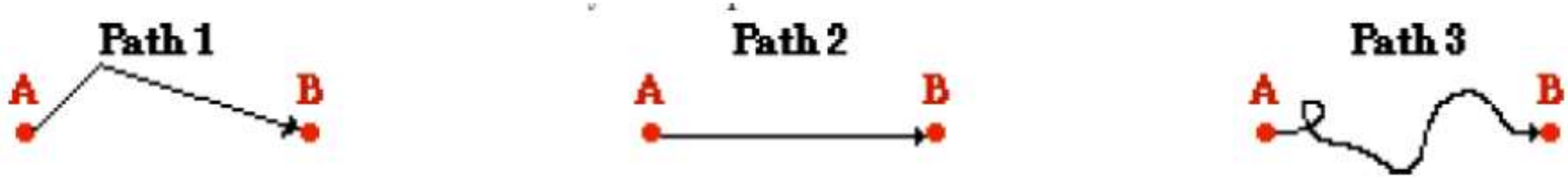


- Distance = 300 m
- Displacement = 0 m
- Why?

NOW TRY THE ACTIVITY IN YOUR WORKBOOK!

STARTER: Individual Problem

Suppose you run three different paths from a to b. Along which path(s) would your distance travelled be different from your displacement



Learning Objectives

Define velocity and acceleration

Calculate velocity for sporting examples

Analyse velocity-time and distance –time graphs for sporting actions

Speed vs. Velocity

Speed is simply how fast you are travelling…

Yohan Blake is travelling at a speed of 10m/s

Velocity is "speed in a given direction"…

Yohan Blake is travelling at a velocity of 10m/s east

Speed or Velocity

metres

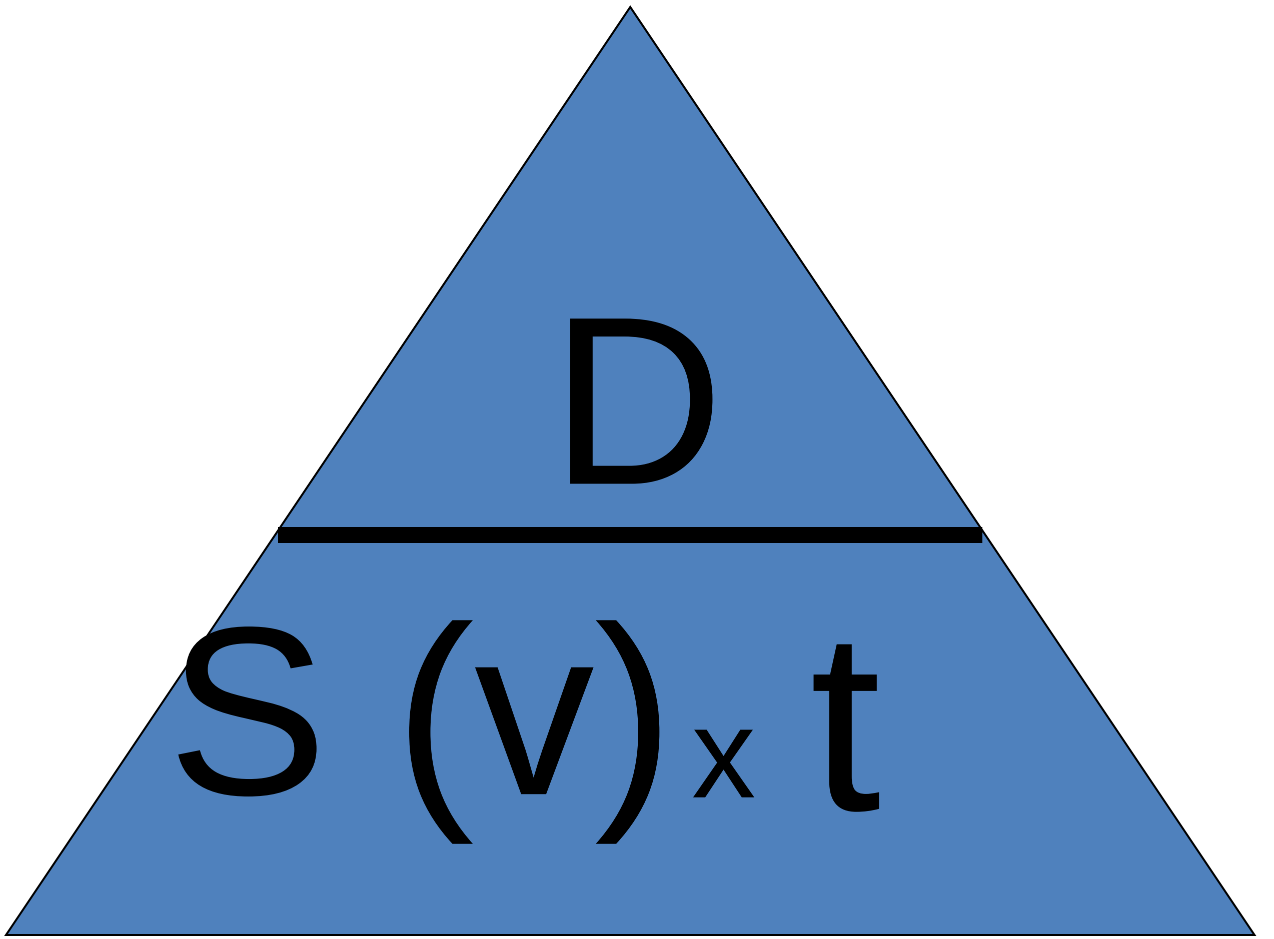
Speed = distance travelled / time taken

(velocity)

Metres per second (m/s)

seconds

Formula triangle



GROUP ACTIVITY

Usian Bolt ran 100m in 9.58 seconds, what was his average speed?

10.43 m/s

Individual activity

- Try the practice questions in your booklet

Lionel Messi kicks a ball 6.5 meters. How much time is needed for the ball to travel this distance if its velocity is 22 meters per second, south?

$t = d/s = 6.5m / 22ms^{-1} = 0.3s$

Andy Murray serves a tennis ball to Rafael Nadal. It travels 9.5 meters south in 2.1 seconds.

a. What is the velocity of the tennis ball?

$v = d/t = 9.5m/2.1s = 4.5\ ms^{-1}$

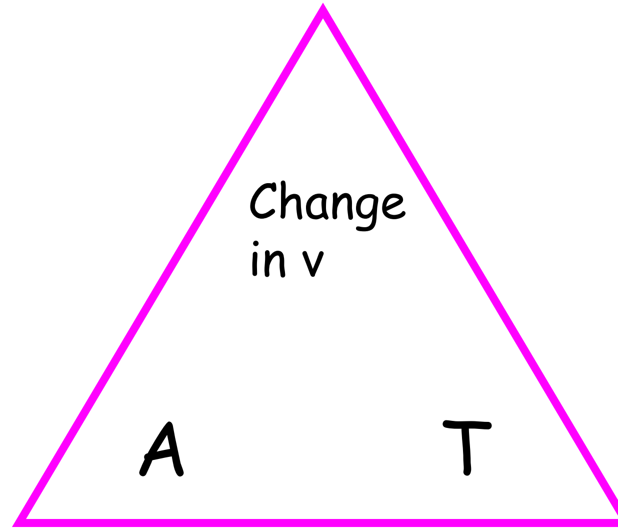
b. If the tennis ball travels at constant speed, what is its velocity when Nadal returns Murray's serve?

$4.5\ ms^{-1}$ north

Acceleration

Acceleration = change in velocity (in m/s)

(in m/s^2) time taken (in s)



E.g:

A Formula 1 McLaren can do from 0 – 300,000m in 8.6 seconds

What is it's acceleration?

$$\frac{3000000\text{m}}{8.6\text{ s}} = \mathbf{34834\ m/s^2}$$

NOW TRY THE ACTIVITY IN YOUR WORKBOOK!

Group Activity: Sketch the graph!

NOW TRY THE ACTIVITY IN YOUR WORKBOOK!

Sketch BOTH a velocity- time graph and a distance-time graph for the following scenarios

- A basketball is dropped on the court and allowed to bounce up and down several times undisturbed.
- A car on a test track performing a zero-to-sixty acceleration test. (This acceleration will *not* be uniform.)
- A race between a tortoise and a hare that unfolds just like the fable of the same name.
- Two cars are adjacent to each other on a four-lane highway. The first car accelerates uniformly from rest the moment the light changes to green. The second car approaches the intersection already moving and is beside the first car at the instant the light changes. It then continues driving with a constant velocity.

THE TORTOISE AND THE HARE

Aesop (Ca. 620 B.C.)

A Hare was one day making fun of a Tortoise for being so slow upon his feet. "Wait a bit," said the Tortoise; "I'll run a race with you, and I'll wager that I win." "Oh, well," replied the Hare, who was much amused at the idea, "let's try and see"; and it was soon agreed that the fox should set a course for them, and be the judge. When the time came both started off together, but the Hare was soon so far ahead that he thought he might as well have a rest: so down he lay and fell fast asleep. Meanwhile the Tortoise kept plodding on, and in time reached the goal. At last the Hare woke up with a start, and dashed on at his fastest, but only to find that the Tortoise had already won the race.

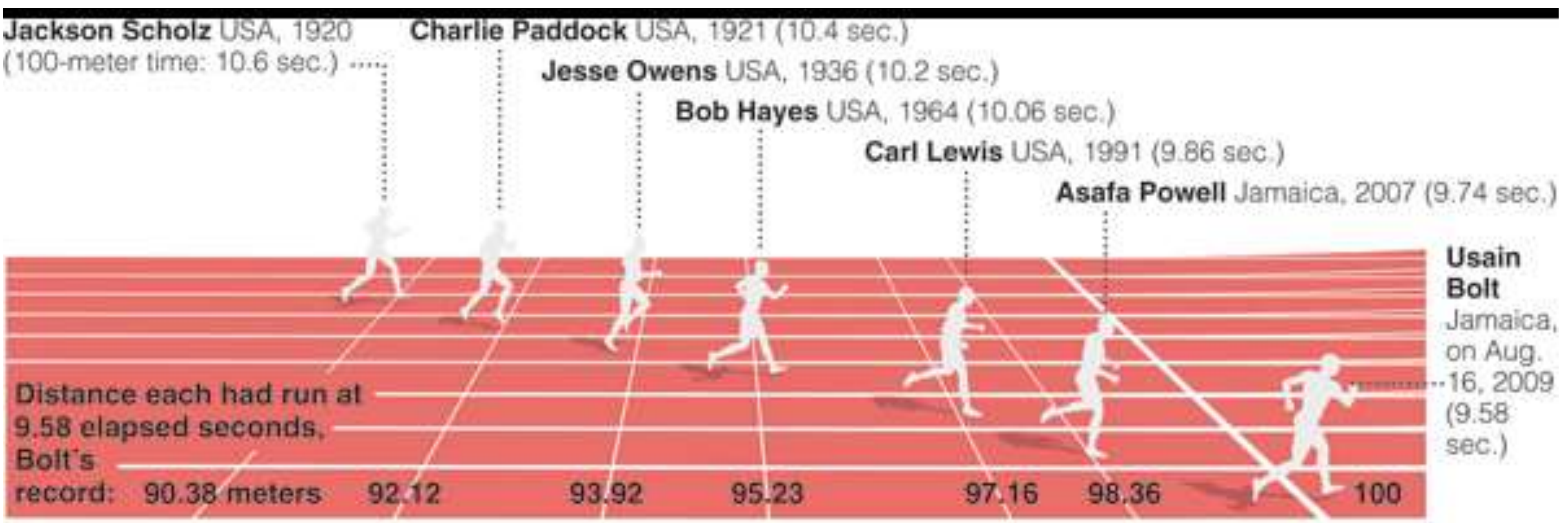
Slow but steady wins the race.

STARTER:

Read the article in your workbook

Hero or villain? Ben Johnson and the dirtiest race in history

Make sure you can define all the words in **bold**



Learning Objectives

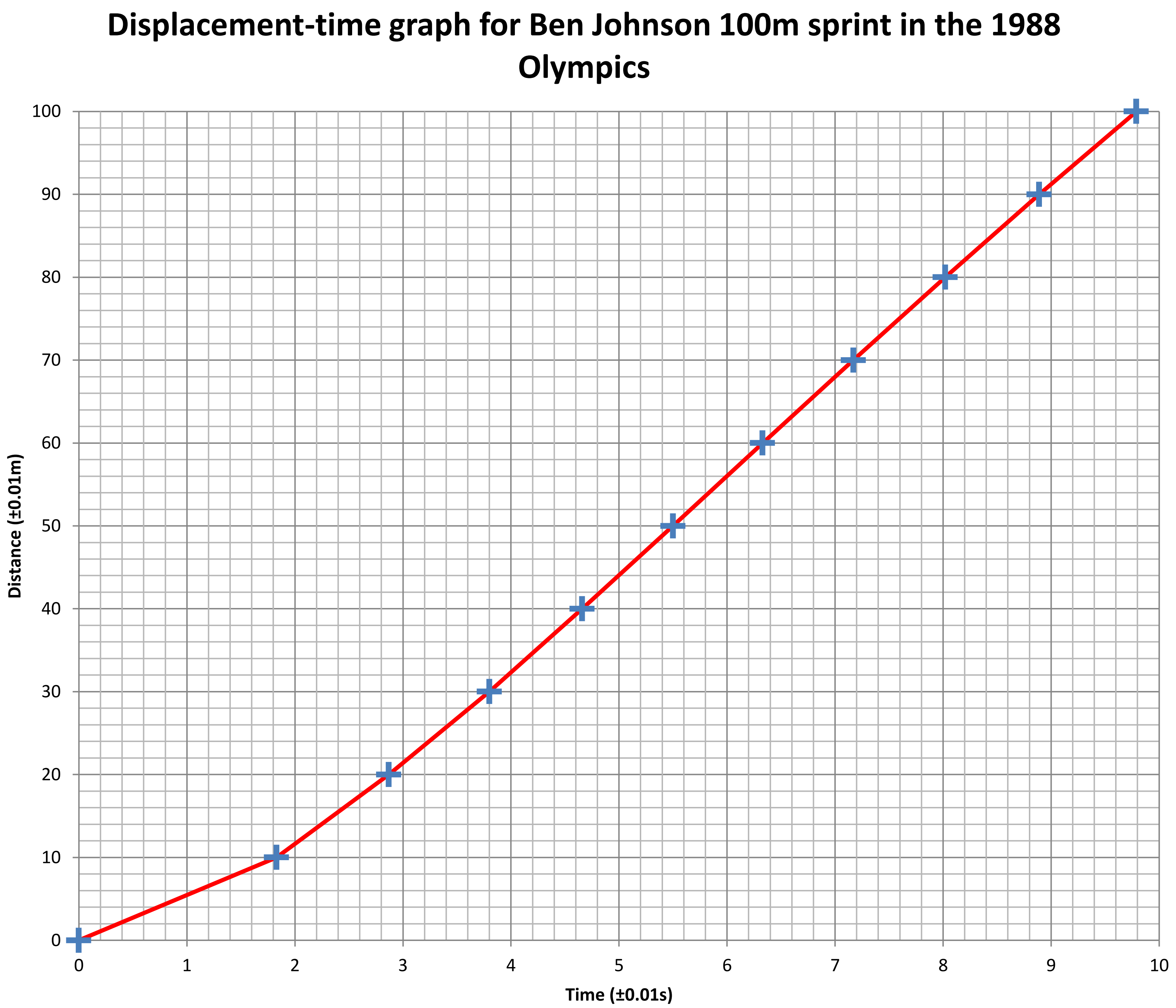
- **Calculate** split times for a 100m sprint
- **Draw** a displacement-graph to
- **Distinguish** between instantaneous velocity and average velocity
- **Show** how a velocity-time graph can be used to **calculate** acceleration

Practical task

Comparing sprinting velocities over 100m

1. Read through the procedure for the practical very carefully – there are many steps t be completed

2. Data will be collected as a class as many individuals are required to times



Displacement-time graph for Ben Johnson 100m sprint in the 1988 Olympics
Distance (±0.01m)
Time (±0.01s)
0
10
20
30
40
50
60
70
80
90
100
0
1
2
3
4
5
6
7
8
9
10

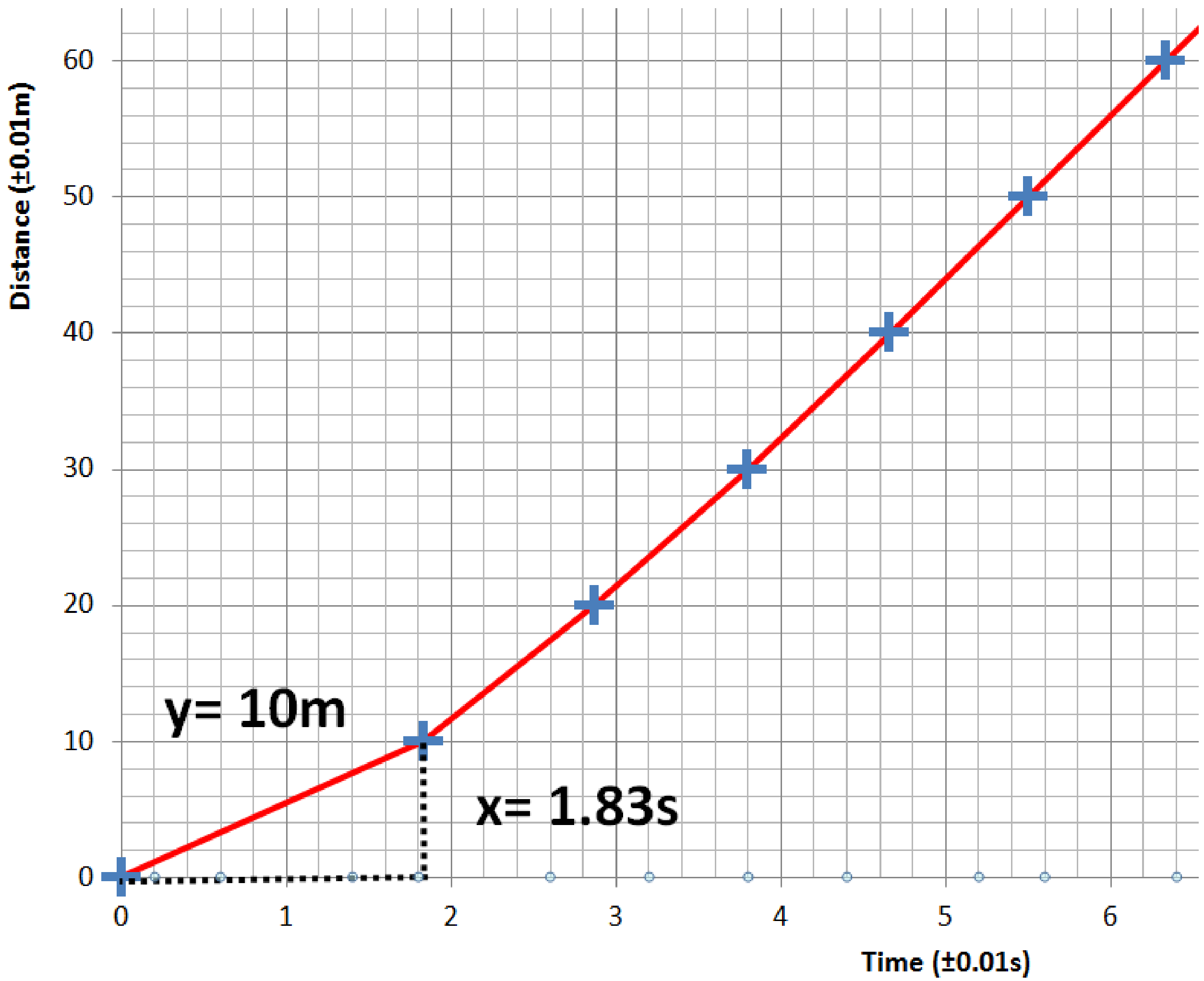
Calculating **average** velocity for Ben Johnson

- Average velocity $= \dfrac{\text{total distance (m)}}{\text{total time (s)}}$

$$= \frac{100\text{m}}{9.79\text{s}}$$

$$= \mathbf{10.21 m/s}$$

Calculating **instantaneous** velocity for Ben Johnson



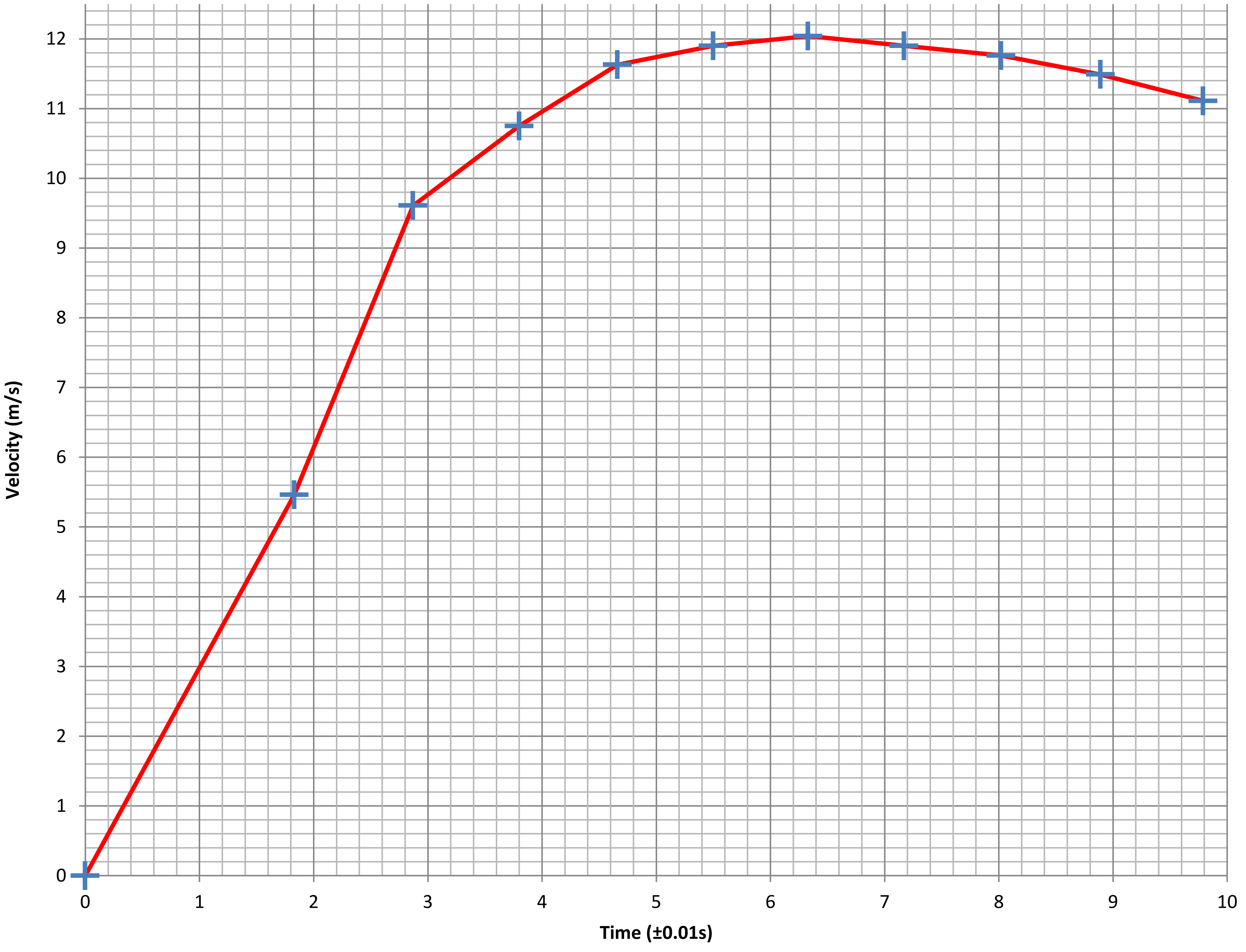
From 0-10m

V = 10m ÷ 1.83s

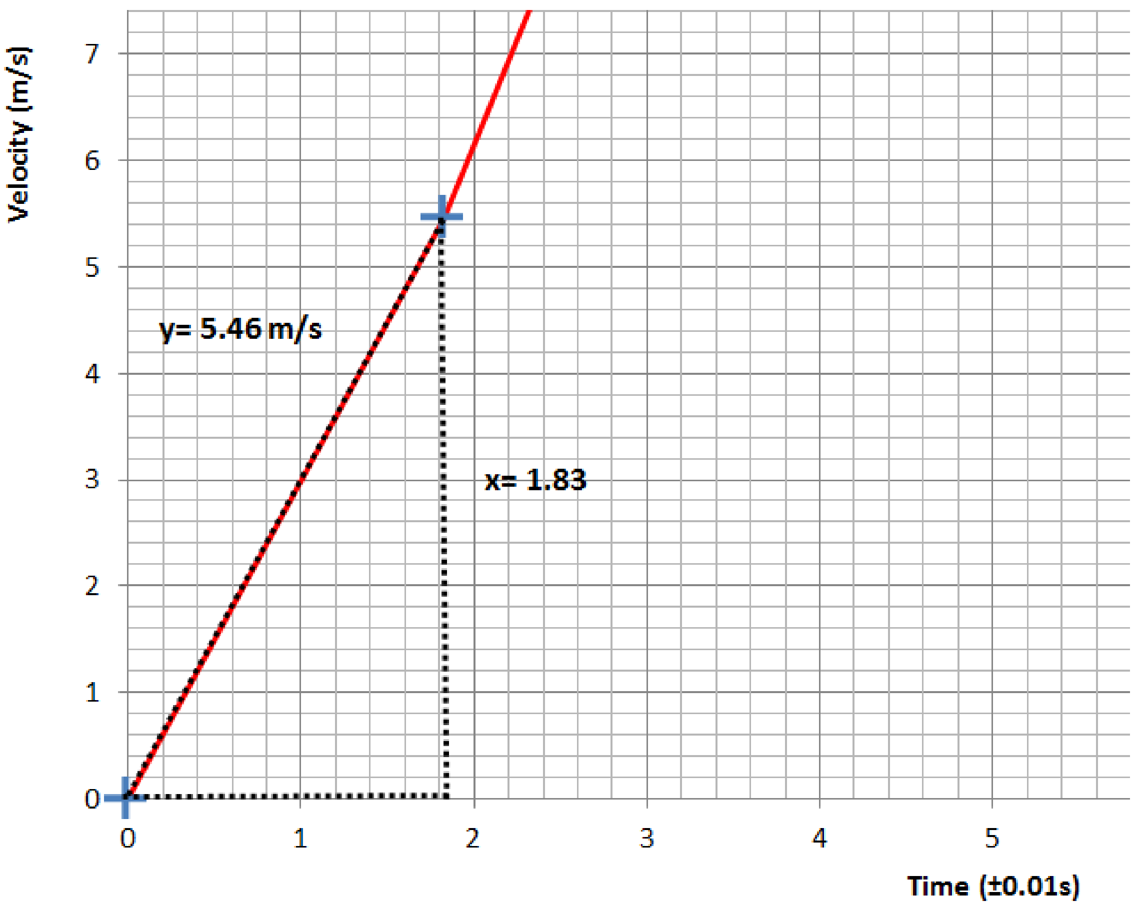
= **5.46 m/s**

Once you have calculated all the velocities for all the runners then go ahead and plot a velocity-time graph

A velocity-time graph of Ben Johnson's 1988 Olympic 100m sprint



Calculating **acceleration** for Ben Johnson

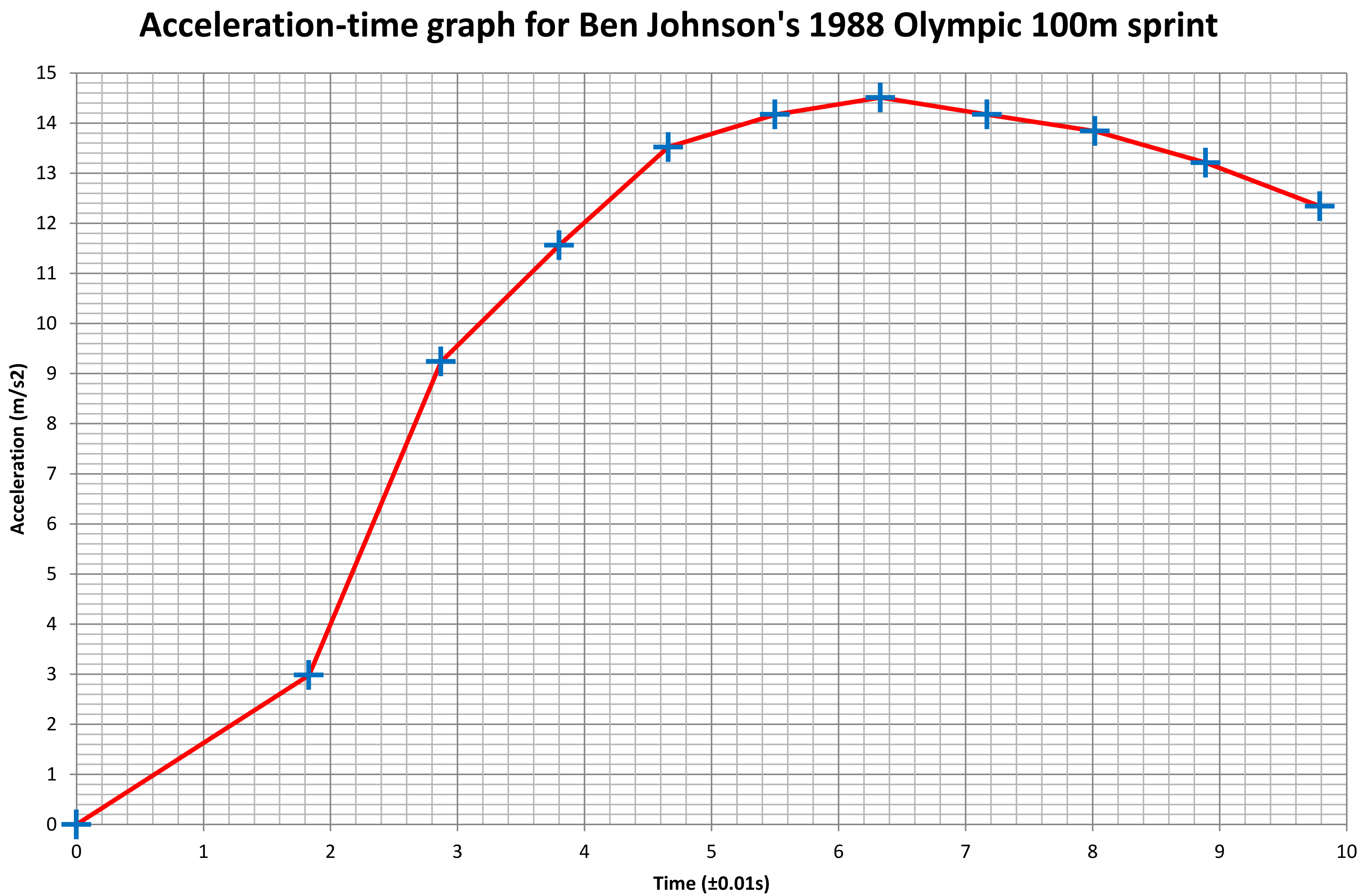


From 0-10m

a = 5.46m ÷ 1.83s

= **$2.98\ ms^2$**

Once you have calculated all the velocities for all the runners then go ahead and plot an acceleration-time graph



Acceleration-time graph for Ben Johnson's 1988 Olympic 100m sprint
Acceleration (m/s2)
Time (±0.01s)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

Starter – Decide whether the statements are true or false

Statement	True or false? Why?
The force of gravity is to do with objects falling. Weight is to do with objects feeling heavy.	
Weight disappears if the air disappears. This is why there is no gravity on the Moon.	
The weight of an object increases with its height above the ground.	
Weight and mass are the same quantity.	
Weight increases if the object is compressed and decreases if the object is spread out.	
Moving objects try to overcome the force of gravity as they move upwards and cancel it out at the point where they stop.	

When a ball is thrown upwards, it stops when the upward force on the ball from the hand is equal to the force of gravity. At this point the force on the ball is zero.

The force of gravity acts only while objects are moving downwards.	
Heavy objects fall faster than light ones.	
To push an object along a flat surface, a force equal to the weight of the object must be applied.	
When an object is pushed on a flat surface for an instant, the force from the hand is cancelled out by friction and this is why the object stops.	
Constant motion (i.e. steady speed) requires a constant force.	

Learning objectives

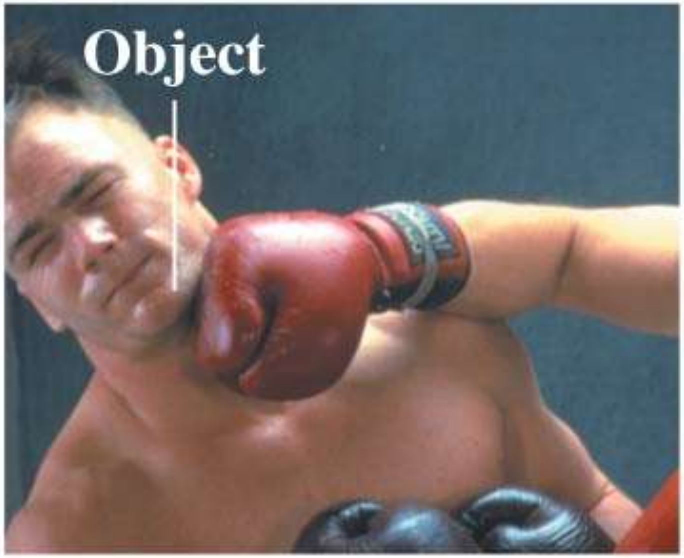
Define force

Outline the different types of forces with sporting examples

What is a force?

- **A force is a *push* or a *pull*.**

- **A force acts on an object.**
- Pushes and pulls are applied *to* something.
- From the object's perspective, it has a force *exerted* on it.

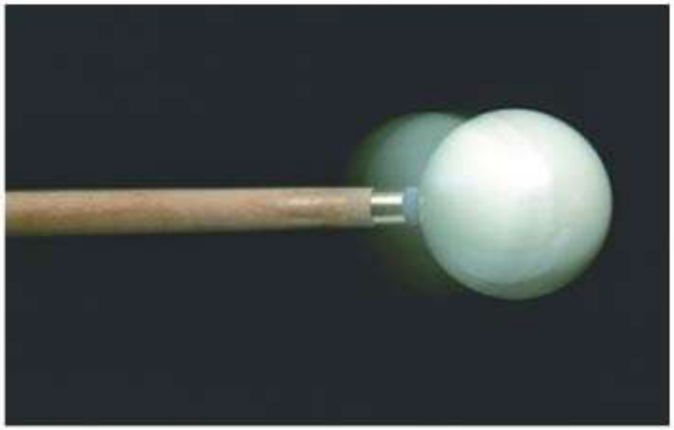


- A force requires an **agent**, something that acts or exerts power.

- If you throw a ball, your hand is the agent or cause of the force exerted on the ball.

- **A force is a vector**.

- To quantify a push or pull, we need to specify both magnitude and a direction.



- **Contact forces are forces that act on an object by touching it at a point of contact.**
- The bat must touch the ball to hit it.

- **Long-range forces are forces that act on an object without physical contact.**
- A javelin released from your hand is pulled to the earth by the long-range force of gravity.

Definition of a force

Force

The fundamental concept of dynamics is that of *force*.

- A force is a push or a pull.
- A force acts on an object.
- A force is a vector.
- A force can be a contact force or a long-range force.

Some important forces that we'll study in this chapter are

Gravity

Tension

Friction

Drag

Now try the practical activity in your workbook

Symbols for different types of forces

Force	Notation
General force	$\vec{F}$
Gravitational force	$\vec{F}_G$
Spring force	$\vec{F}_{sp}$
Tension	$\vec{T}$
Normal force	$\vec{n}$
Static friction	$\vec{f}_s$
Kinetic friction	$\vec{f}_k$
Drag	$\vec{D}$
Thrust	$\vec{F}_{thrust}$

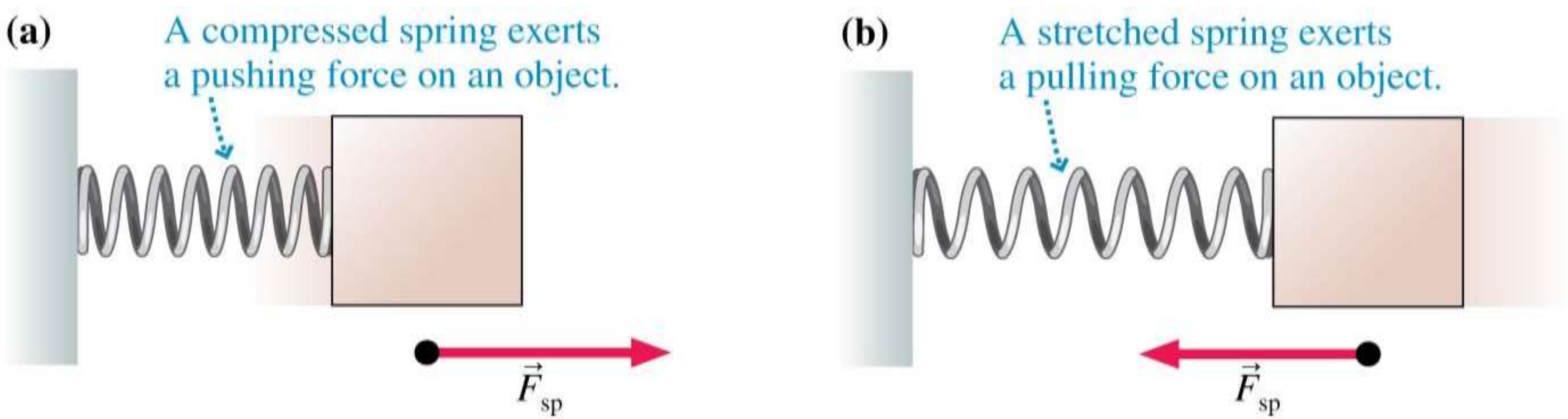
Try fill in the table in your workbook as we move through the next few slides

Spring Force

- A spring can either push (when compressed) or pull (when stretched)

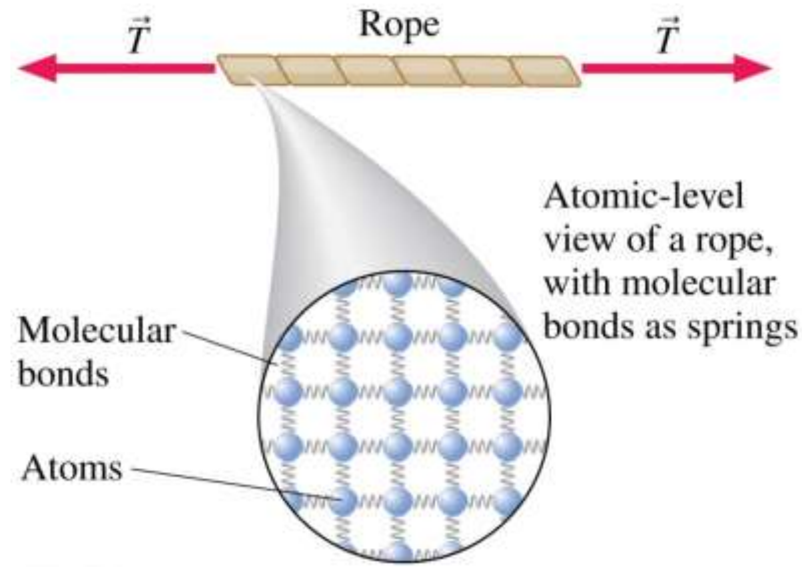
- Not all springs are metal coils.

- Whenever an elastic object is flexed or deformed in some way, and then "springs" back to its original shape when you let it go, this is a **spring force**.



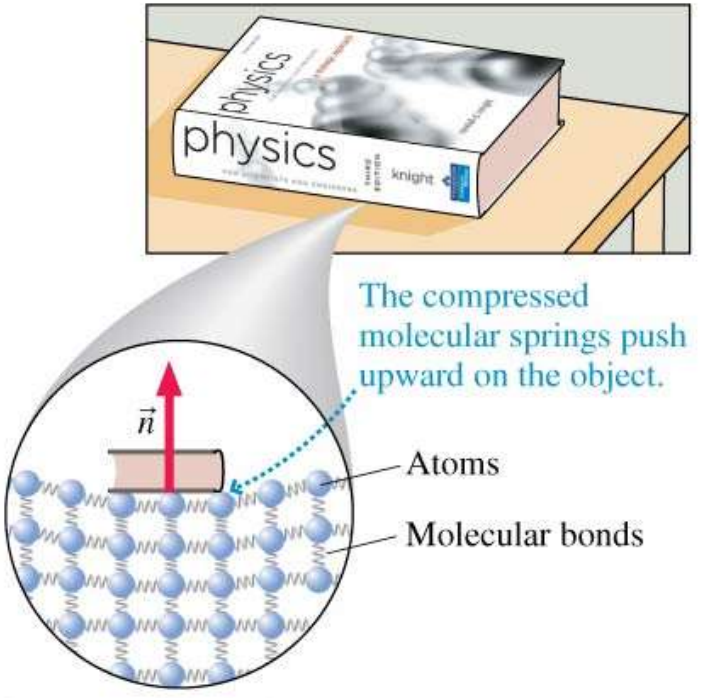
Tension Force

- When a string or rope or wire pulls on an object, it exerts a contact force called the **tension force**.
- The tension force is in the direction of the string or rope.
- A rope is made of *atoms* joined together by *molecular bonds.*
- Molecular bonds can be modeled as tiny *springs* holding the atoms together.
- Tension is a result of many molecular springs stretching ever so slightly.



Normal

- When an object sits on a table, the table surface exerts an upward contact force on the object.



- This pushing force is directed *perpendicular* to the surface, and thus is called the **normal force**.

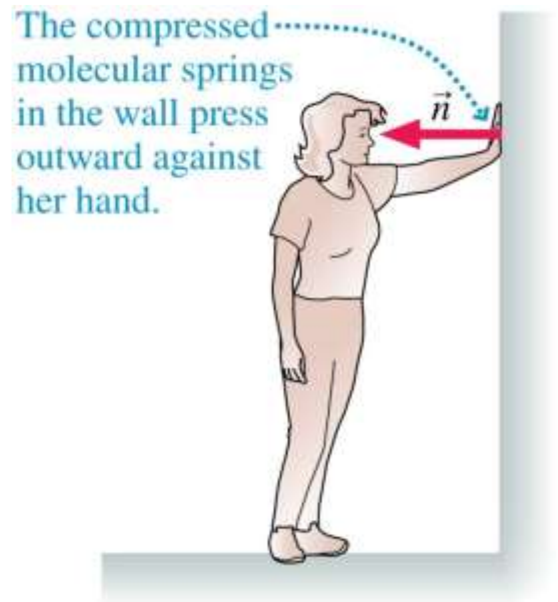
- A table is made of *atoms* joined together by *molecular bonds* which can be modeled as springs.

- Normal force is a result of many molecular springs being compressed ever so slightly.

Examples

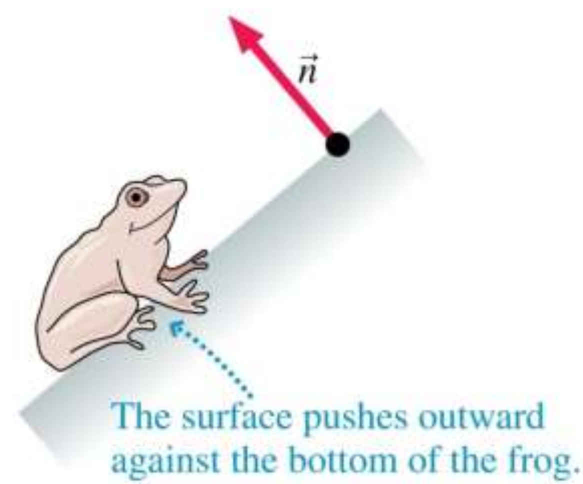
- Suppose you place your hand on a wall and lean against it.

- The wall exerts a horizontal **normal force** on your hand.



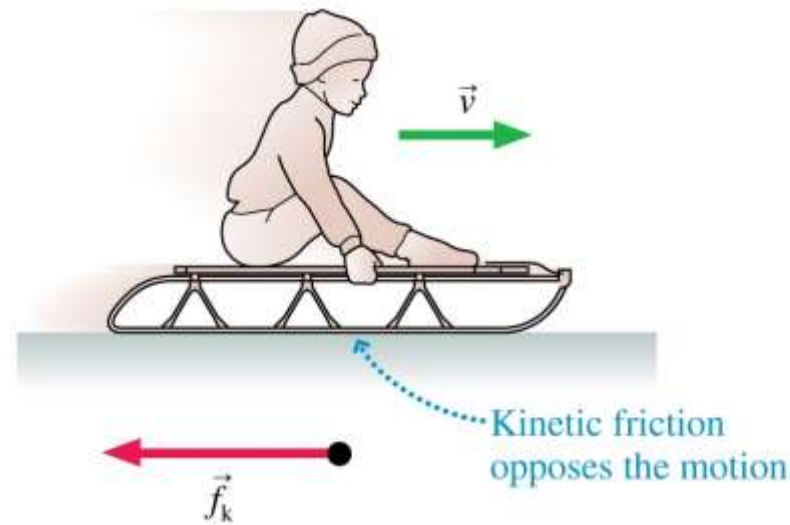
- Suppose a frog sits on an inclined surface.

- The surface exerts a tilted **normal force** on the frog.



Friction

- When an object slides along a surface, the surface can exert a contact force which opposes the motion.



- This is called sliding friction or **kinetic friction**

- The kinetic friction force is directed *tangent* to the surface, and opposite to the velocity of the object relative to the surface.

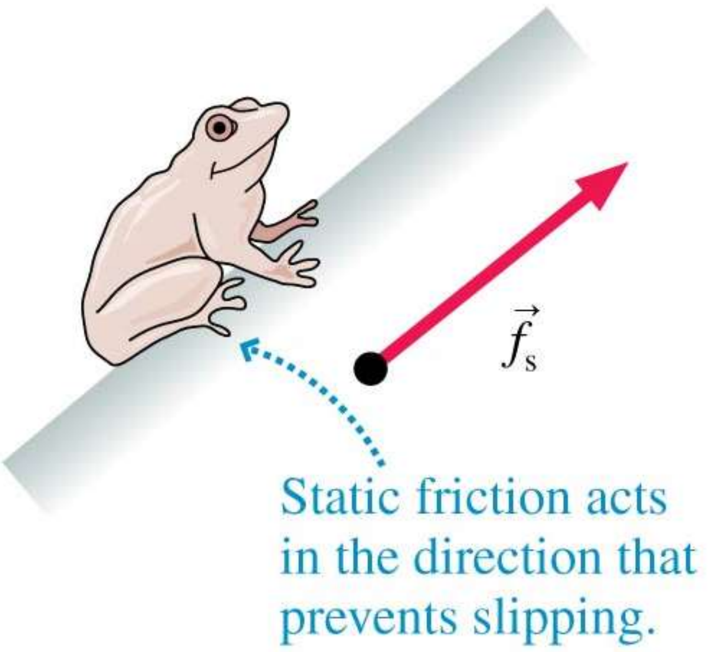
- Kinetic friction tends to slow down the sliding motion of an object in contact with a surface.

Friction

- **Static friction** is the contact force that keeps an object "stuck" on a surface, and prevents relative motion.

- The static friction force is directed *tangent* to the surface.

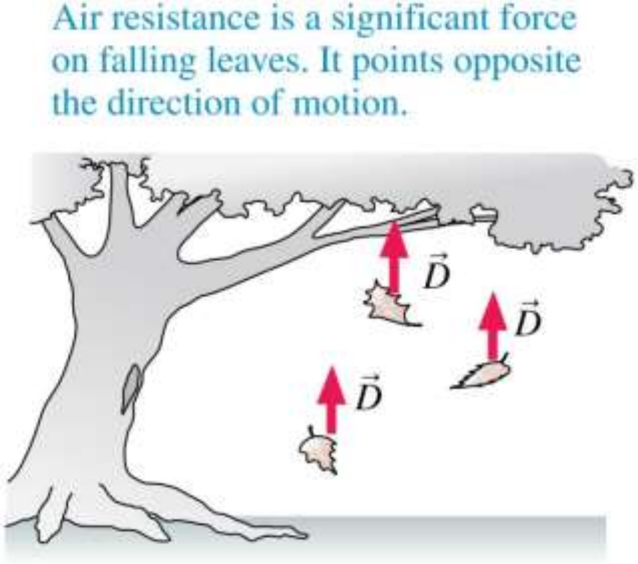
- Static friction points opposite the direction in which the object *would* move if there were no static friction.



Drag

- Kinetic friction is a *resistive force*, which opposes or resists motion.

- Resistive forces are also experienced by objects moving through fluids.



- The resistive force of a fluid is called **drag**.

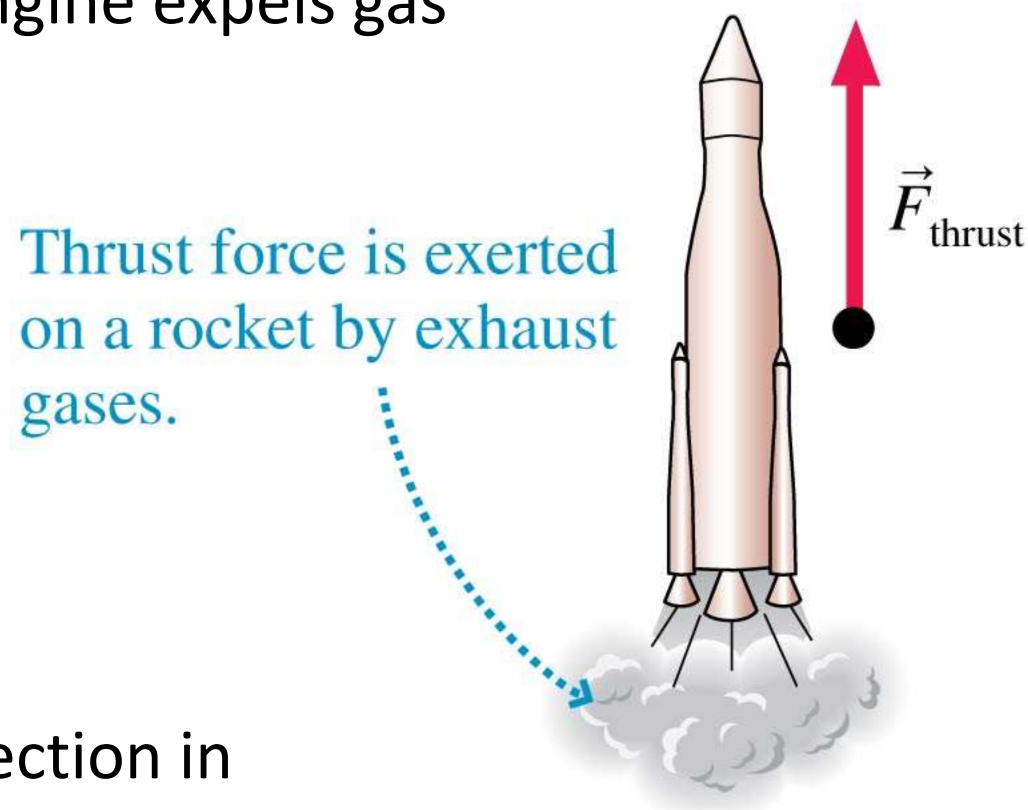
- Drag points opposite the direction of motion.

- For heavy and compact objects in air, drag force is fairly small.

- **You can neglect air resistance in all problems unless a problem explicitly asks you to include it**.

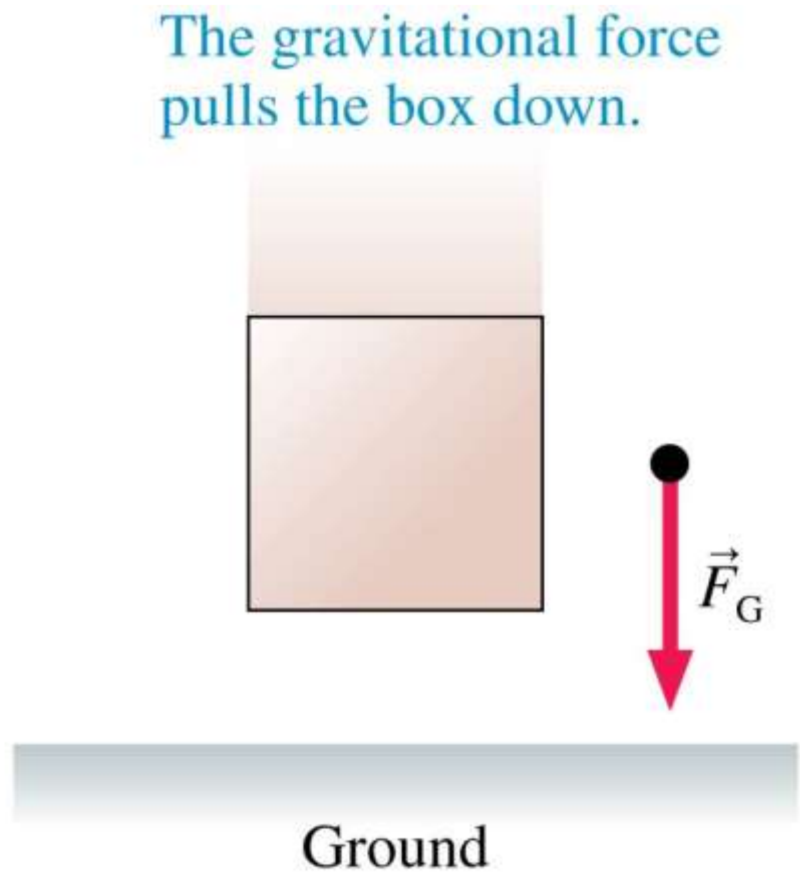
Thrust

- A jet airplane or a rocket has a **thrust** force pushing it forward during takeoff.
- Thrust occurs when an engine expels gas molecules at high speed.
- This exhaust gas exerts a contact force on the engine.
- The direction of thrust is opposite the direction in which the exhaust gas is expelled.



Gravity

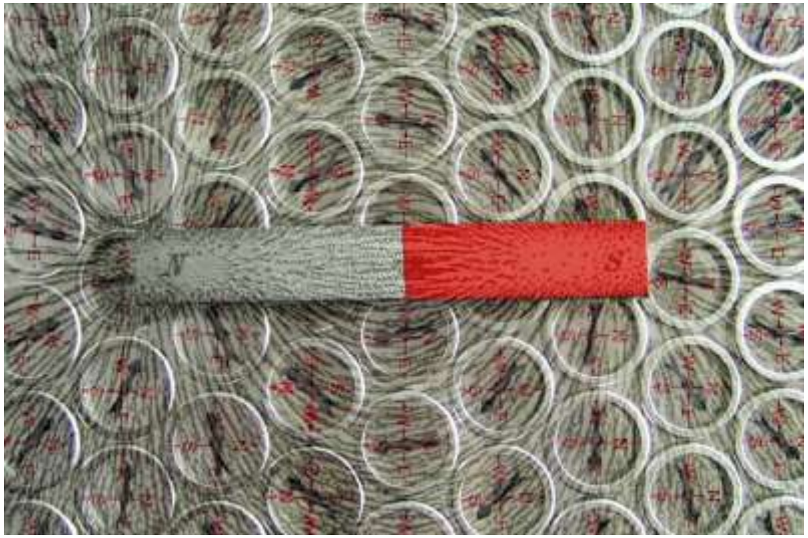
- The pull of a planet on an object near the surface is called the **gravitational force**.
- The agent for the gravitational force is the *entire planet*.
- Gravity acts on *all* objects, whether moving or at rest.
- The gravitational force vector always points vertically downward.



Electric and Magnetic Forces

- Electricity and magnetism, like gravity, exert long-range forces.

- Atoms and molecules are made of electrically charged particles.

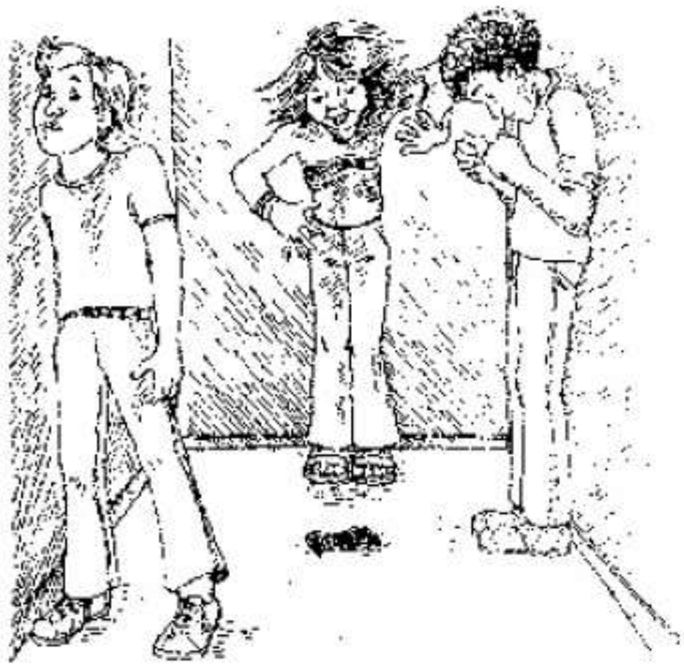


- Molecular bonds are due to the electric force between these particles.

- Most forces, such as normal force and tension, are actually caused by electric forces between the charged particles in the atoms.

Group Activity: Identify the forces in each of these activities

STARTER: Bet you can't pick up a coin off the floor!



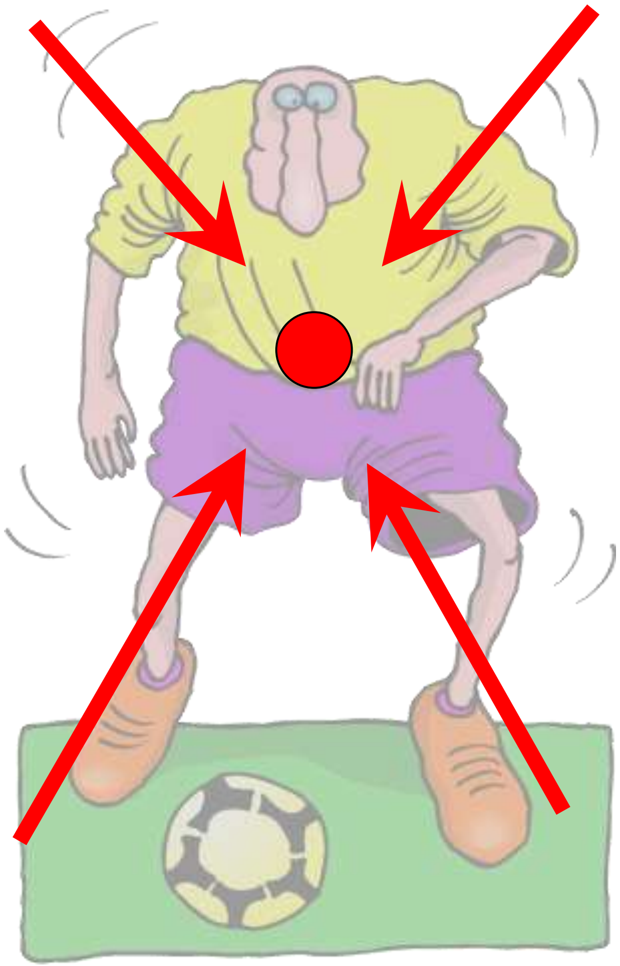
Stand with your back straight against the wall.
Place a coin on the floor at your feet and pick it up.
Try and explain what is happenning

Learning Objectives

- **Define** the term *centre of mass*
- **Explain** that a change in body position during sporting activities can change the position of the centre of mass

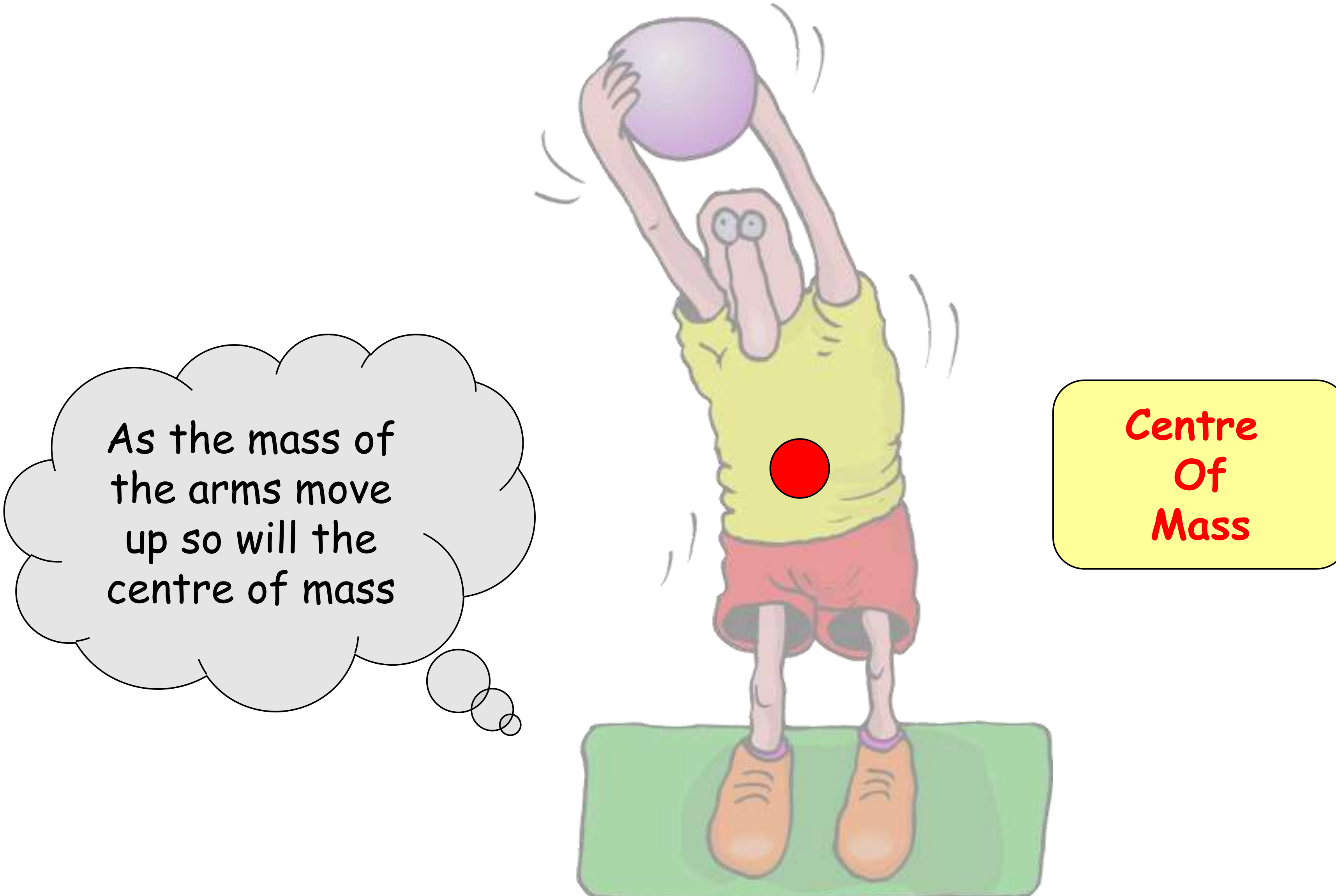
Centre of Mass

Point at which the mass and weight of an object are balanced in all directions..



Centre Of Mass

Can you copy this definition into your workbook?


As the mass of the arms move up so will the centre of mass
Centre Of Mass

- **The Base of Support is the location on a body or object where most of the weight is supported**.
- The larger the area the base of support covers, the more stable an object will be.

Wide BOS

BOS

Narrow BOS

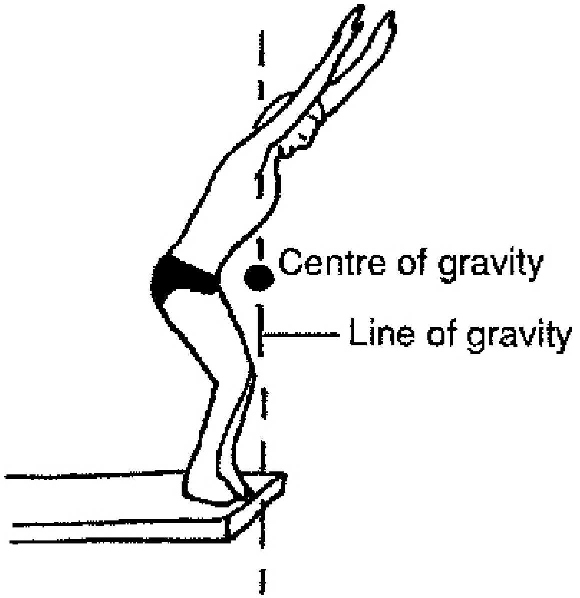
BOS

The object on the left is more stable because of its relatively larger BOS

Can you copy this definition into your workbook?

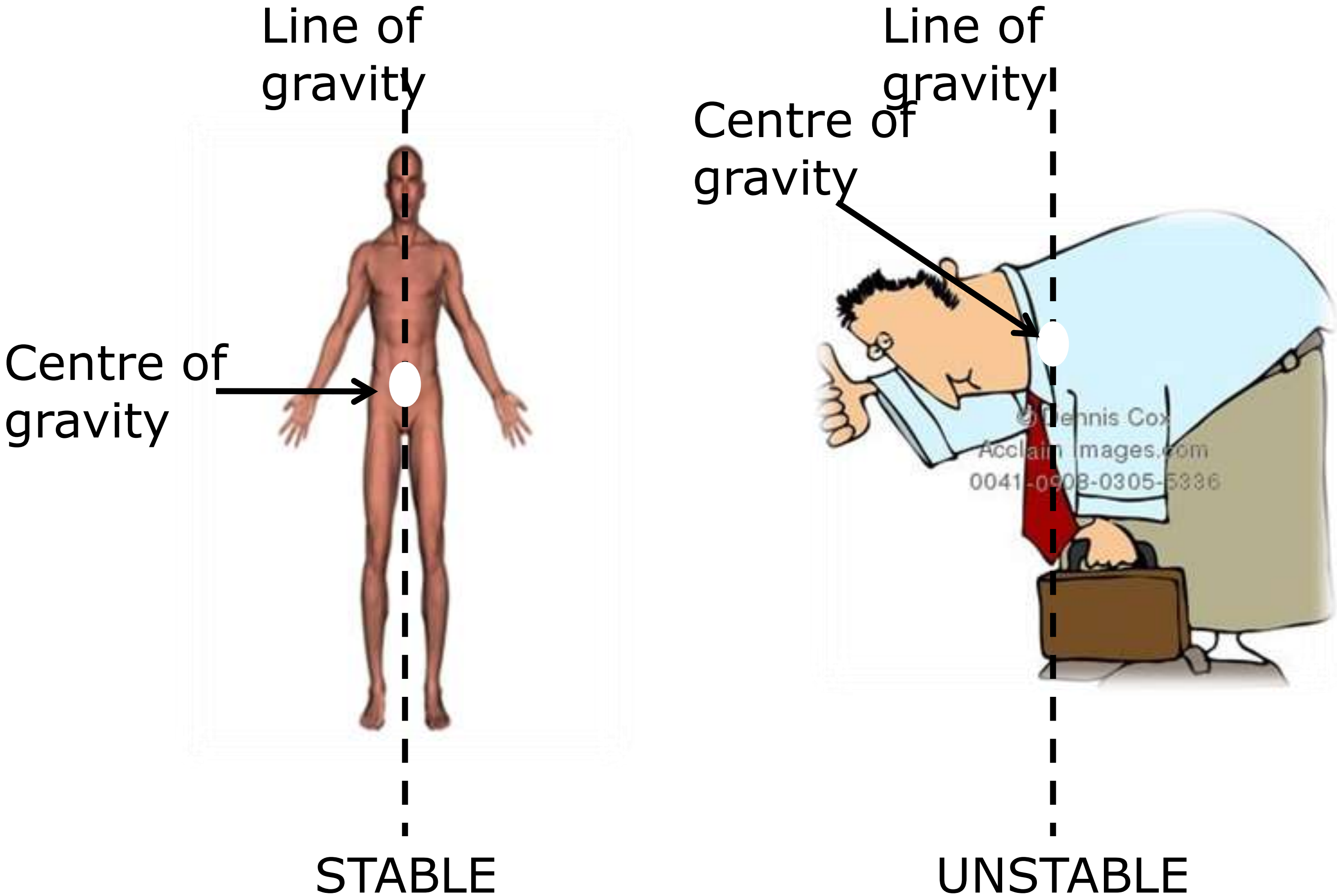
- The **line of gravity** is an imaginary vertical line passing through the center of gravity down to a point in the base of support.

Can you copy this definition into your workbook?



- If the line of gravity falls within the object's base of support (i.e. its contact with the ground), the object is relatively stable.

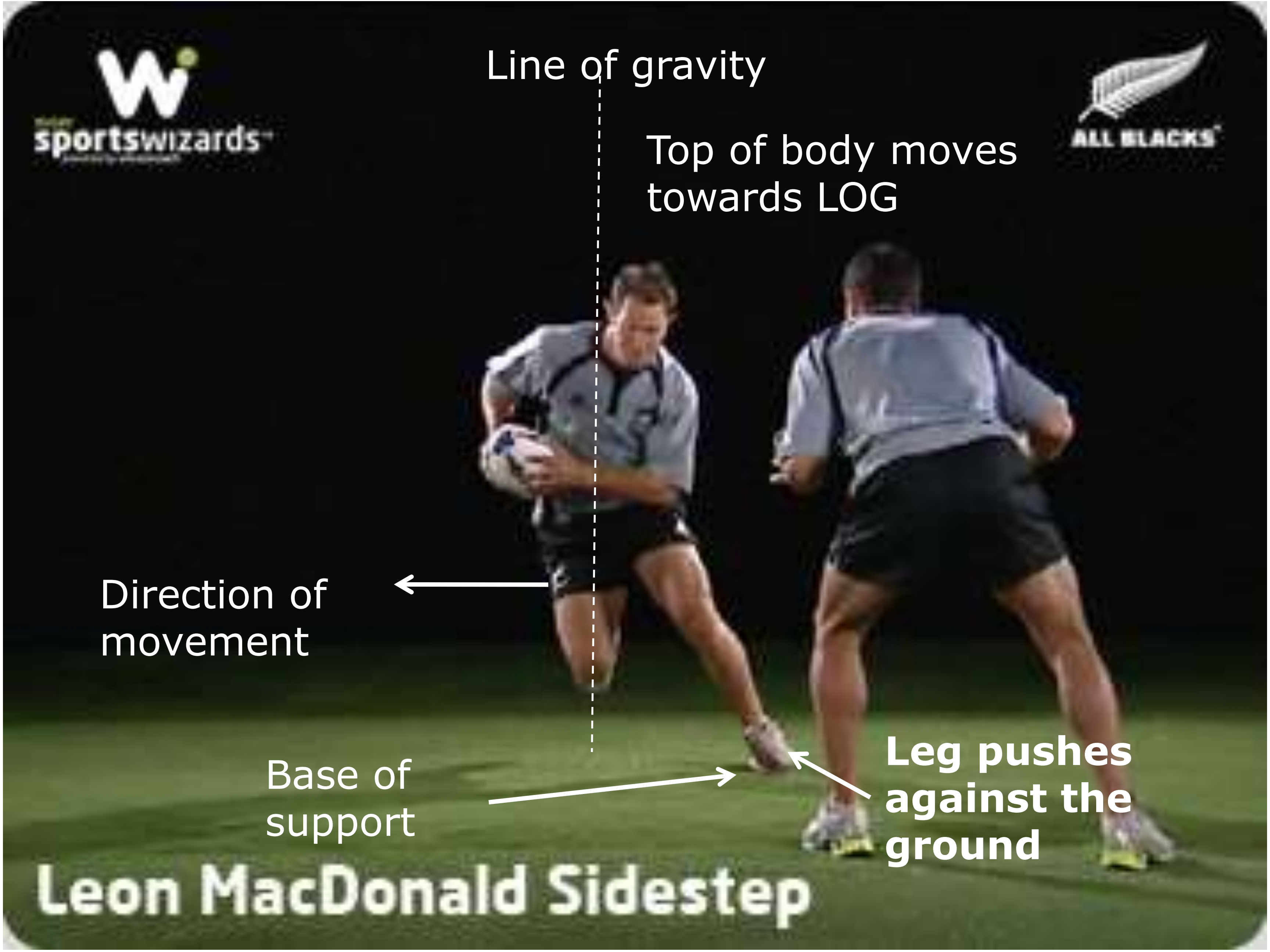
- If the line of gravity falls outside the object's base of support (i.e. its contact with the ground), the object is relatively unstable.



Line of gravity

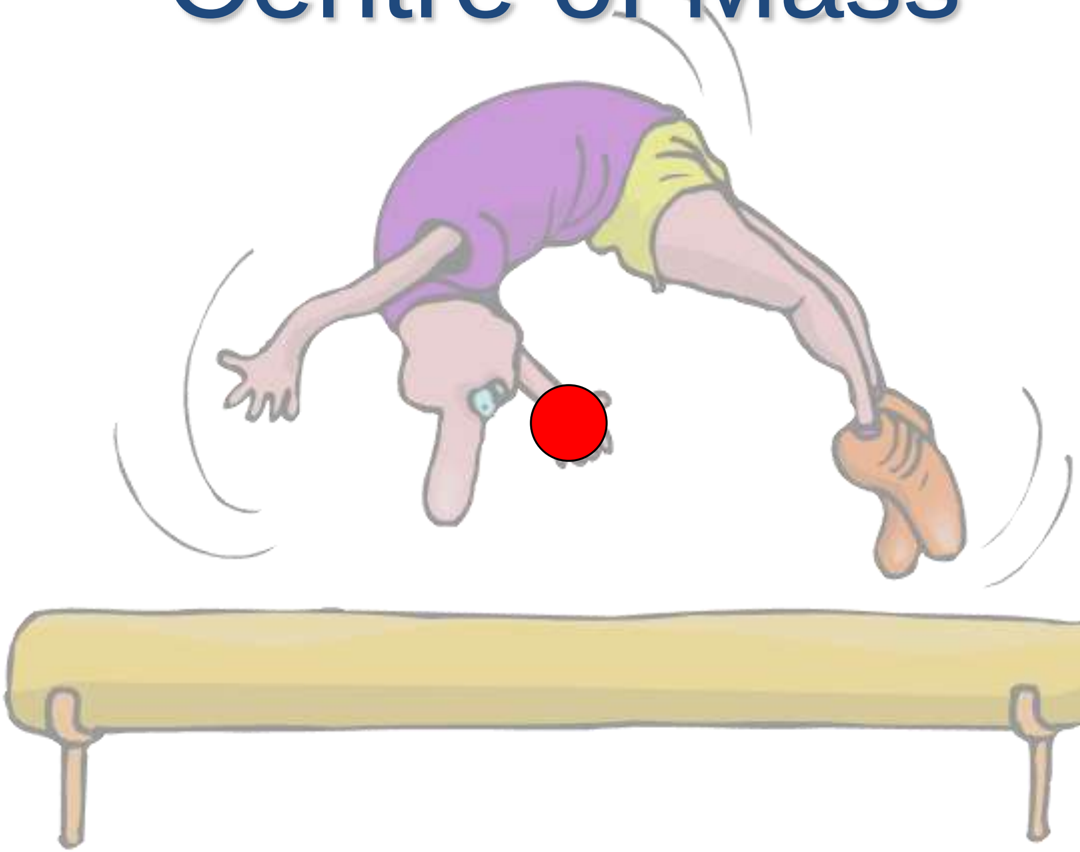
LOG, BOS and movement

- The line of gravity (LOG) must go outside the base of support to initiate or continue movement.
- The direction that the line of gravity takes relative to the BOS will be the direction of the resulting movement.
- The further away the LOG is from the BOS, the greater the tendency the body has to move in that direction. E.g. Evasive running.



Now try the individual activity in your workbook

Centre of Mass

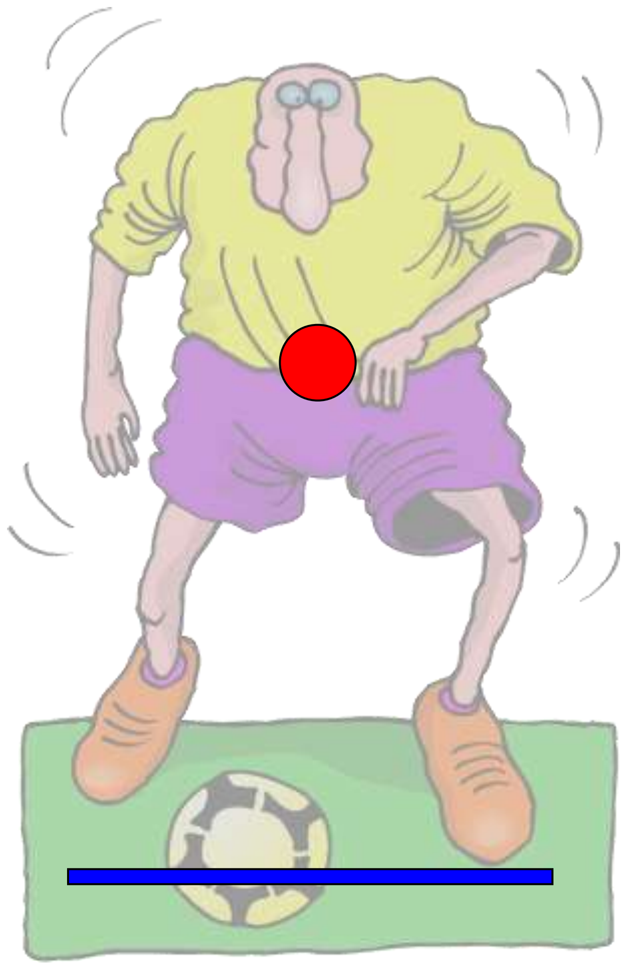


Remember Centre Of Mass **<u>doesn't</u>** always need to be inside the body

Group Thought: Can you list some examples of when centre of mass is outside the body?

Stability

Stability is dependant on the Centre of Mass being directly above the Base of Support



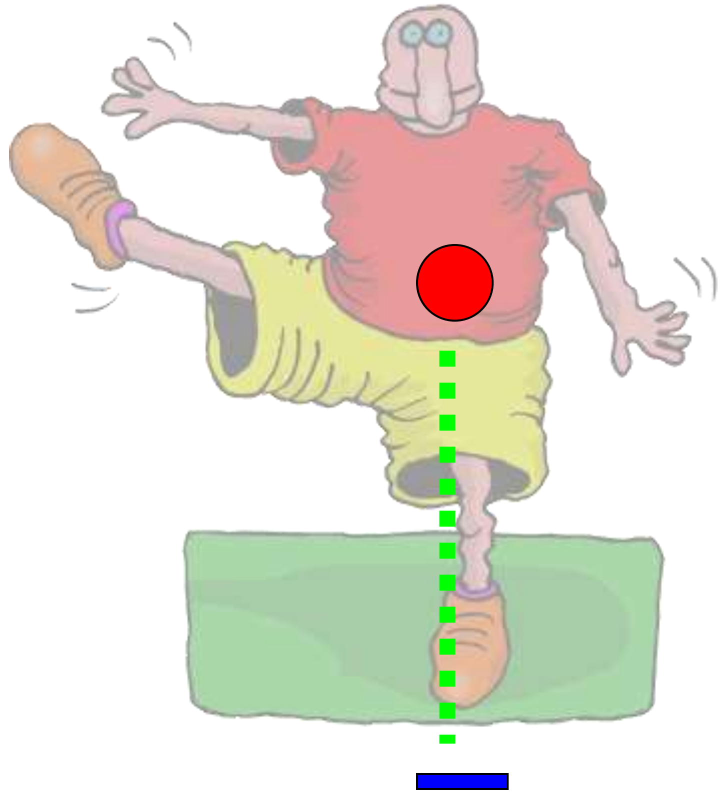
Centre Of Mass

Base of Support

Can you copy this definition into your workbook?

Stability

Stability is dependant on the Centre of Mass being directly above the Base of Support



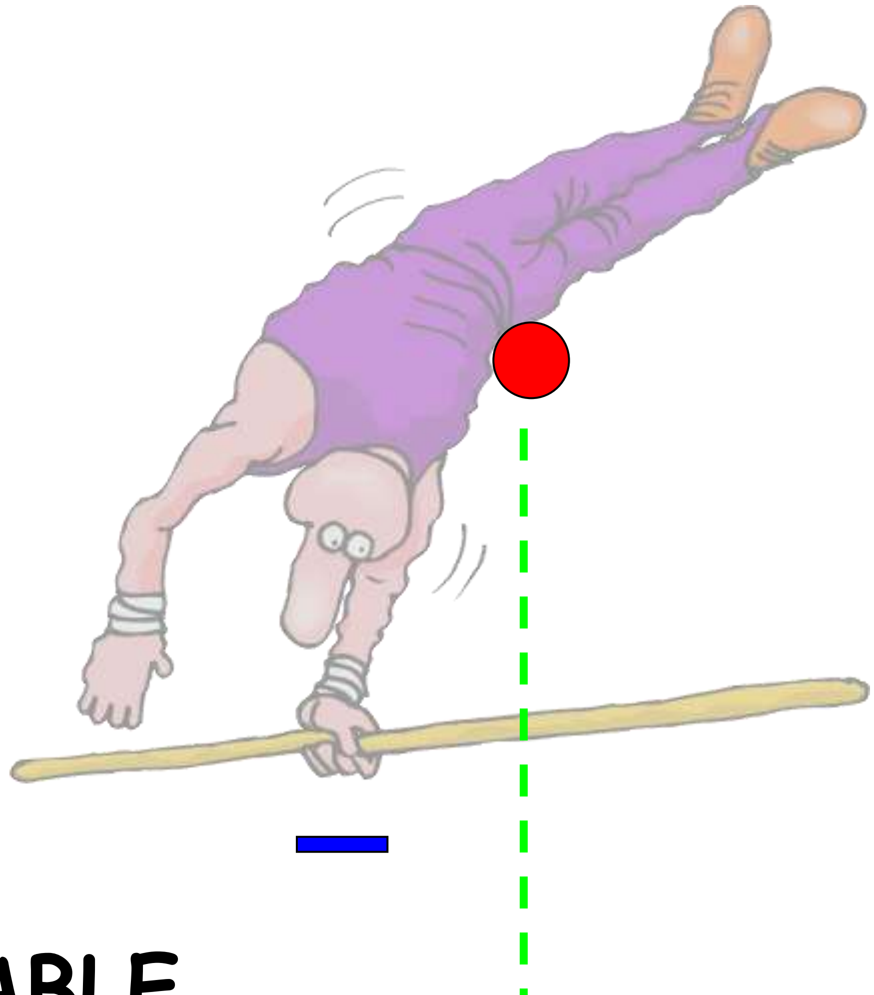
Centre Of Mass

Line of Gravity

Base of Support

Stability

Stability is dependant on the Centre of Mass being directly above the Base of Support



Centre Of Mass

Line of Gravity

Base of Support

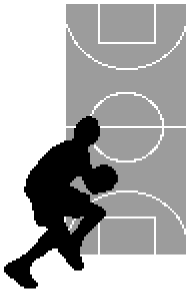
UNSTABLE

GROUP THOUGHT: What factors effect an athlete's stibility?

Stability is dependant on 4 things

Position of the centre of mass

Size of the base of support

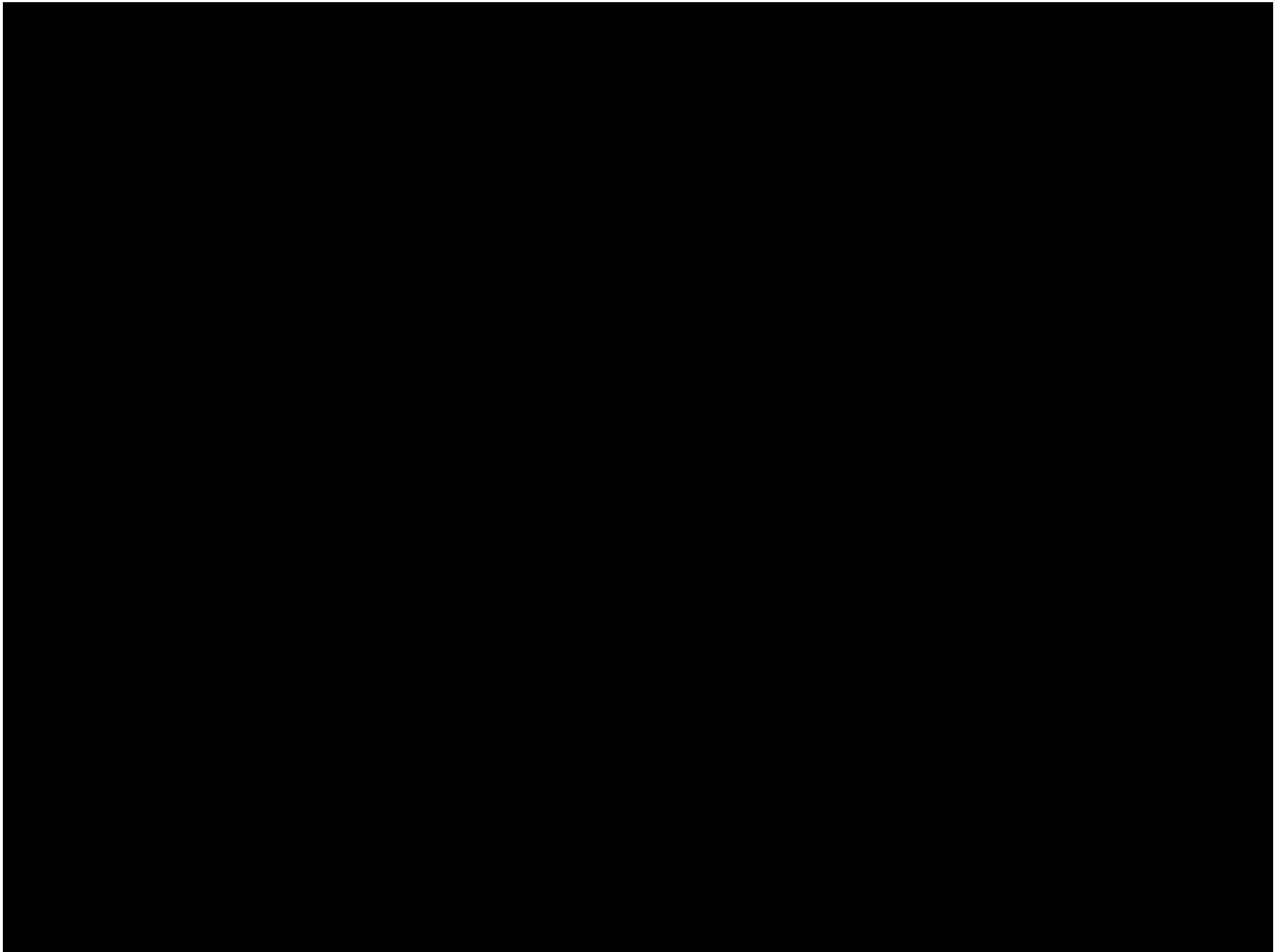


Mass of the Athlete

Where the line of gravity is

Now try the practical activity in your workbook

STARTER – Explain what you see happening in terms of the falls



Learning Objectives

- **Define** Newton's First Law of Motion
- **Outline** a sporting example of Newton's First Law of Motion

Newton’s First Law of Motion

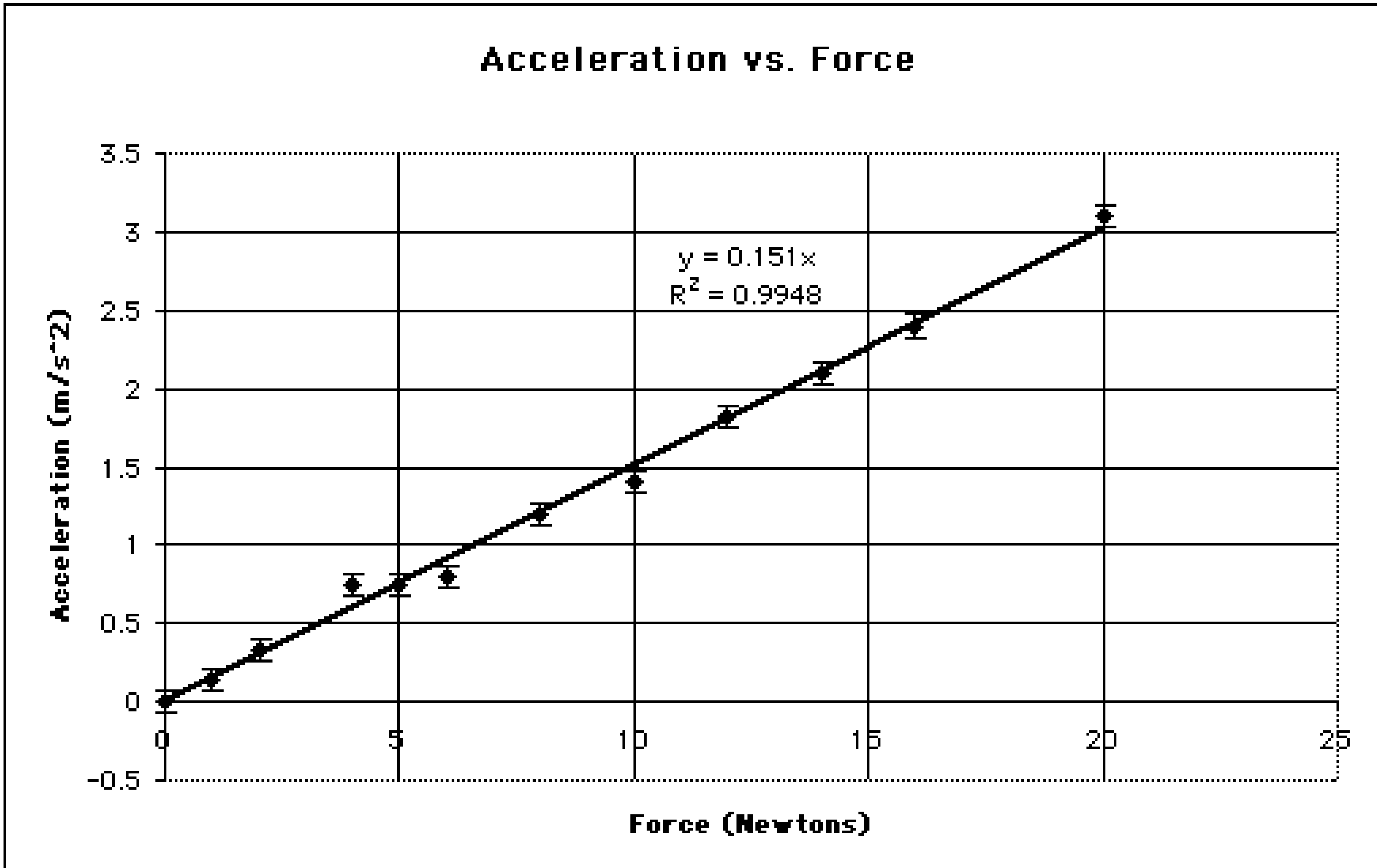
“Every body continues in a state of rest, or uniform motion in a straight line unless acted upon by an external or internal force to change that state. To achieve motion or bring about a change in motion, a force must be applied.”

Newton's First Law - INERTIA

- Inertia is the natural tendency of an object to resist changes in motion
- Inertia is a physical property of matter
- The more mass an object has, the more inertia it has

Now complete the section on Inertia and try the practical activity in your workbook

Starter: Deduce the relationship displayed in the graph

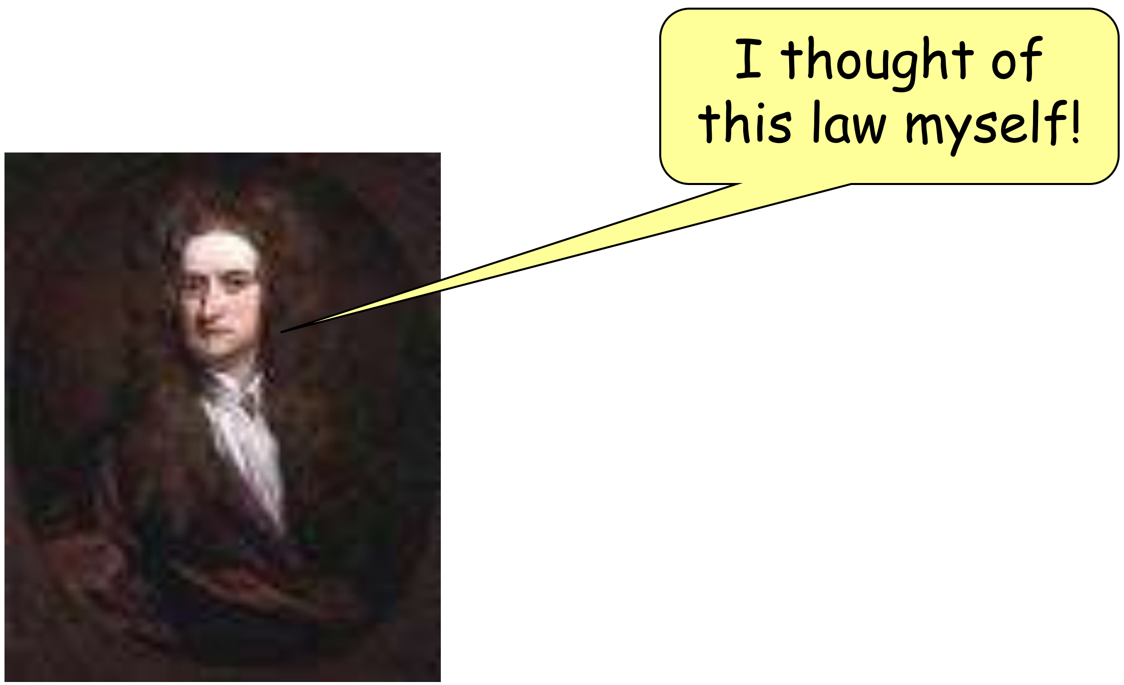


Learning Objectives

- **Define** Newton’s Second Law of Motion
- **Outline** a sporting example of Newton’s Second Law of Motion

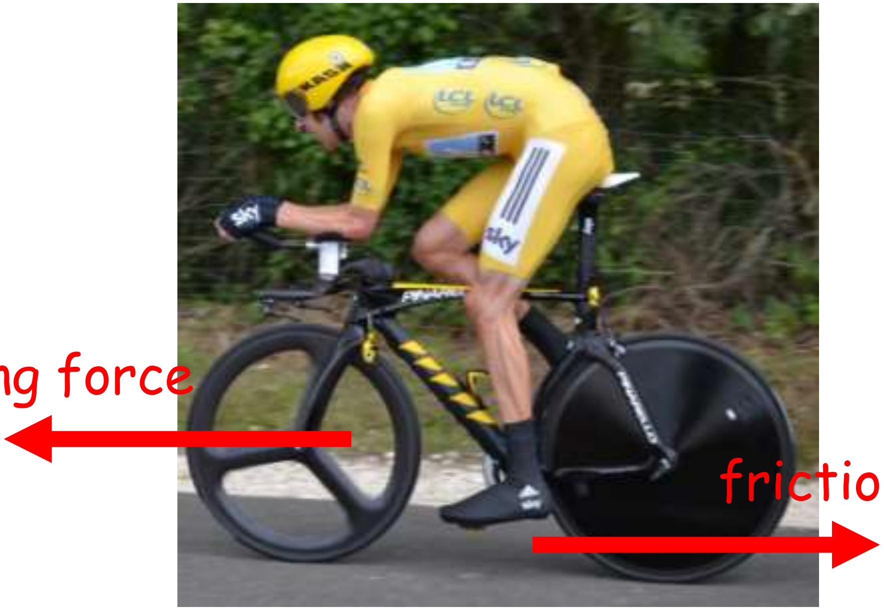
Newton’s second law

Newton’s second law concerns examples where there is a resultant force.



Let’s go to Bradley Wiggins….

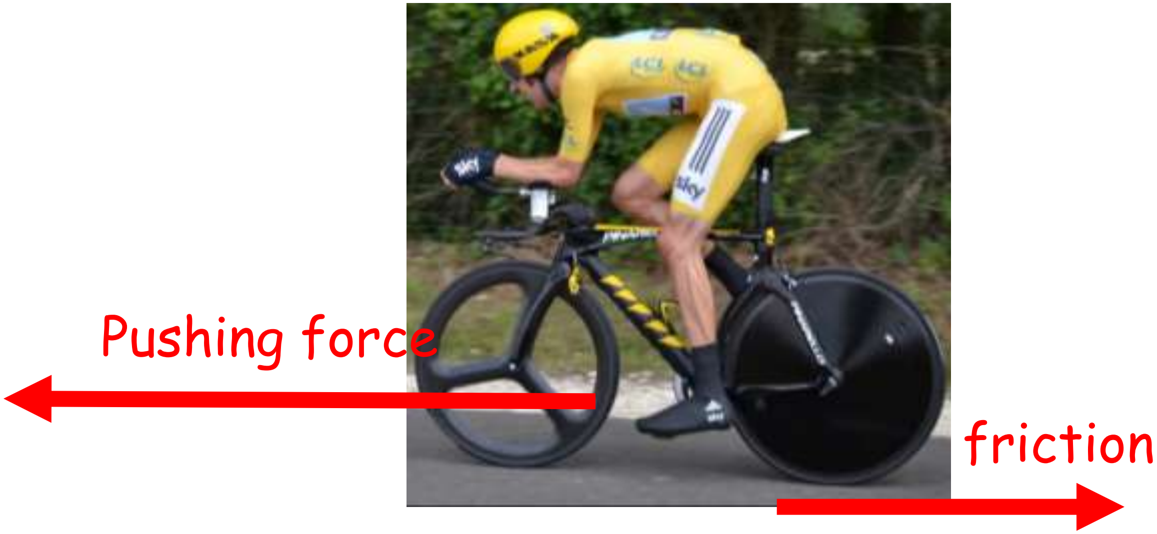
Remember when the forces are balanced (no resultant force) he travels at constant velocity.



Constant velocity

Newton's 2nd law

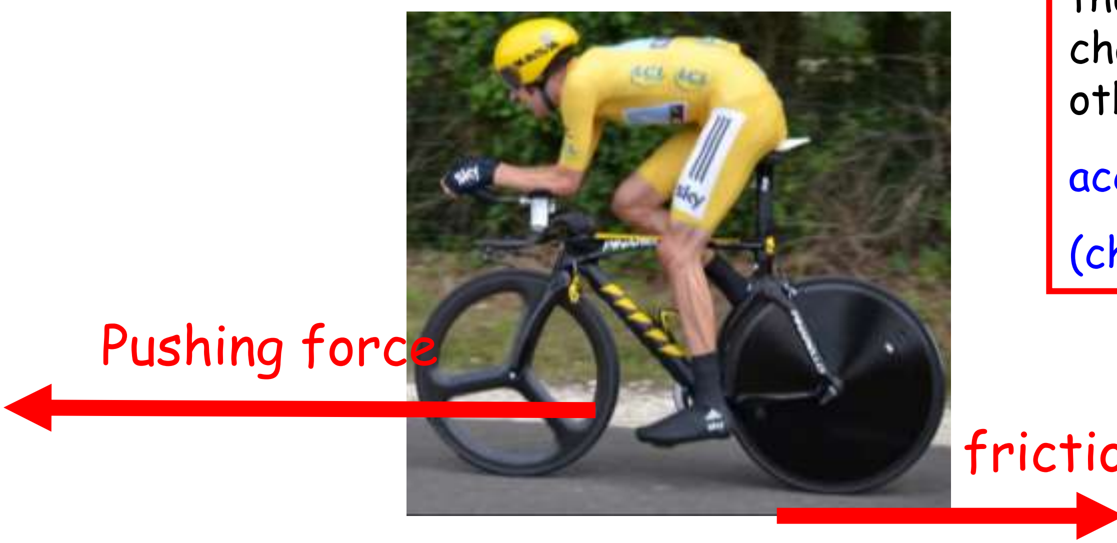
Now lets imagine what happens if he pedals faster.



Newton's 2nd law

His velocity changes (goes faster).

He accelerates!



Remember from last year that acceleration is rate of change of velocity. In other words

acceleration =

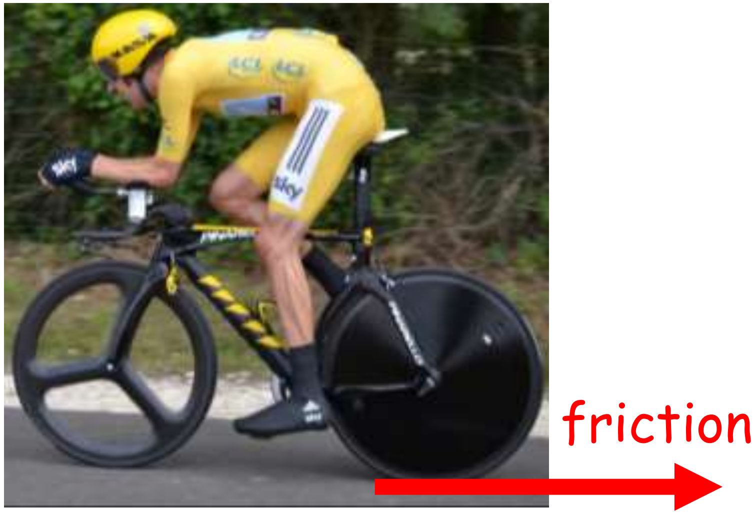
(change in velocity)/time

Newton's 2nd law

Now imagine what happens if he stops pedalling.

Newton’s 2nd law

He slows down (decellerates). This is a negative acceleration.

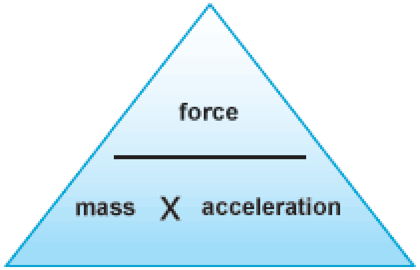


Newton's 2nd law

So when there is a resultant force, an object accelerates (changes velocity)

Nikki Lauda's Ferrari

Newton's 2nd law

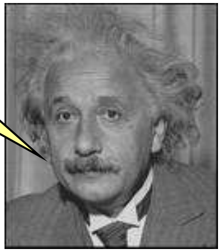


There is a mathematical relationship between the resultant force and acceleration.

Resultant force (N) = mass (kg) x acceleration (m/s^2)

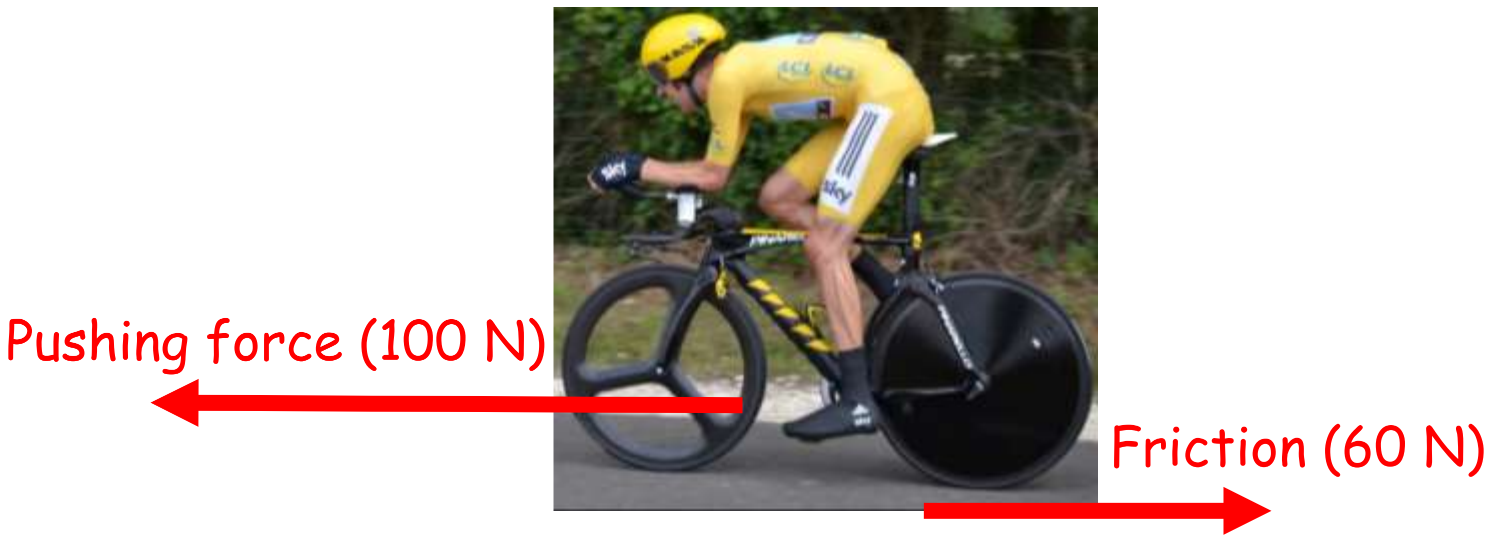
$$F_R = ma$$

It's physics, there's always a mathematical relationship!



Group Problem

What will be Bradley Wiggin's acceleration?



Mass of Wiggins and bike = 100 kg

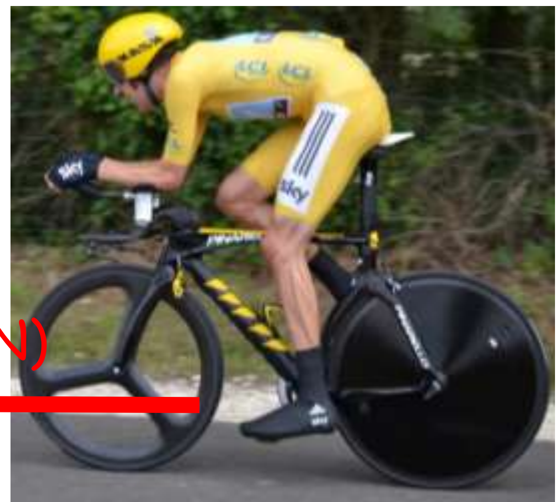
Answer

Resultant force = 100 – 60 = 40 N

$F_R = ma$

40 = 100a

$a = 0.4\ m/s^2$



Pushing force (100 N)

Friction (60 N)

Now complete the individual activity in your workbook and then carry out the practical activity.

STARTER: Pairs discussion

- What makes an object hard to stop?
- Is it harder to stop a bullet, or a truck travelling along the highway?
- Are they both as difficult to stop as each other?

Learning Objectives

- **Define** linear momentum and impulse
- **Explain** the relationship between linear momentum and linear impulse
- **Analyse** force-time graphs

Momentum

- The bullet is hard to stop because it is travelling very fast, whereas the truck is hard to stop because it has a very large mass.

Momentum

- It makes sense to assume that a bullet travelling twice as fast would be twice as hard to stop, and a truck twice the mass would also be twice as hard to stop.

Momentum

- ***The quantity of motion of a moving body, measured as a product of its mass and velocity***

Momentum ($kg.m.s^{-1}$) = Mass (kg) x Velocity ($m.s^{-1}$)

$$\mathbf{p = mv}$$

Group Problem

- A shotput has a mass of 7kg and a velocity of 3 $m.s^{-1}$. What is its momentum?

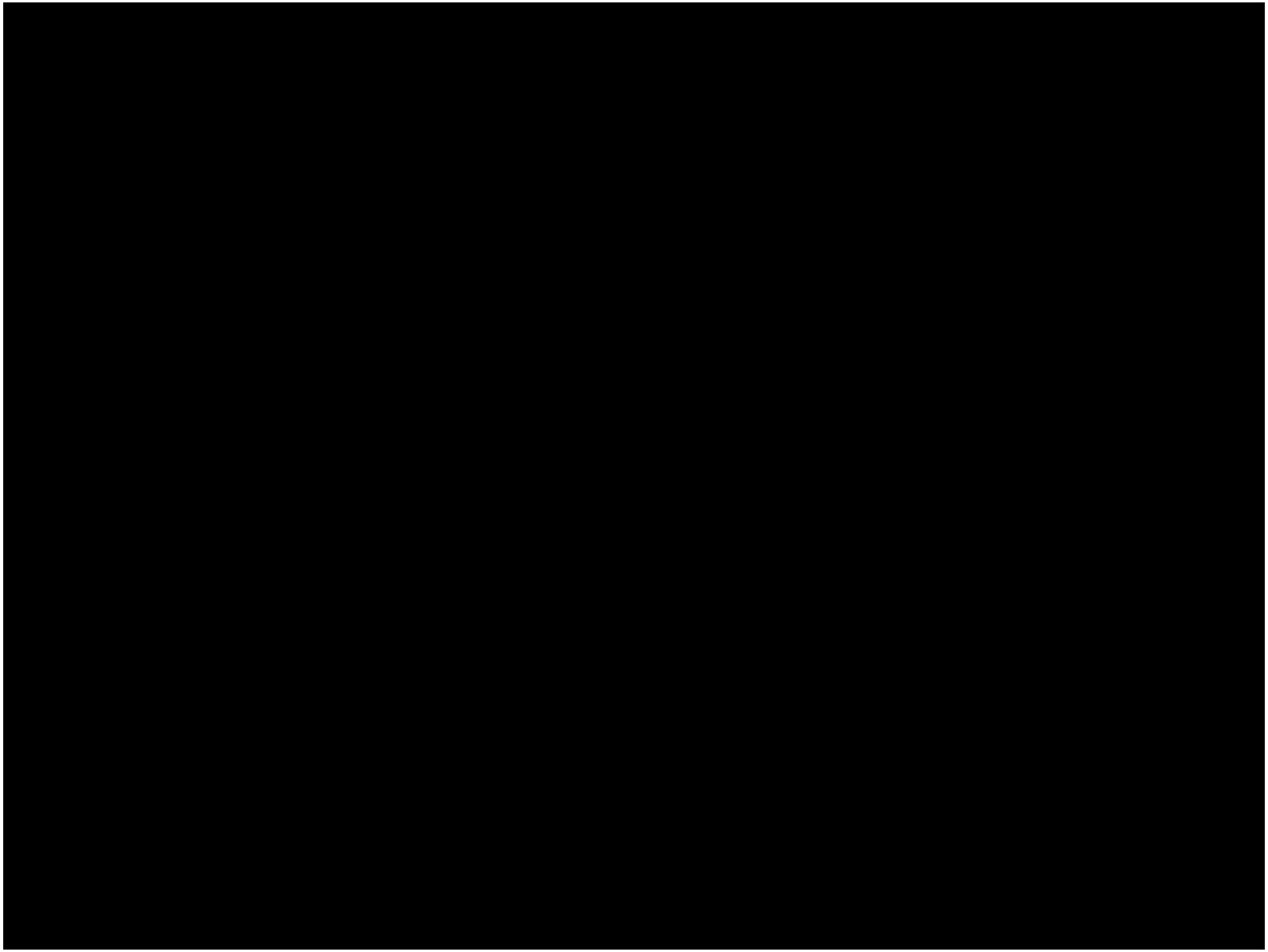
Momentum = Mass x velocity

= 7kgx 3 $m.s^{-1}$

= 21 $kg.m.s^{-1}$.

Now complete the individual activity in your workbook

Individual Activity: Answer the questions in your workbook as you watch this video



How hard is it to stop a moving object?

To stop an object, we have to apply a force over a period of time.

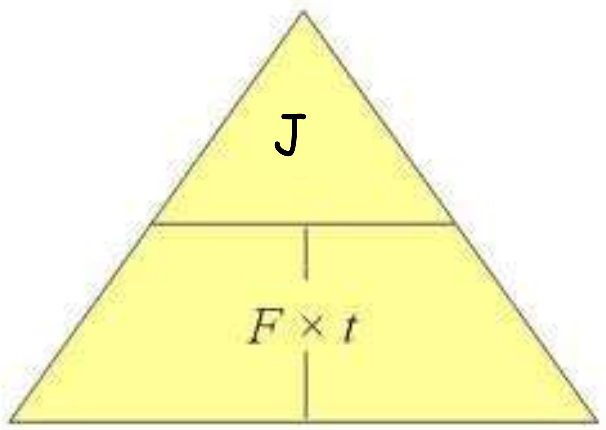
This is called **Impulse**

Impulse = FΔt

J = impulse (N·s)

F = force (N)

Δt = time elapsed (s)



Relationship between impulse and momentum

- Using Newton's 2nd Law we get

$$F = m * a = m * \frac{\Delta v}{t}$$

or

$$F = m * \frac{\Delta v}{t}$$

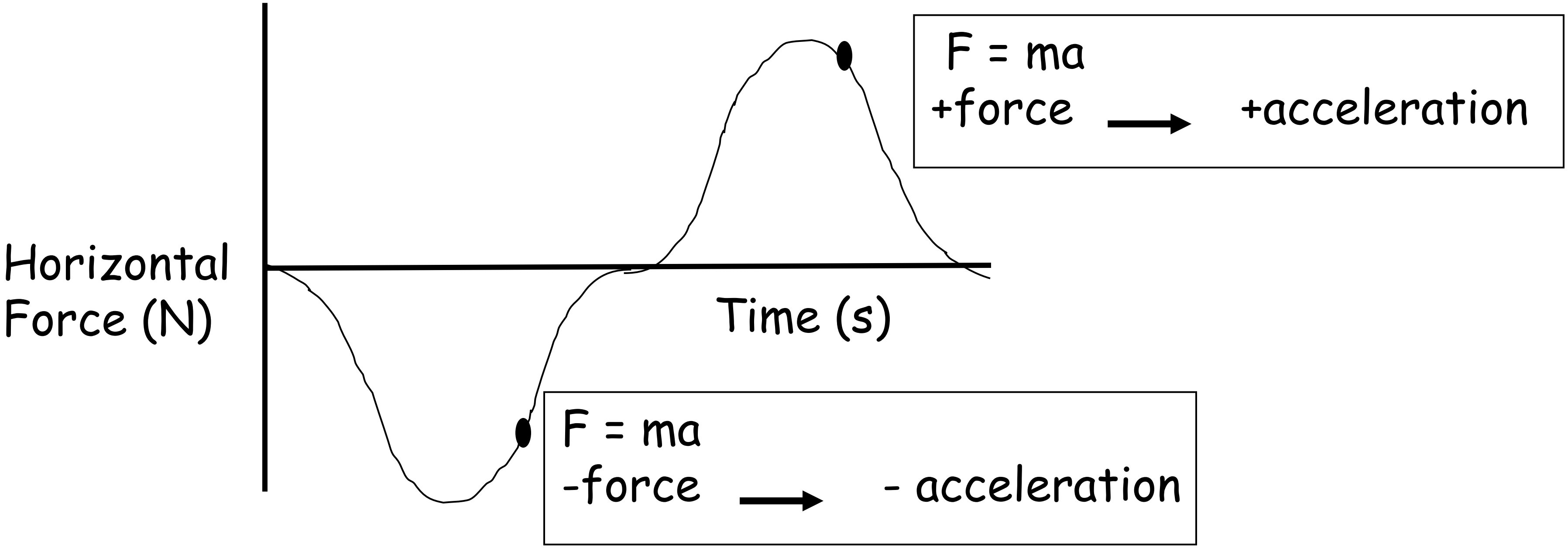
If both sides of the above equation are multiplied by the quantity t, a new equation results

Now complete the section on impulse in your workbook

$$F * t = m * \Delta v$$

Which means
Impulse = change in momentum

Impulse and Force-time graphs



At each instant in time during a contact, a force acts to produce an acceleration. The Impulse is the net effect of all those instantaneous forces. In other words, it is the average force multiplied by the total time over which the forces have acted.

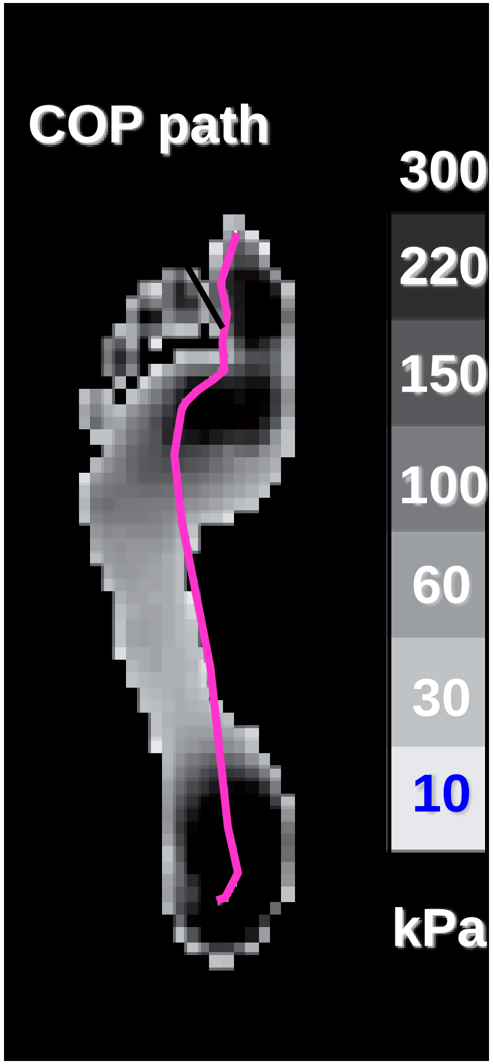
Impulse = Average Force x Time force was applied or $\int F\,dt$
Impulse produces Mass x Change in Velocity or $m\Delta v$

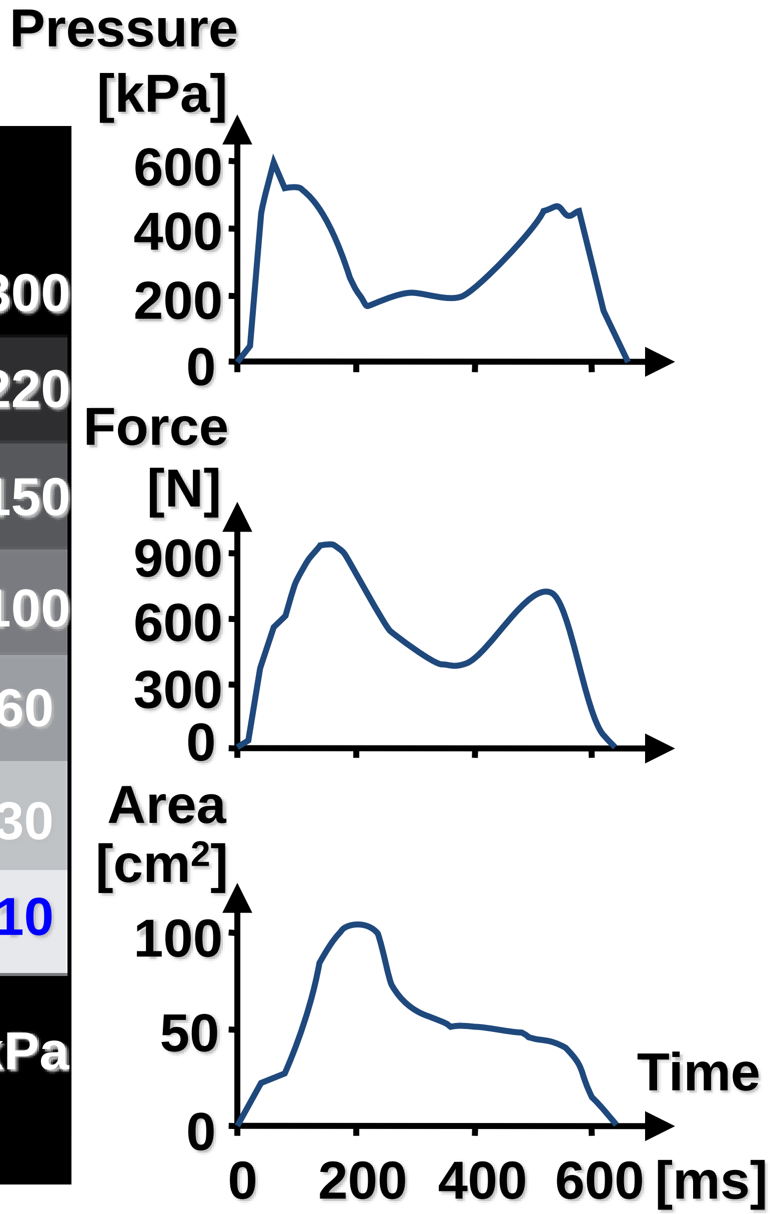
Running Contact

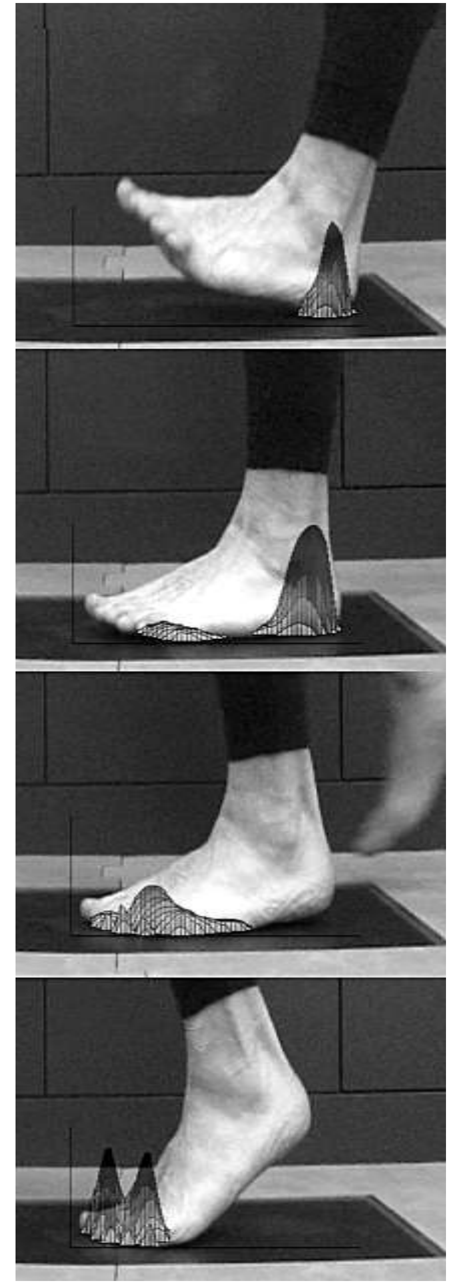
- During a single running contact, your body undergoes both positive and negative forces that produce positive and negative accelerations.

- A force acting for a period of time produces an impulse.

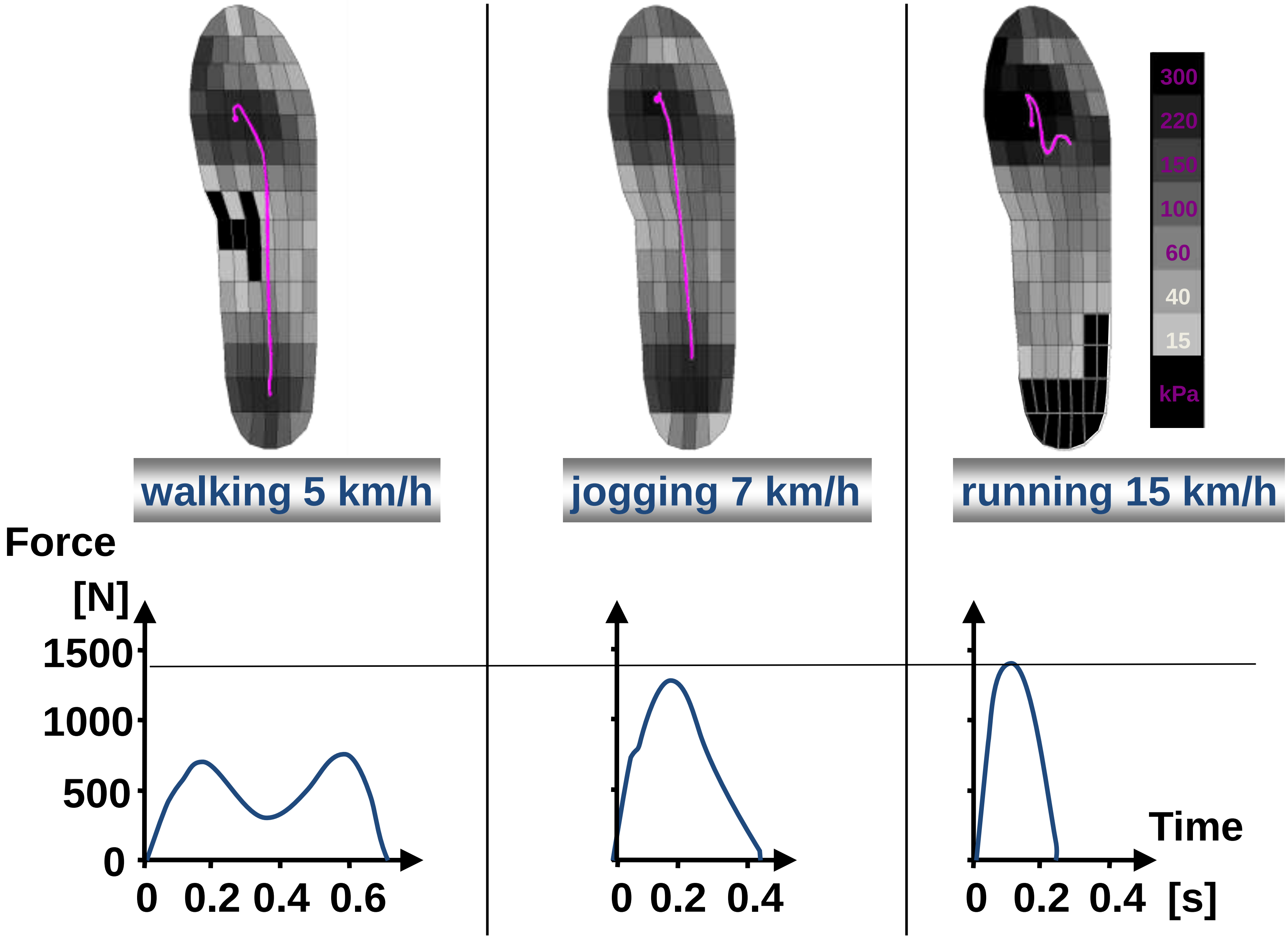
- If the positive and negative impulses cancel each other out (equal areas), then the net impulse is zero and the runner is moving at a constant speed.





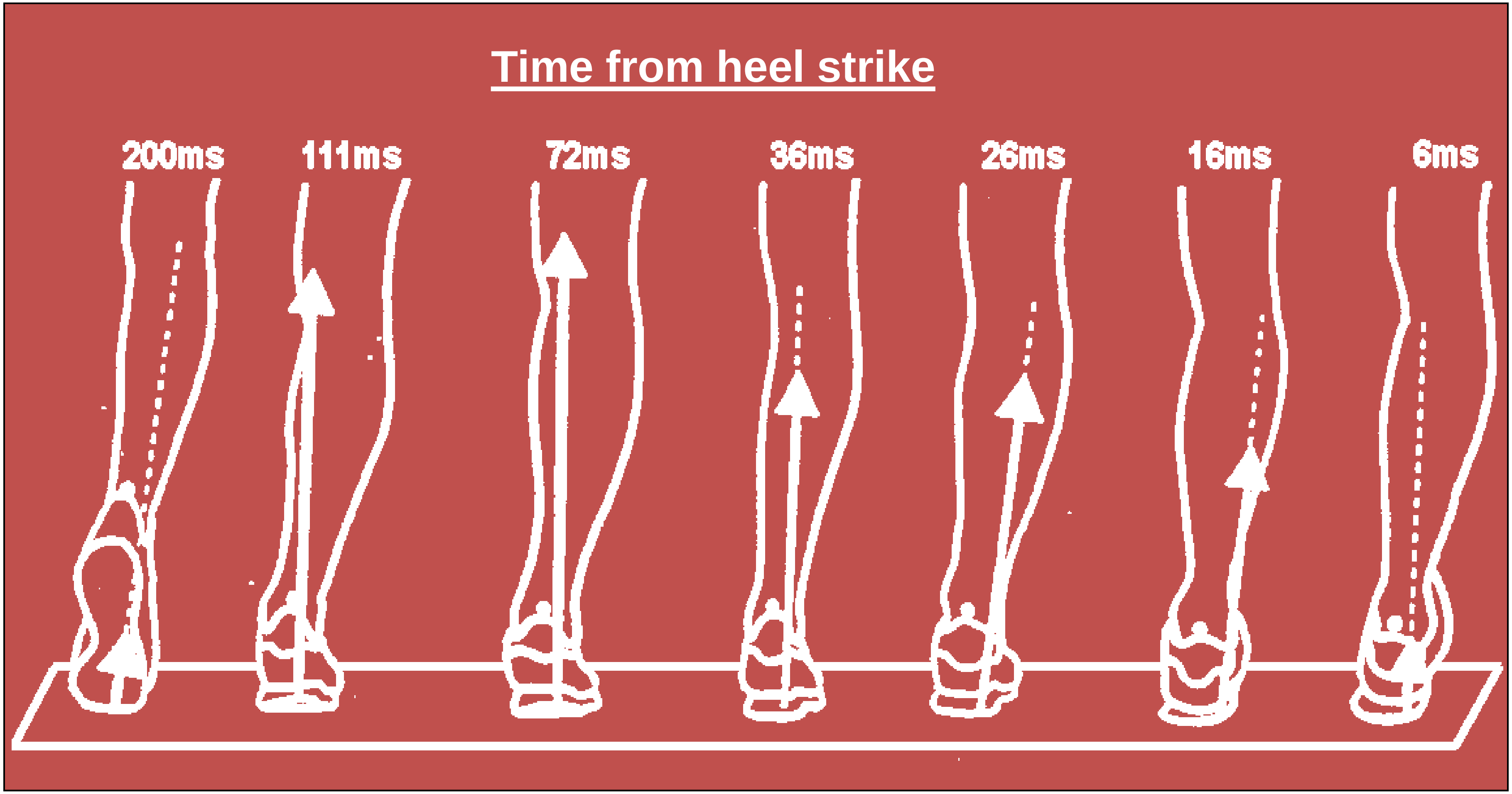


Biomechanicanics of the Musculo-skeletal System
Nigg, B.M. and Herzog, W. Eds., 3rd Edition, 2007



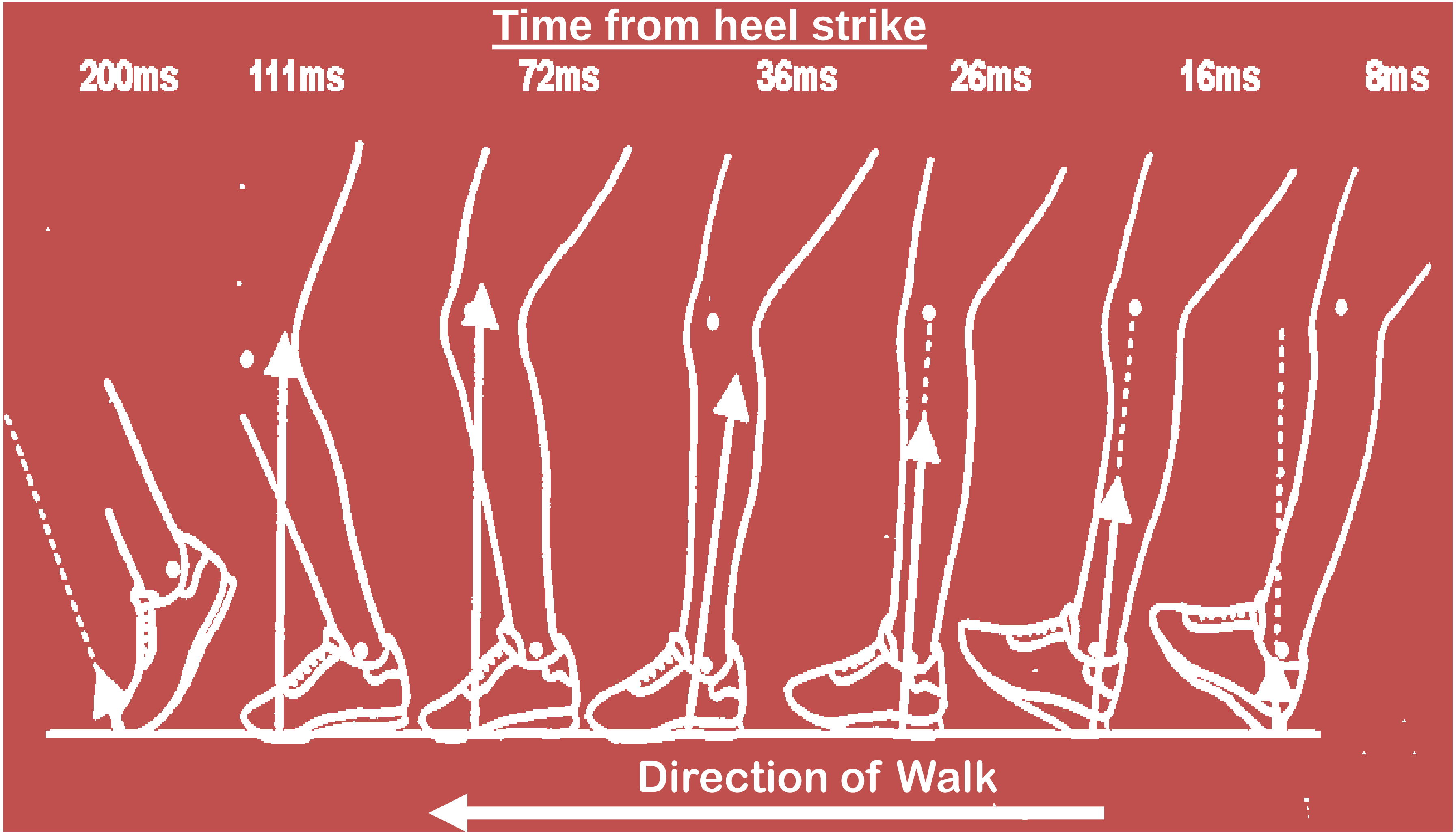
Biomechanicanics of the Musculo-skeletal System
Nigg, B.M. and Herzog, W. Eds., 3rd Edition, 2007

GRF During Walking (Rear)



Biomechanicanics of the Musculo-skeletal System
Nigg, B.M. and Herzog, W. Eds., 3rd Edition, 2007

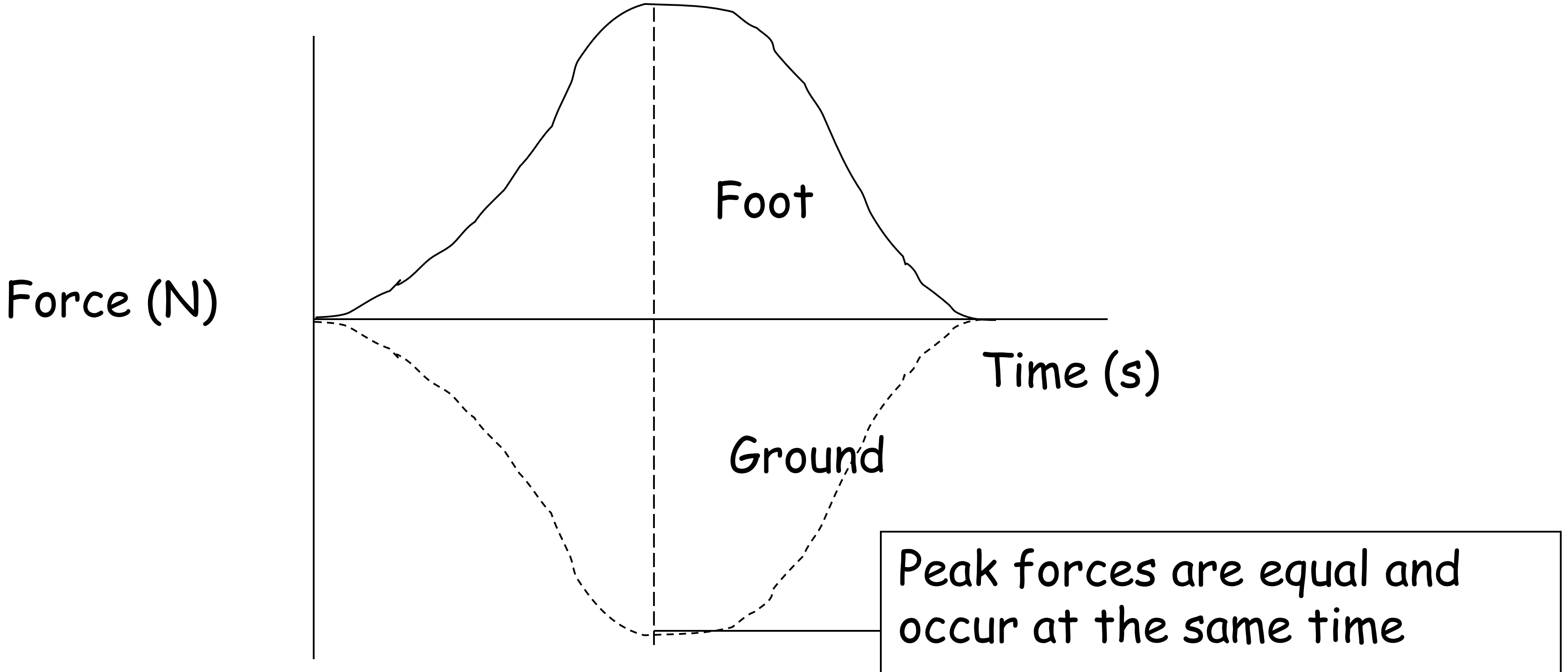
GRF During Walking (Lateral)

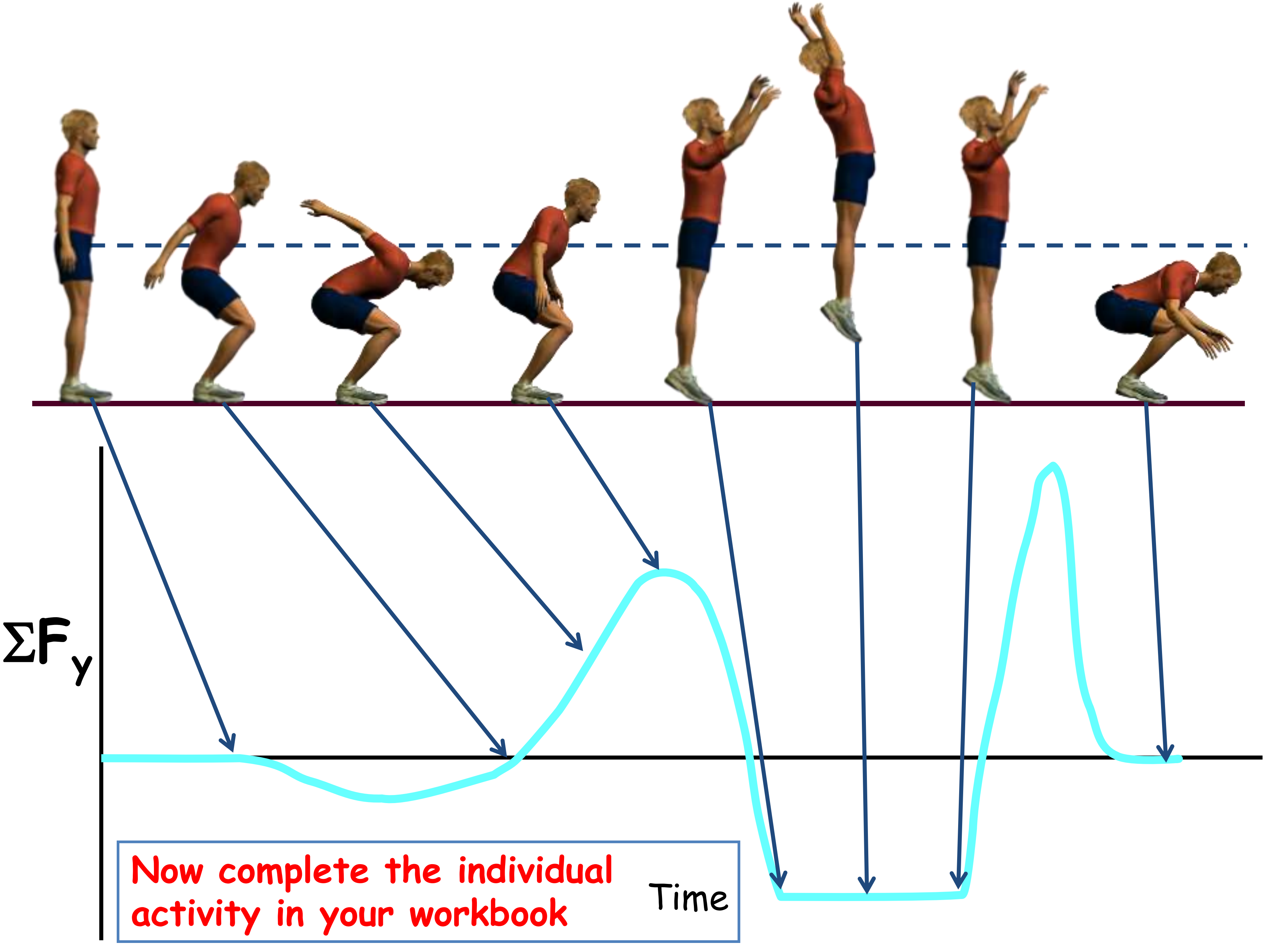


Biomechanicanics of the Musculo-skeletal System
Nigg, B.M. and Herzog, W. Eds., 3rd Edition, 2007

Equal and Opposite

When a ball hits a bat, or a foot lands on the ground, there are equal and opposite impulses applied to both objects. The force-time curve of one is the inverted force time curve of the other.





Now complete the individual activity in your workbook

STARTER: Impulse Past Paper Question

You have 10 minutes to try the PPQ in your workbook
Answer individually as if in exam conditions

Q1a Define the term impulse. (1)

The product of force and time / the application of force over a period of time (which changes the velocity of the body);

The area under a force-time graph;

The product of the magnitude of a torque and its time of application;

Q1b Net impulses are a combination of positive and negative impulses. Describe the net impulse during the 100m sprint for each of the following stages: (1)

i. Early Stage (1)

Net positive impulse

ii. Middle Stage (1)

Net zero impulse

iii. Final Stage (1)

Net negative impulse

Q1c **Compare the acceleration of Asafa Powell in the early stage to the final stage of the 100m sprint. (2)**

In the early stage, Powell is accelerating / there is positive acceleration, in the final stage Powell is decelerating / there is negative acceleration;

In both the early and final stage the deceleration is rapid;

Q1d **Usain Bolt, the winner of the 100m sprint at the 2008 Olympics, reaches his peak velocity later in the sprint than Asafa Powell.**

Using the information above, predict how Usain Bolt's middle stage force-time graph would be different from Asafa Powell's for the 100m sprint. (2)

Net impulse is positive for Bolt;

Bolt's graph would show a greater amount of positive force than negative force;
Ratio of positive to negative force is greater / ratio of negative to positive force is less;
Bolt's graph would show a lesser amount of negative force;

Award credit for an accurate graphical representation

Learning Objectives

- **Define** Netwon’s Third Law of Motion
- **Explain** how Newton’s Third Law of Motion applies to various sporting activities

GROUP THOUGHT

Push the block down into the water

THINK!

What do you see happening?

Why is it happening?

Newton's 3rd law

If a body A exerts a force on body B, body B will exert an equal but opposite force on body A.

Hand exerts force on table

ACTION

Together these arrows are known as a **FORCE PAIR**

Table exerts force on hand

REACTION

Can you copy this definition into your workbook

Action and Reaction Forces Don't Cancel

- You constantly use action-reaction force pairs as you move about.
- When you jump, you push down on the ground.
- The ground then pushes up on you. It is this upward force that pushes you into the air.

- You constantly use action-reaction force pairs as you move about.
- When you jump, you push down on the ground.
- The ground then pushes up on you. It is this upward force that pushes you into the air.

This is unbelievably cool!

Large and Small Objects

- When you walk forward, you push backward on the ground.
- Your shoe pushes Earth backward, and **Earth pushes your shoe forward.**

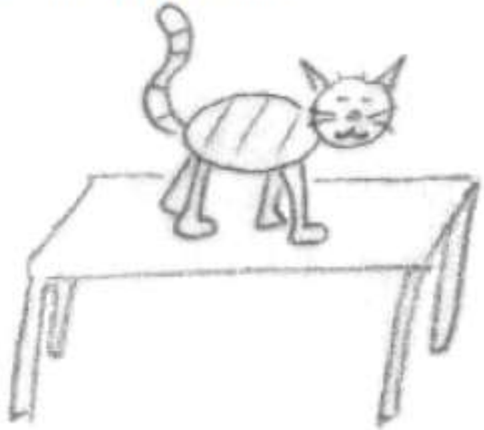
- Earth has so much mass compared to you that it does not move noticeably when you push it.

- If you step on something that has less mass than you do, like a skateboard, you can see it being pushed back.

GROUP ACTIVITY:

Draw the FORCE PAIRS onto the diagrams below

A: Cat on the table



B: Pencil on the paper

C: Board on the wall

D: Fuel on the rocket

A: Cat on the table

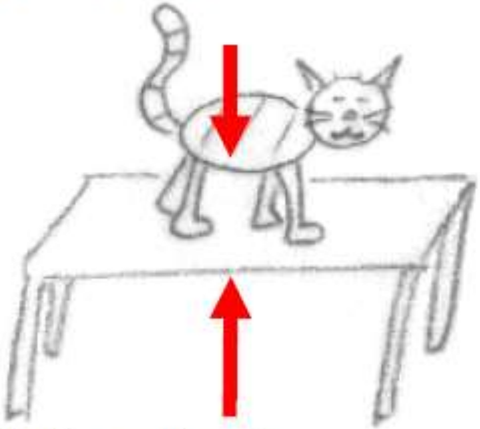
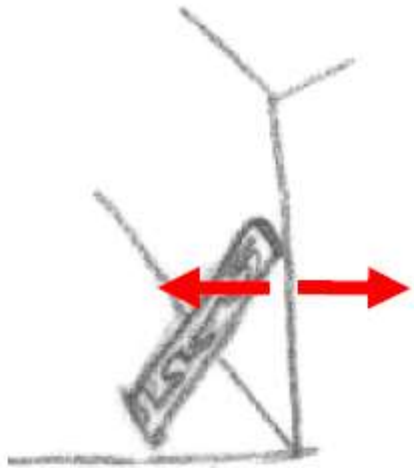


Table on the cat

B: Pencil on the paper

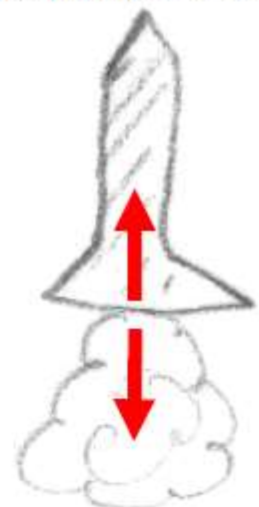
Paper on the pencil

C: Board on the wall



Wall on the board

D: Fuel on the rocket



Rocket on the fuel

Now try the individual activity in your workbook

GROUP THOUGHT

- Why use starting blocks in a sprint?

Newton's Third Law - PPQ

Using Newton's third law of motion, explain how a basketball/volleyball player can jump off the ground to play the ball. (3)

Using Newton's third law of motion, explain how a basketball/volleyball player can jump off the ground to play the ball. (3)

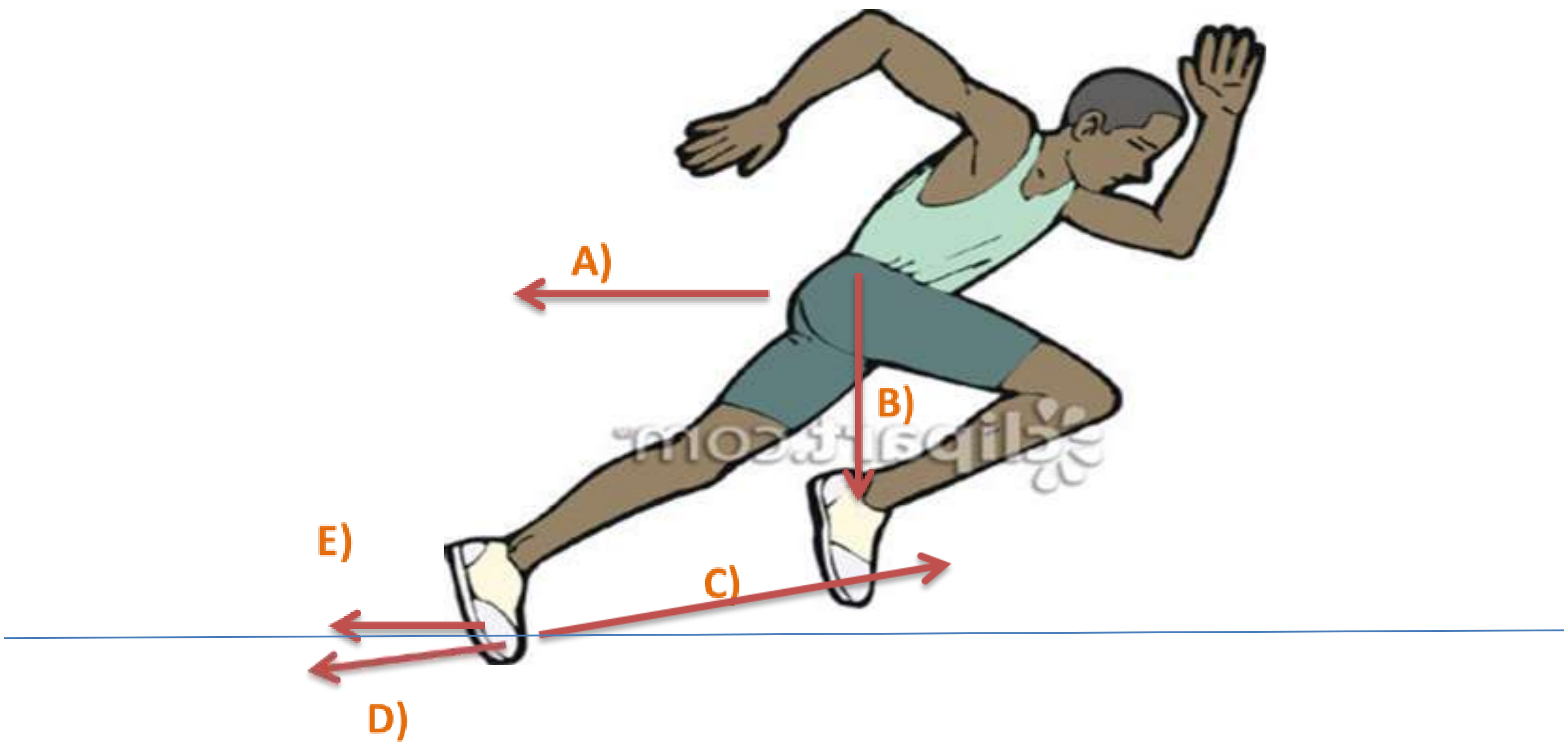
The basketball/volleyball player uses muscular force (action) to push down against the ground/earth (action);

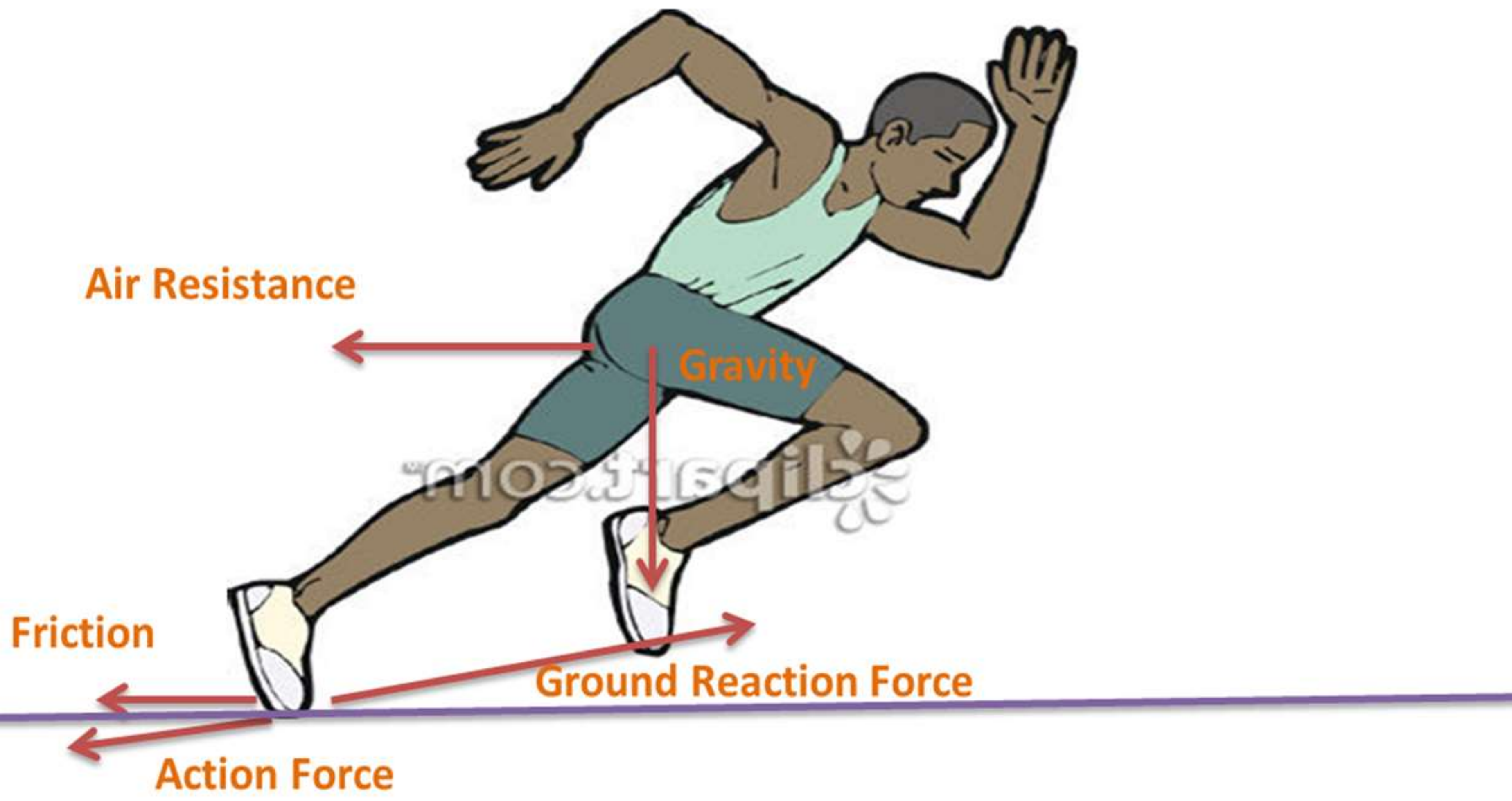
The ground/earth exerts an opposed equal force (action), resulting in upwards motion of the basketball/volleyball player (reaction);

Because the ground/earth is more massive than the individual, the effect on the individual is greater than the effect on the ground/earth, pushing the player off the ground;

The impulse pushes the player off the ground;

STARTER: Identify the forces A-E in the image below, that act on the sprinter during the race (5marks)




Air Resistance
Gravity
Friction
Ground Reaction Force
Action Force

Learning Objectives

- **Define** the Law of Conservation of Momentum

- **Discuss** the coefficient of restitution

Law of conservation of momentum

- **The law of conservation of linear momentum** says that

“in an isolated system, momentum remains constant”.

Conservation of momentum

- In a **collision** between two objects, momentum is conserved (total momentum stays the same). i.e.

Total momentum before the collision = Total momentum after

Momentum is not energy!

GROUP THOUGHT: Which sports involve *collisions?*

BEFORE

Fullback → p=100 kg m/s

Linebacker ← p=120 kg m/s

AFTER

Combined Unit

← p= 20 kg m/s

Individual Activity: Answer the questions in your workbook

The Science of NFL Football: Newton's Third Law of Motion

More Episodes | About The Science of NFL Football | More Special Reports

Newton's Third Law of Motion: *NBC's Lester Holt looks at Newton's Third Law of Motion and the role that conservation of momentum plays whenever players collide on the football field, with former NFL linebacker Hardy Nickerson, Tony Schmitz of the University of Florida and Jim Gates of the University of Maryland.*

Group Activity

1. Drop a cold rubber ball from a metre in height
2. How how does it bounce?
3. Soak the ball in hot water for a few minutes
4. Drop the ball from 1m again
5. Is there any difference in bounce height?
6. Why do you think that is?

Individual Activity: Complete the reading and concept synthesis activity in your workbook

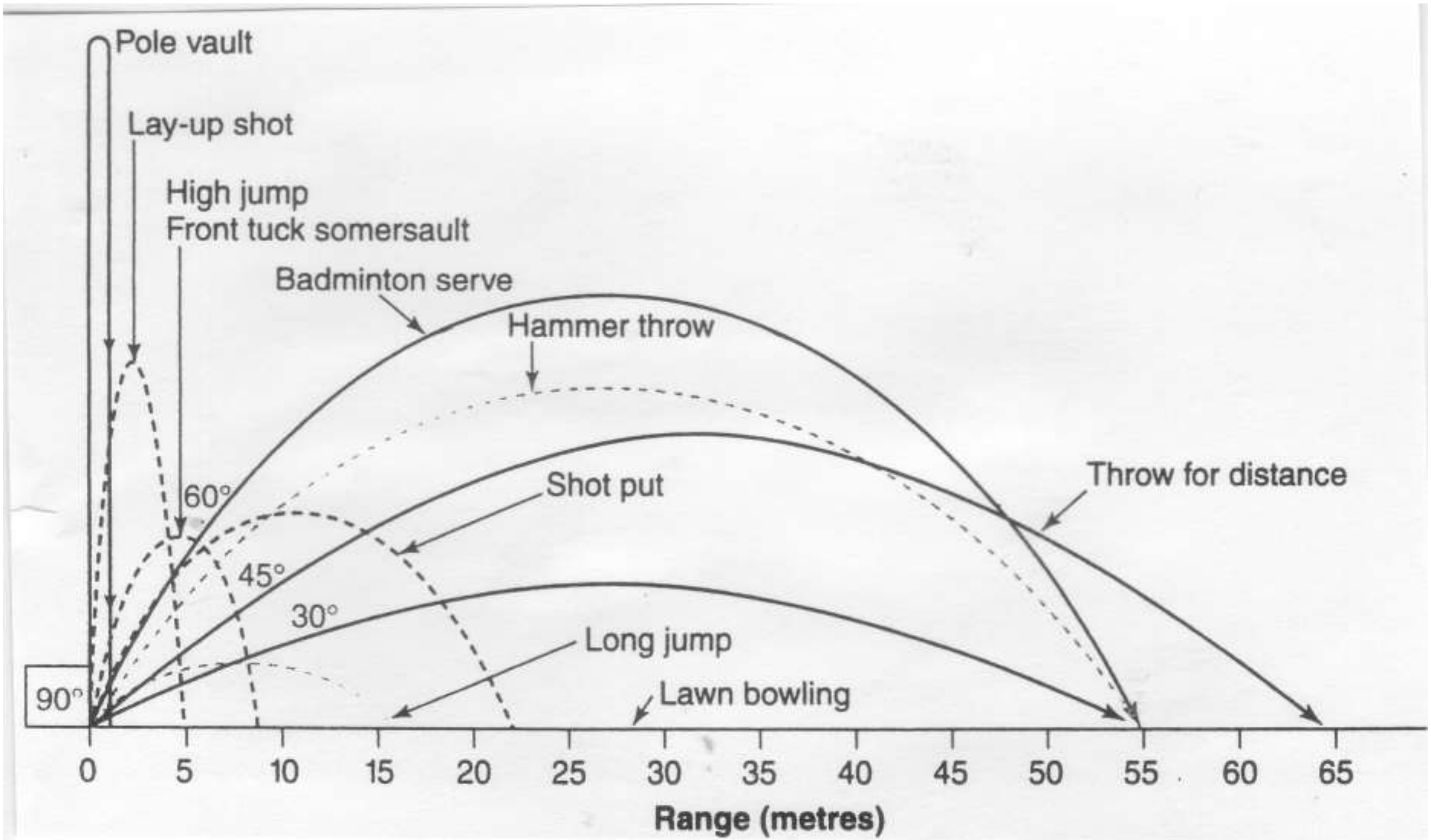
STARTER – Group Activity

1. Each group needs a metre rule, 3 objects and a container – you should have a kit on your bench
2. Go outside with your kit
3. Place the container 5m away from the metre stick
4. Try and thrown your objects into the container
5. How do the actions differ for each object?
6. Can you land each object in the container using exactly the same velocity and angle? Try and explain this concept

Learning Objectives

- **Define** projectile motion
- **Explain** the factors that affect projectile motion at take-off or release

Range of trajectories for various sporting activities



Class task

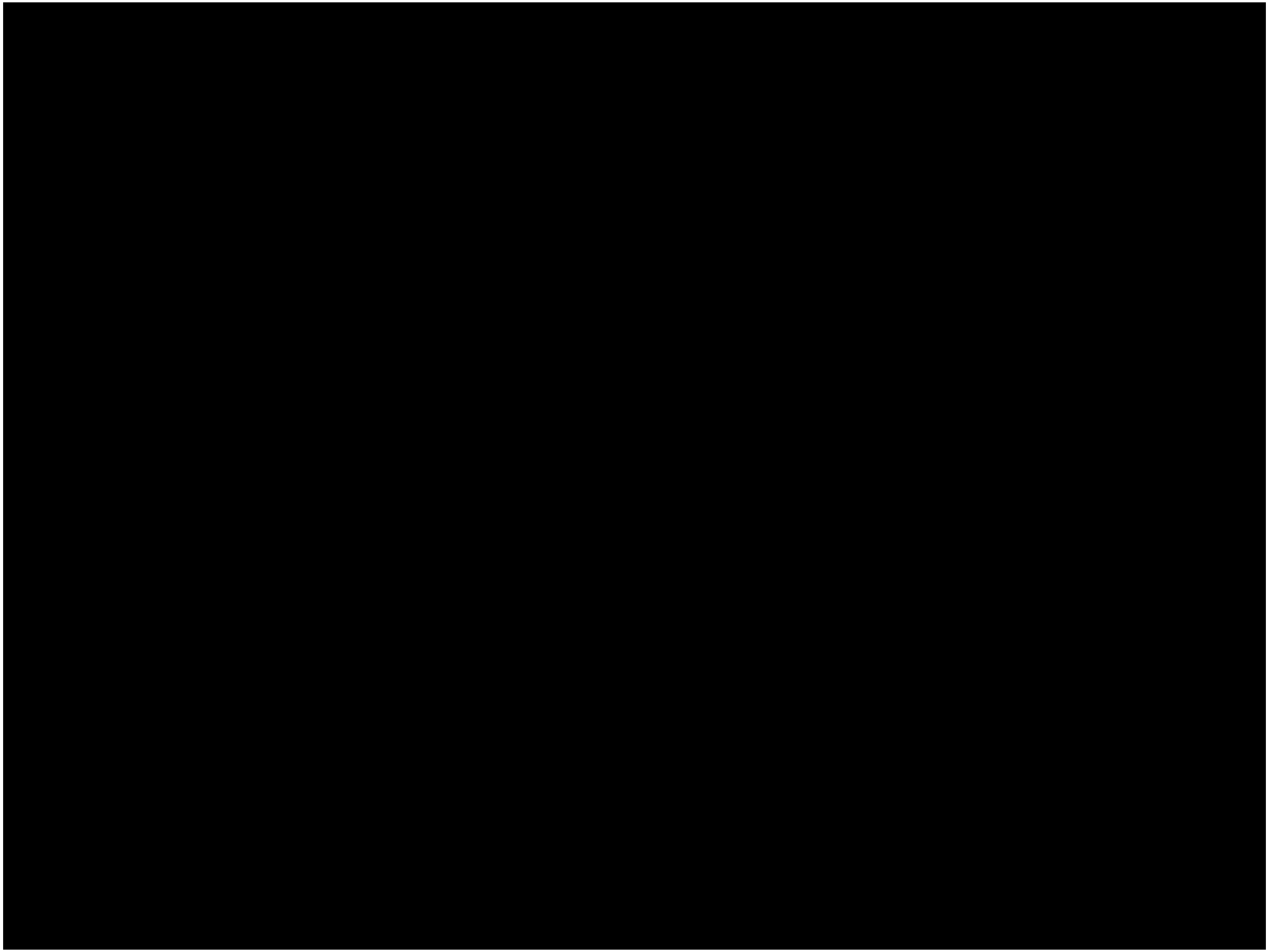
1. In pairs you will move around the posters and use the information to complete the notes on projectile motion in your individual workbooks

2. You will then be divided into groups. Each group will be given a poster – your job is to become an expert on that poster

3. The groups will then be divided again to contain an 'expert' for each poster. You will have time to explain your poster to the others so everyone understands.

4. We will check your learning by trying a PPQ on projectile motion individually and under timed conditions

Learning the O´Brian technique in shot put



Individual Activity - Projectile Motion Past Paper Question

Discuss how the factors that affect projectile motion can influence shot put technique. (6)

i

Bodies launched into the air (e.g. shot put) that are subject only to the forces of gravity and air resistance are termed projectiles;

Speed of release: (2 max)

Speed of release is defined as the magnitude of the projectile's velocity vector at the instant of release;

When projectile angle and height are held constant (e.g. an elite shot putter using the O'Brien technique), speed of release will determine range (horizontal displacement);

The O'Brien technique increases speed by application of force over a longer period of time, as it incorporates a one and three quarter turn / OWTTE;

Height of release:

For a given projection and speed angle, the greater the relative projection height the longer the flight time and greater the range (horizontal displacement);

Given that speed of release and angle of release are equal for two shot put athletes, the taller athlete has an advantage;

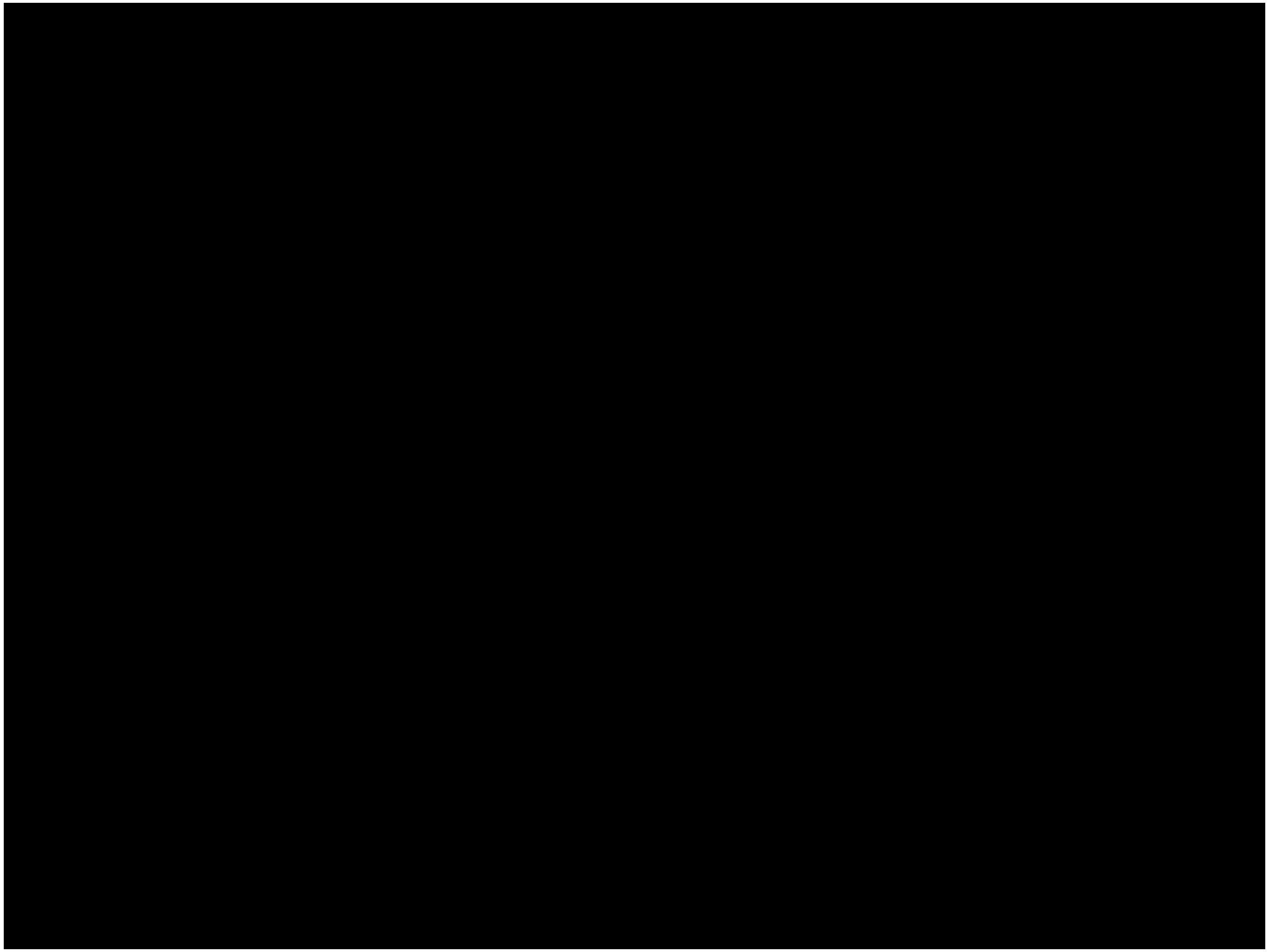
Angle of release: (2 max)

Angle of release is defined as the angle between the projectile's velocity vector and the horizontal at the instant of release;

Activities requiring maximum horizontal range such as shot put tend to use smaller angles than those in which maximum height is the objective;

Between 35 and 45 degrees is the optimal angle of release for shot put which should be incorporated into the athlete's technique;

STARTER: Answer these questions individiually



- Do you agree with the banning of the LZR swimsuit?
  Should the Fastskin be banned as well?
  Can you explain the physics behind the design of these swimsuits?

Learning Objectives

- **List** the components of fluid dynamics
- **Describe** the different types of drag force and **explain** how they are minimised
- **Outline** Bernoulli's Principle with reference to sporting movementsd

Individual thought: What is a fluid?

A substance that has no fixed shape and yields easily to external pressure; a gas or (especially) a liquid.

Fluid Dynamics – 2 major forces involved

- **Drag**
  – Fluid force that opposes the forward motion of the body and reduced the body's velocity

- **Lift**
  – Component of air resistance that is directed at right angles to the drag force

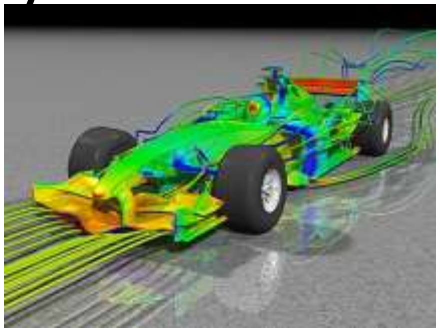
Individual Activity: copy these definitions into your workbook

Individual Activity: Copy these definitions into your workbook

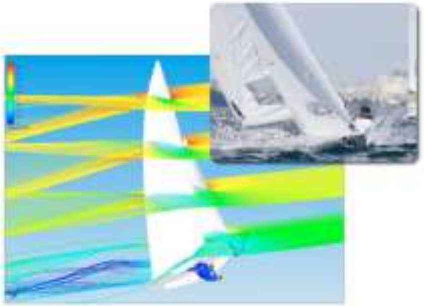
Forms of Drag

- **Surface**

  -referring to interaction between body surface and the fluid



- **Form**
  - refers to resistive forces caused by shape of object or body



- **Wave**

  -opposing force caused by the body or object making waves in the fluid

Surface Drag

When swimming, the water must move around your body and limbs

A thin layer of water next to the body actually sticks to it, and moves with it causing up to 30% resistance.

The overall effect of this is a considerable drag on the forward progress of the swimmer.

GROUP THOUGHT: How could you overcome this**?**

Form Drag

Low pressure pocket forms and "holds back" the cyclist. As velocity doubles this resistive force quadruples!!!!

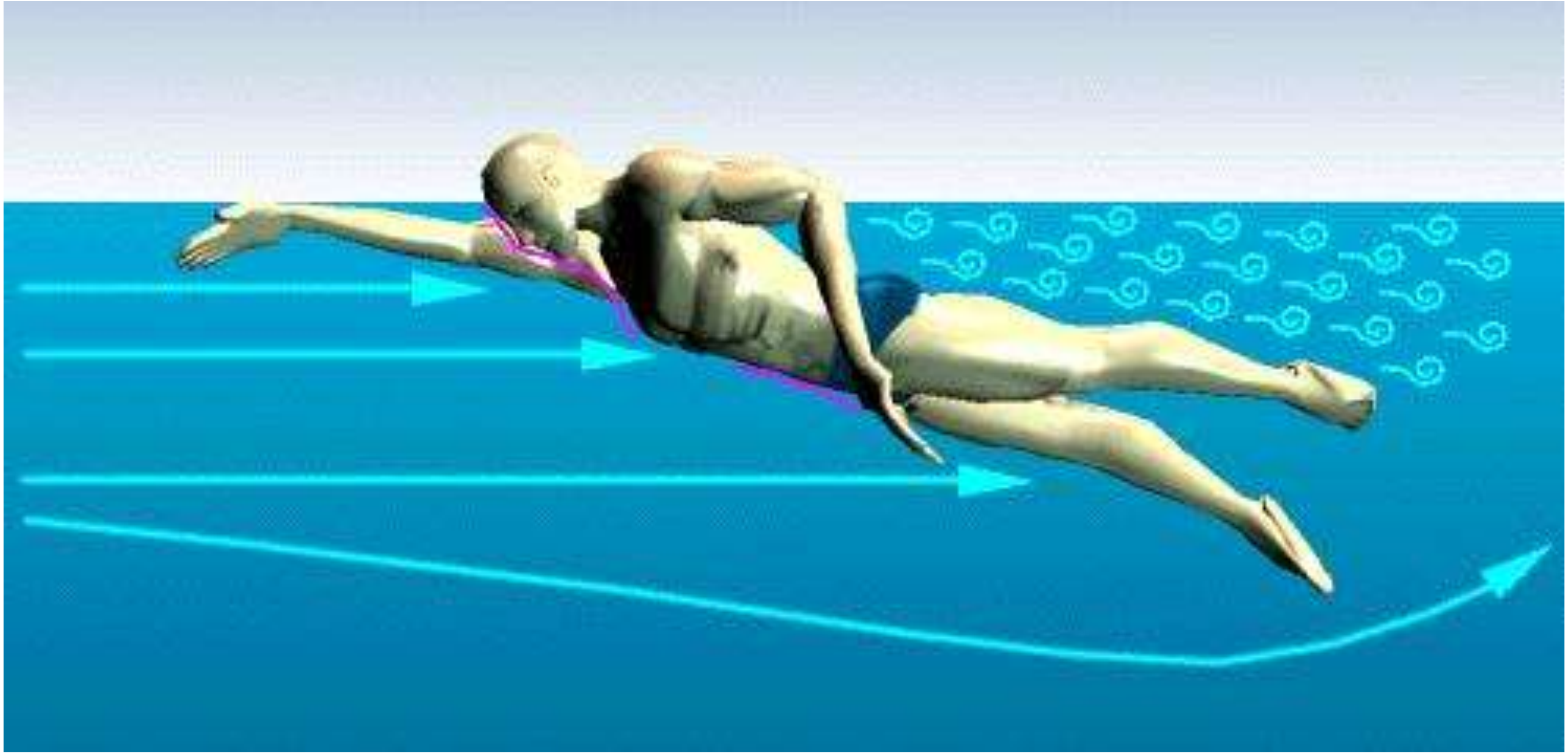
Important factors:

•Shape
•smoothness
•orientation (crouch can lower resistance ~30%

Reducing Drag

- *Frame designs on bikes are often "tear-shaped" to reduce drag*

- *Drafting within 1 m can reduce drag accounting for 6% of energy cost (e.g., ducks flying)*



GROUP THOUGHT:

Where will form drag feature most in swimming performance?
How can you minimise its effects?

Wave Drag (or Frontal Resistance)

Caused by waves developing on the water's surface.

Determined by the amount of surface area exposed to the direction of forward movement.

Small drag in streamlined position

Large drag in unstreamlined position

Swimmers must maintain a swimming position that is as streamlined as possible – i.e. present as small a surface area as possible to the water

Position of head is important. If too high, wave drag increases

Form Drag

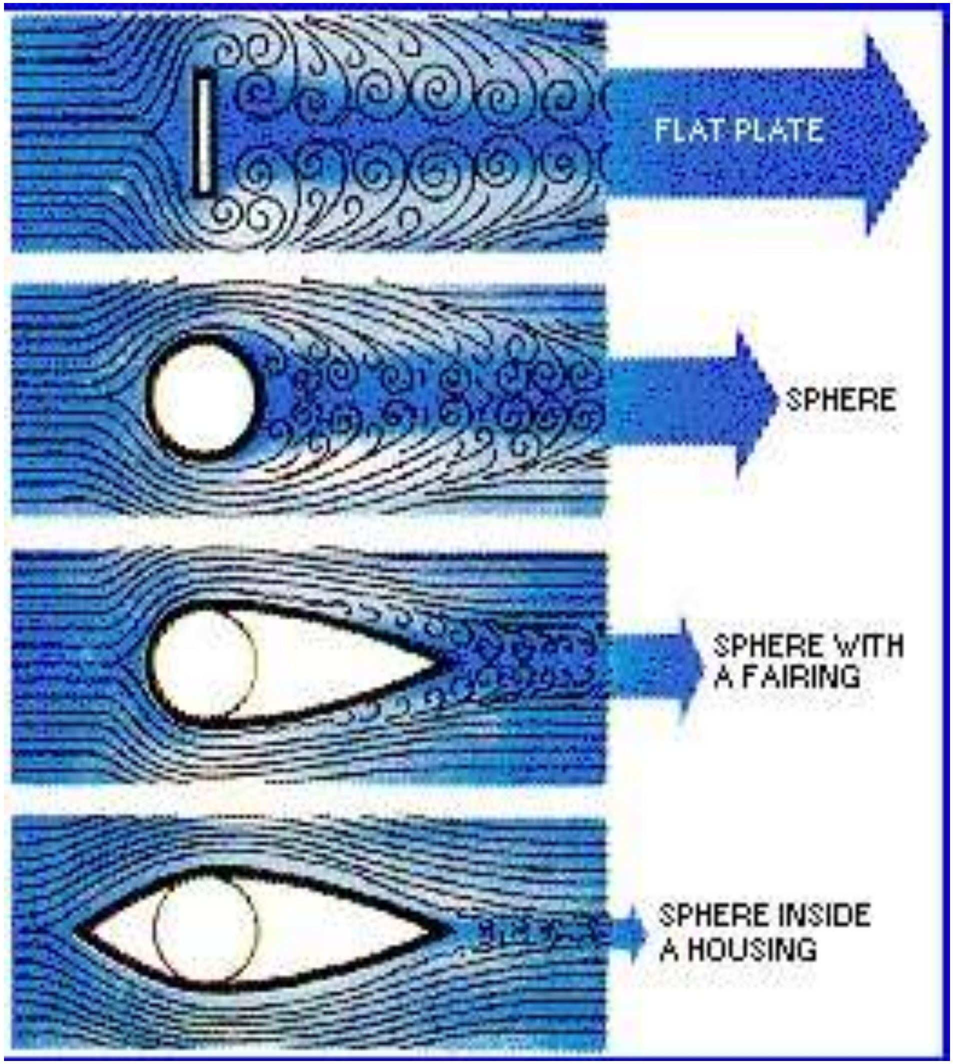
Depends on the size, shape and speed of the swimmer

- When the irregular shaped human body is propelled through the water, the flow lines don't remain smooth.

- Instead they are deflected and break up into a number of whirls creating a great deal of turbulence

- This type of resistance is very costly in terms of energy output

- The greater the frontal area hitting the water, the greater the resistance



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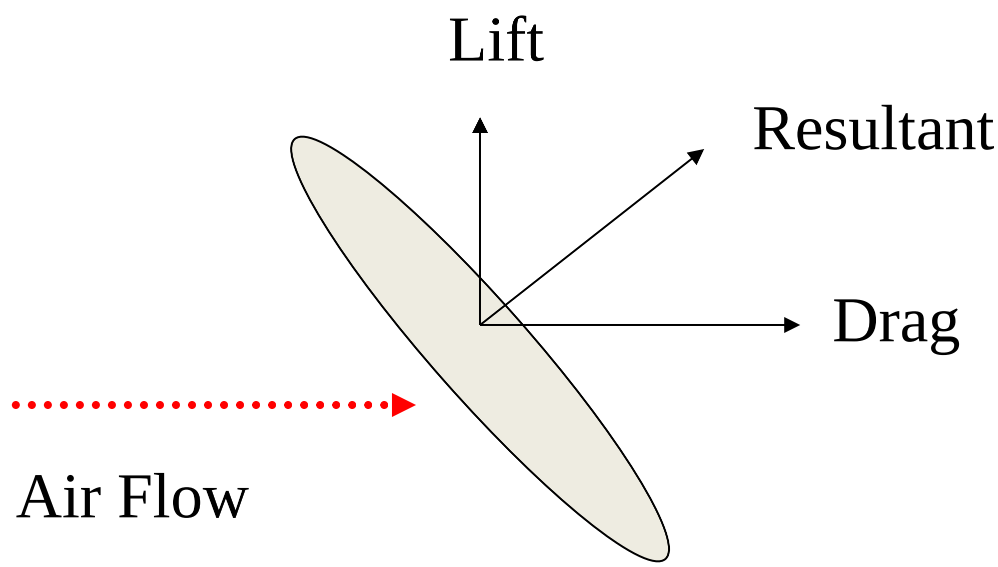
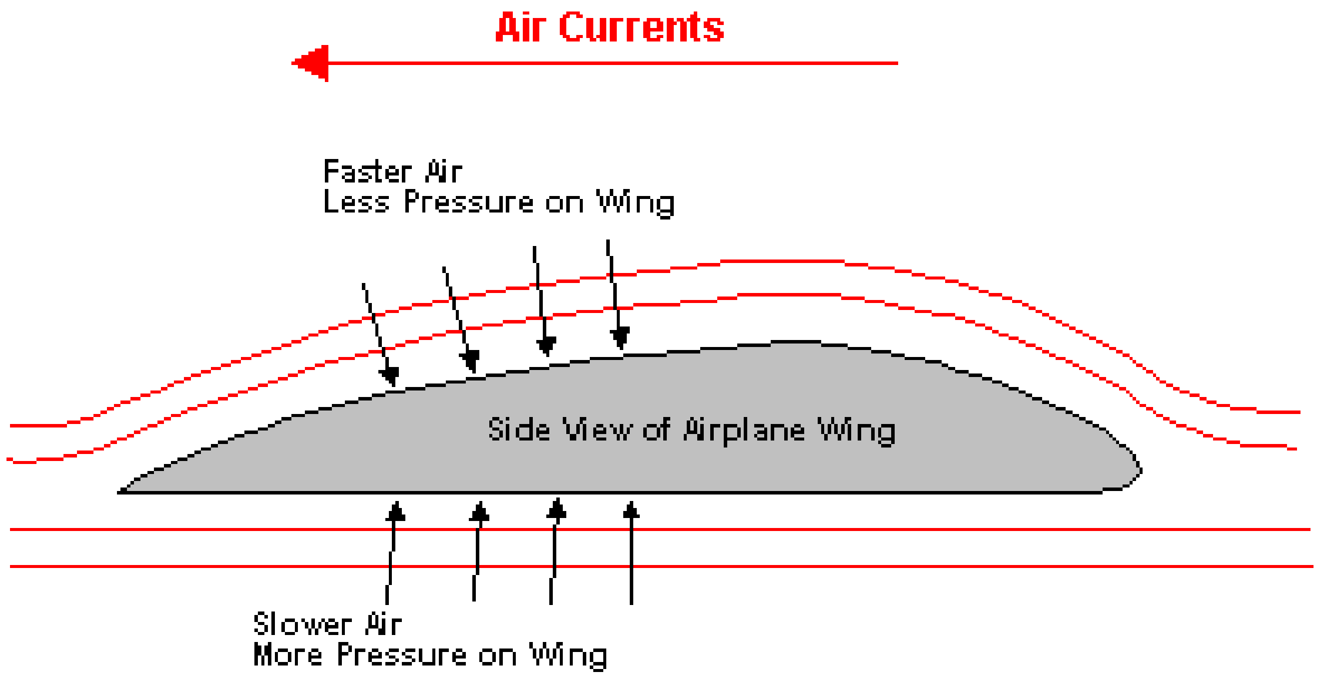
Lift

Component of air resistance that is directed at right angles to the drag force



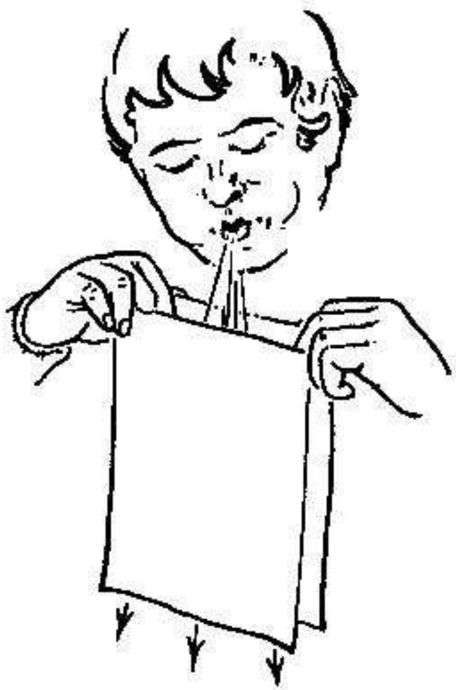
Lift - common example



According to **Bernoulli's Principle**:

- faster air has lower air pressure
- the high pressure beneath the wing pushes up to cause lift.

PAIRS ACTIVITY



- Hold two pieces of thin paper vertically a short distance apart and blow down into the space between them.

- Hold one end of a small sheet of paper in both hands.
- Keep the held edge horizontal while the other end sags under its own weight.
- Blow steadily over the top of this horizontal edge.

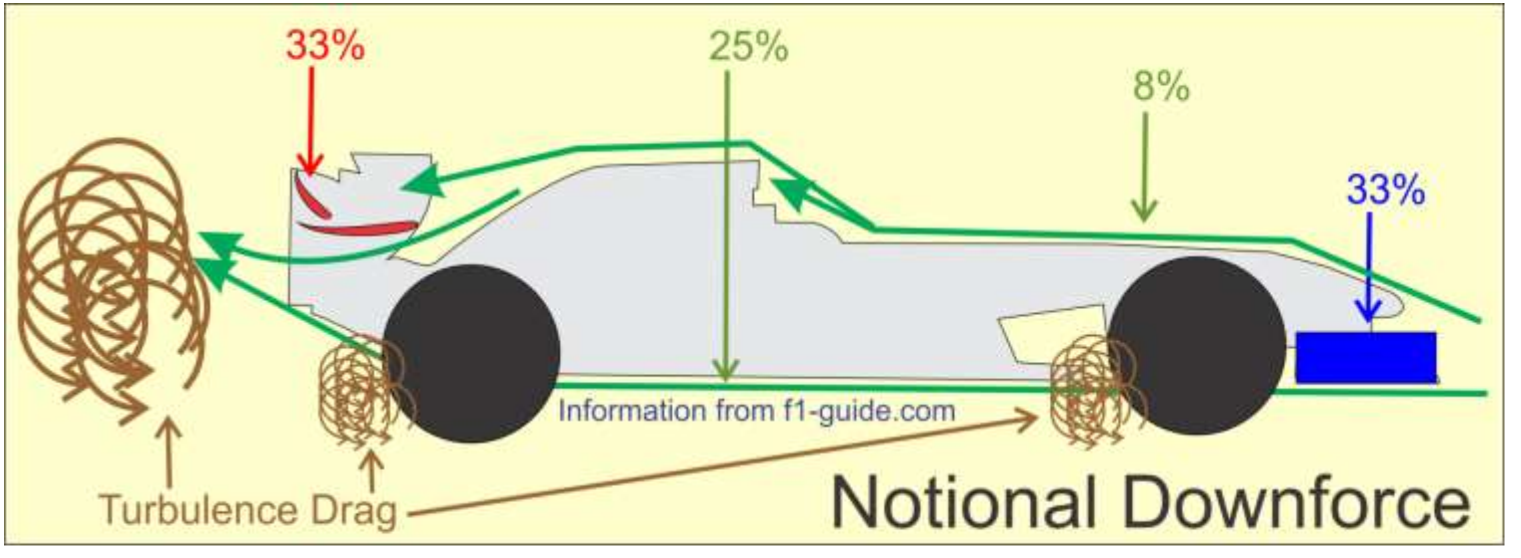
Lift and Formula I

- Race car wings operate on exactly the same principle as aircraft wings, only in reverse.

- Air flows at different speeds over the two sides of the wing (by having to travel different distances over its contours) and this creates a difference in pressure, a physical rule known as Bernoulli's Principle.

- As this pressure tries to balance, the wing tries to move in the direction of the low pressure.

- Planes use their wings to create lift, race cars use theirs to create downforce.

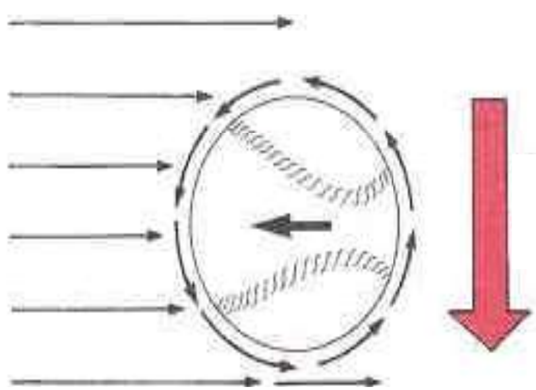


Individual Activity: Copy this definition into your workbook

What is the Magnus effect?

Topspin

Relative low velocity flow
Relative high pressure

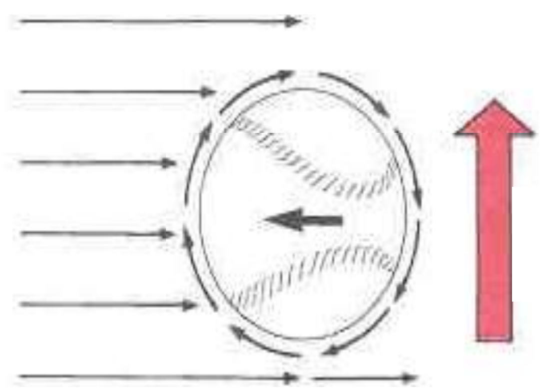


Magnus force

Relative high velocity flow
Relative low pressure

Backspin

Relative high velocity flow
Relative low pressure

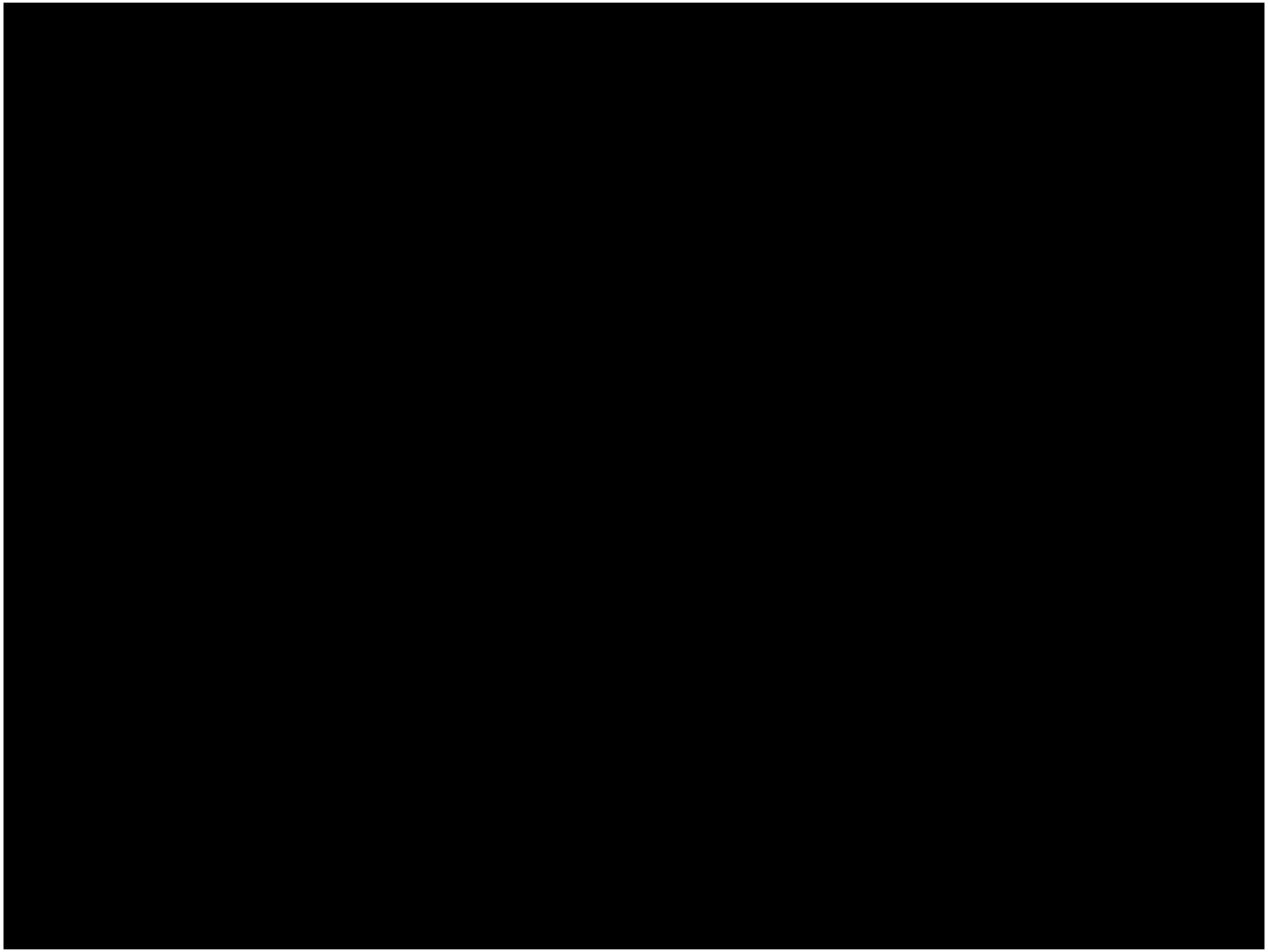


Magnus force

Relative low velocity flow
Relative high pressure

Magnus effect results from a pressure differential created by a spinning body.

Group Activity: Use the Magnus Effect to explain Roberto Carlos' swerving free kick in the 1997 World Cup against France



- After Carlos sent the ball flying, the airflow started pushing against the ball in the direction of Carlos.
- This means that the side of the ball spinning toward Carlos would move with the airflow while the opposite side would move against it.
- The airflow moving with the spinning direction was dragged around the ball toward the back because of frictional forces.
- Meanwhile, the airflow moving against the spinning ball would be abruptly stopped.
- Consequently, there's higher pressure on the side of the ball where the airflow is suddenly halted, and this pushes the ball in the opposite direction.
- So when Carlos put enough spin on the ball, the right side was fighting against the air and the resulting high pressure forced the ball to spin back toward the net.

Starter: Netwon’s Laws PPQ

Use Newton’s laws to explain how the ball moves once the player makes contact with it in football. (7 marks)

- 1st law- law of inertia. Force is needed to change body’s state of motion.
- The ball will remain stationary until an external force is applied to it- kick from footballer.
- Net forces will be zero until external force is applied.

- 2nd law- magnitude and direction of force applied is proportional to acceleration of a body.
- Ball will accelerate in the direction that the player kicks it.
- The rate of acceleration of the ball is proportional to the force applied (how hard it is kicked).

- Newton’s third law- action/reaction.
- When a force is given to football from the players foot, equal and opposite force is given back to foot.
- Ball moves because the player has greater inertia than the ball.

Learning Objectives

- **Distinguish** between first, second and third class levers

- **Label** anatomical representations of levers

Principles of Levers

Key Vocabulary

- Lever
- Fulcrum
- Resistance
- Effort

Levers are…

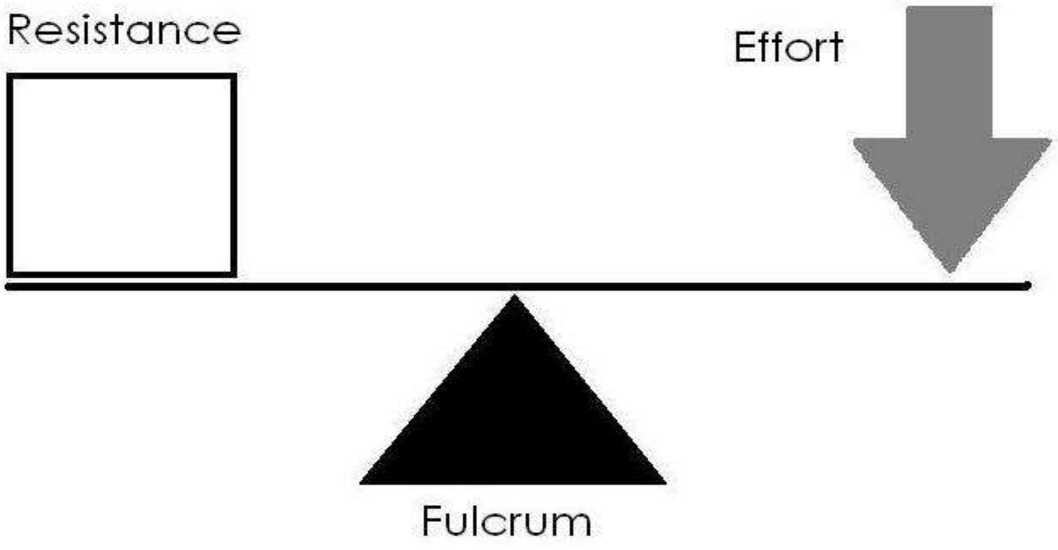
- Simple machines that help us apply force.
- Rigid structures, hinged at some part with forces applied at two other points.

- **GROUP ACTIVITY:** Where are the levers in the pictures below

We have levers within our body, and also use them externally for many different reasons.

All levers have three parts:

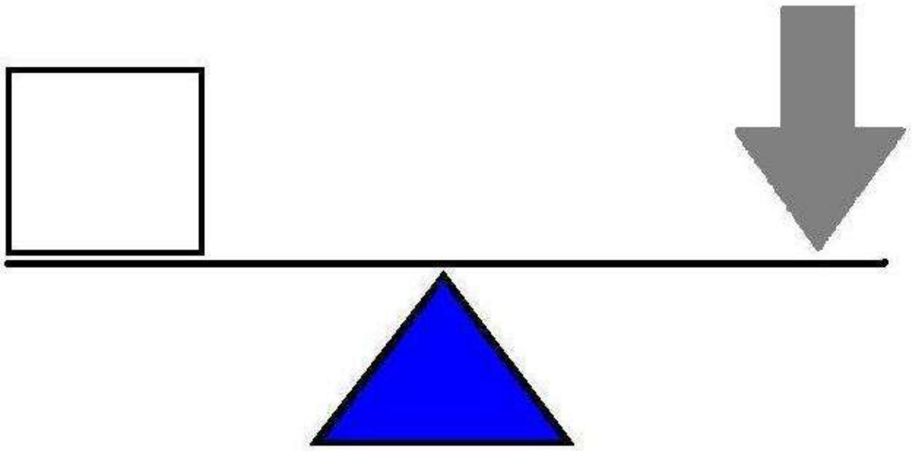
- ***Fulcrum***
- ***Load***
- ***Effort***



Individual Activity: Copy this definition into your workbook

Fulcrum

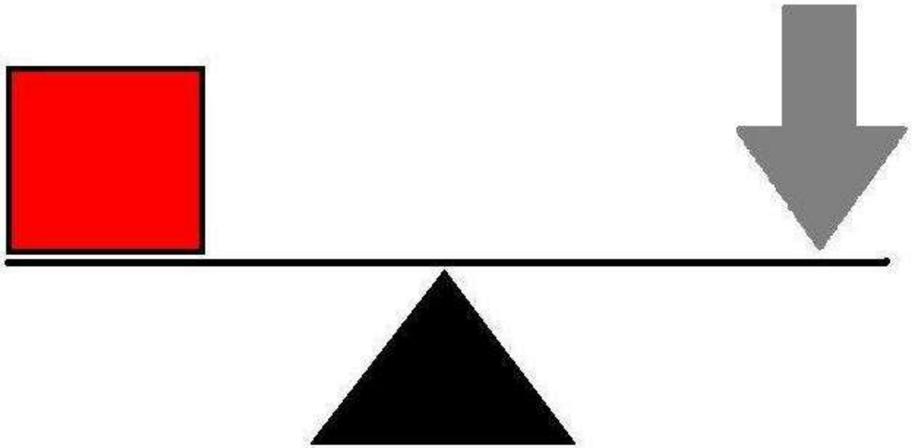
The pivot point.



Individual Activity: Copy this definition into your workbook

Load (resistance)

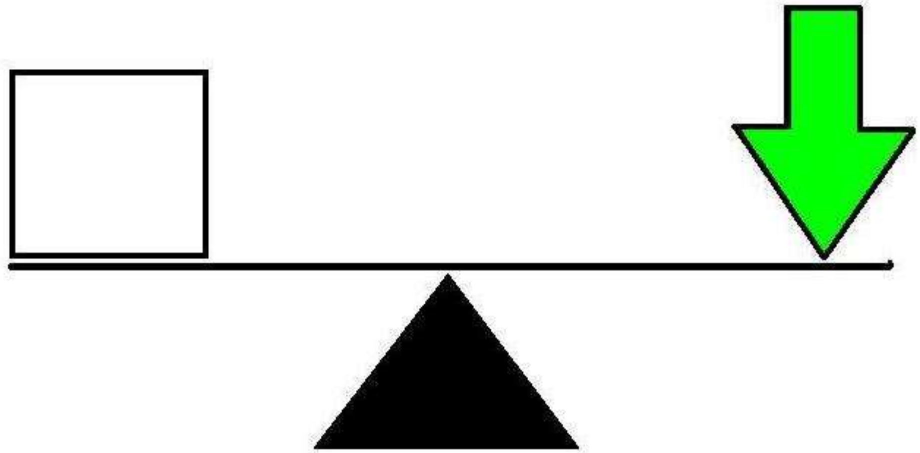
The weight that needs to be moved.



Individual Activity: Copy this definition into your workbook

Effort

The force that is applied to move the resistance (or load).



Individual Activity: Complete the relevant section in your workbook

Functions of a Lever

Levers perform two main functions:

To ***increase the load*** (or force) that can be moved with a given effort e.g. a crowbar.

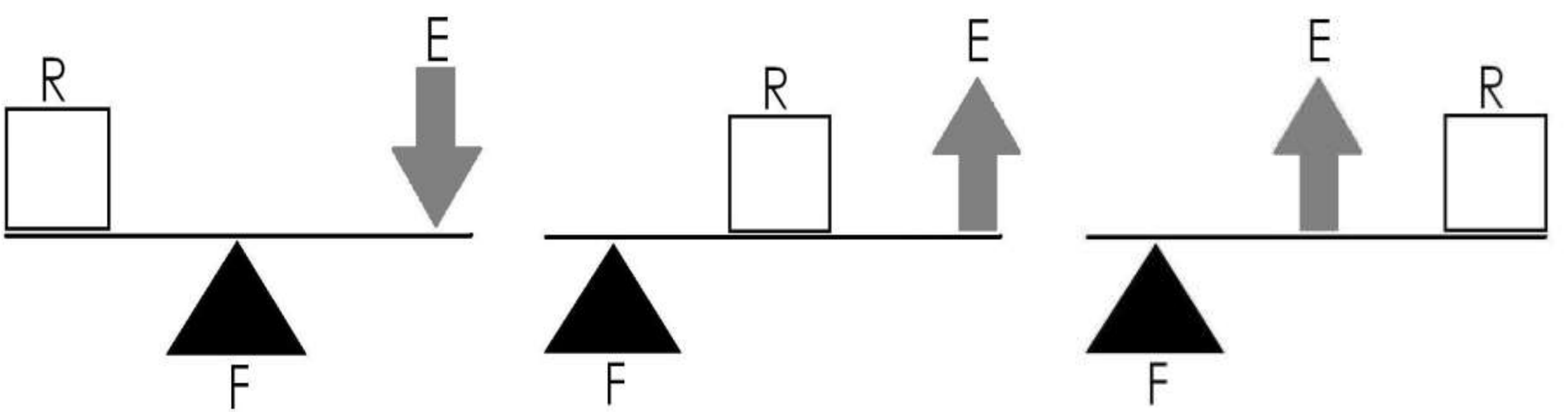
To ***increase the velocity*** at which an object will move with a given force. E.g. A golf club.

Individual Activity: Complete the table in your workbook as we move through the next few slides

Classes of Levers

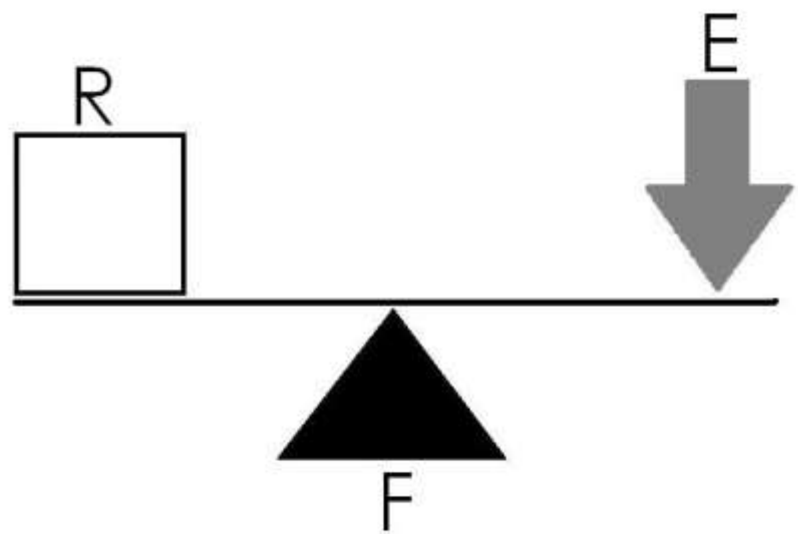
There are 3 classes of levers.

Each is structured in a different manner and has different advantages.



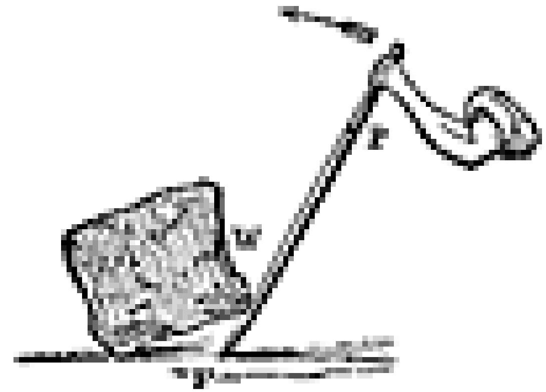
First Class Levers

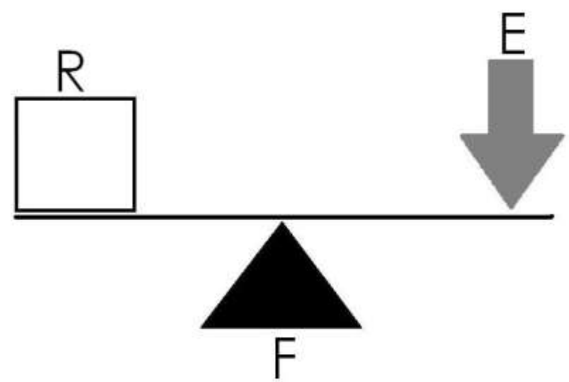
The fulcrum lies between the effort and the load.



First Class Levers

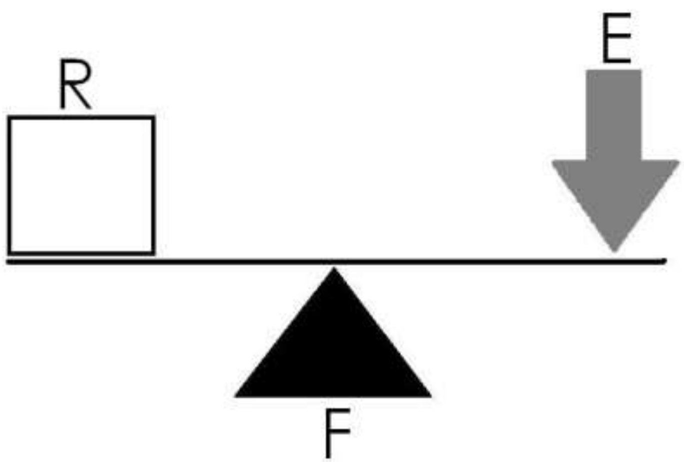
Using a crowbar to move a rock.





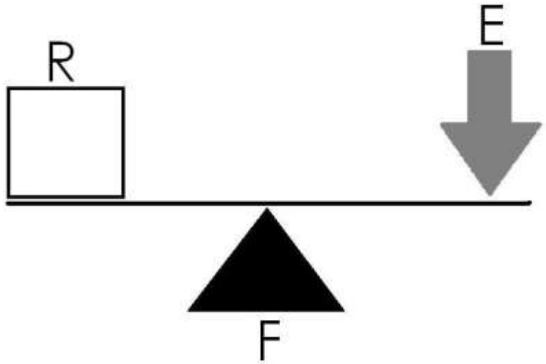
First Class Levers

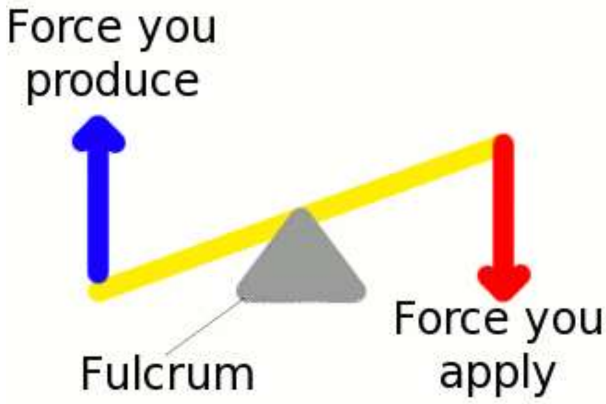
Using a hammer to pull out a nail.



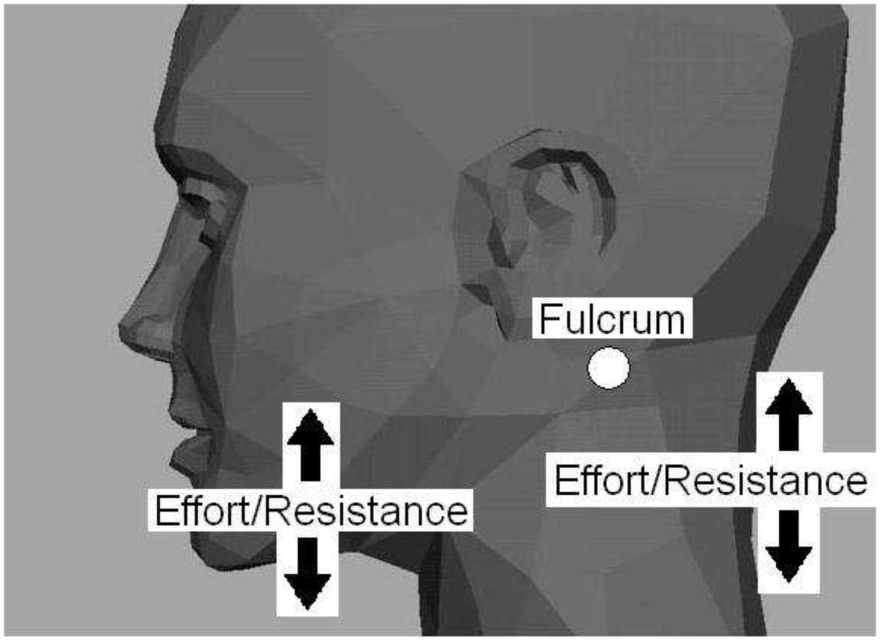
First Class Levers

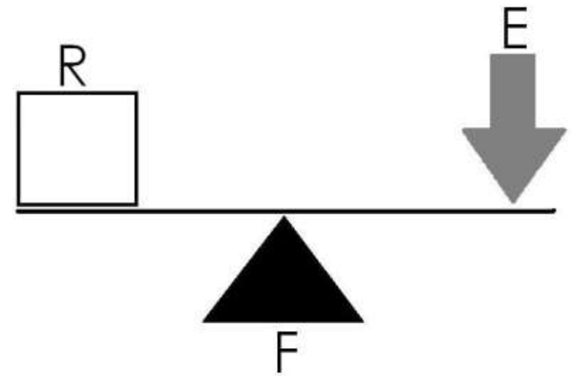
A see-saw.





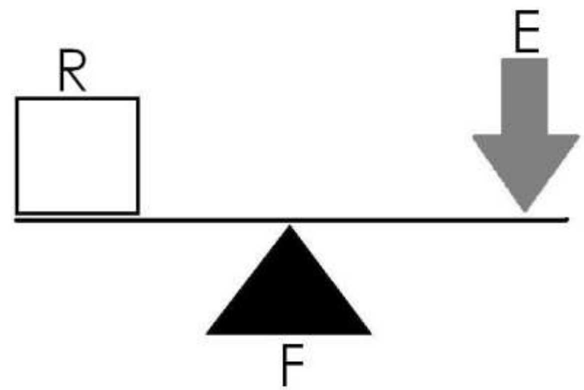
First Class Levers





Up and down movement of the head about the atlas joint.

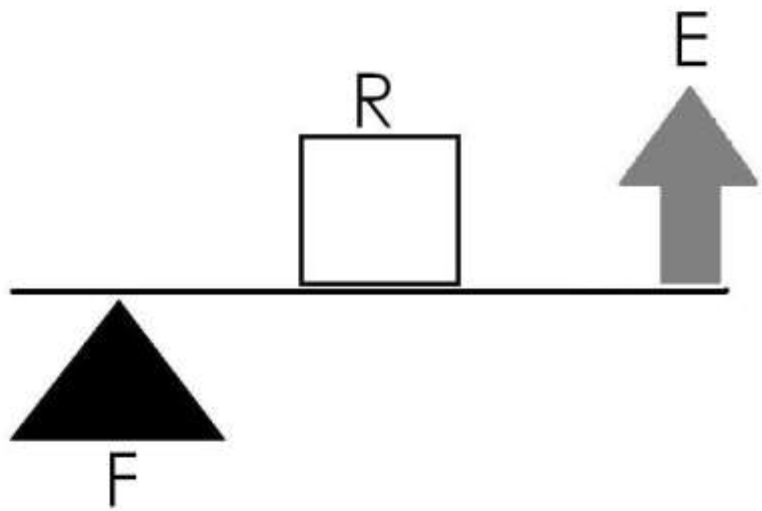
First Class Levers



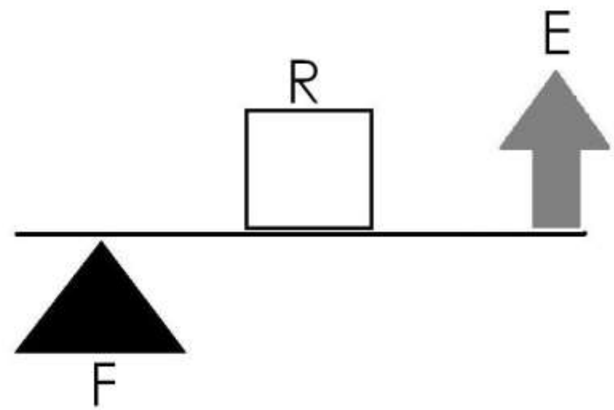
Pulling an oar in a row
boat.

Second Class Levers

The load lies between the fulcrum and the point of effort.



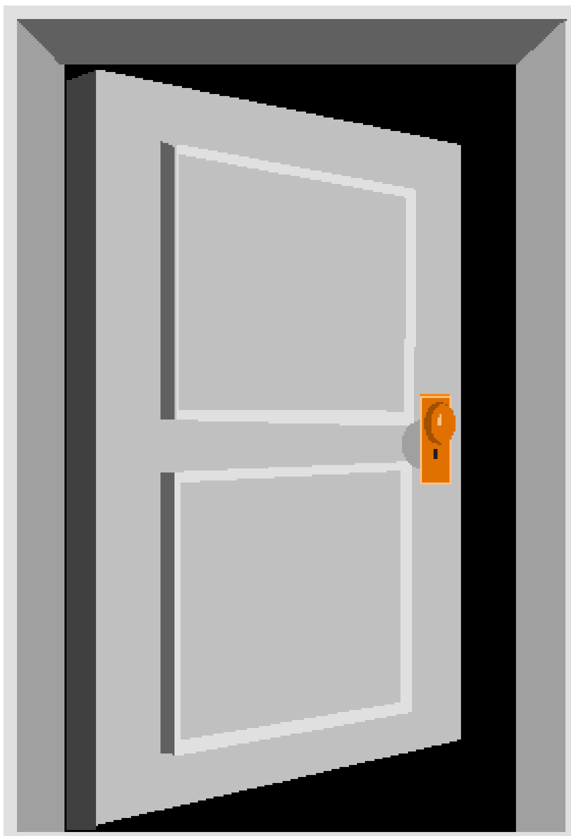
Second Class Levers



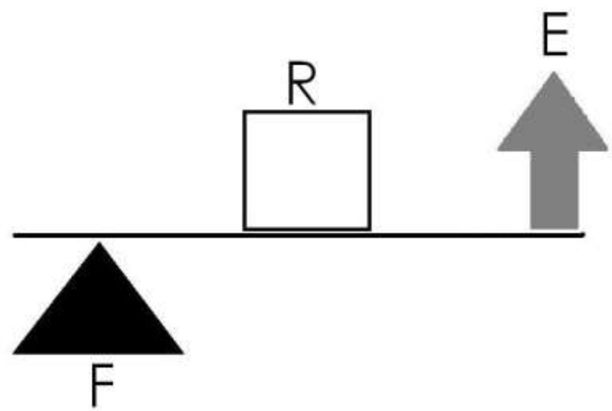
The movement of the foot when walking.

(the calf muscle provides the effort and the ball of the foot is the pivot)

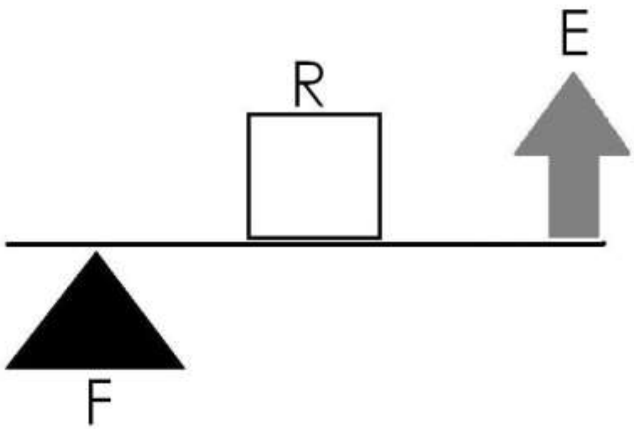
Second Class Levers



Opening a door by the handle.



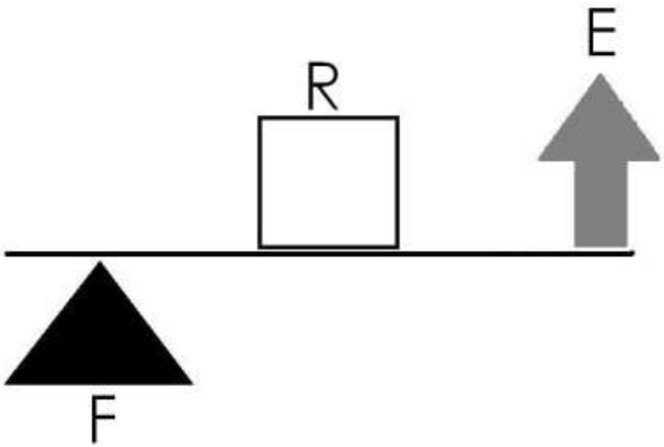
Second Class Levers



Opening a bottle with a bottle opener.

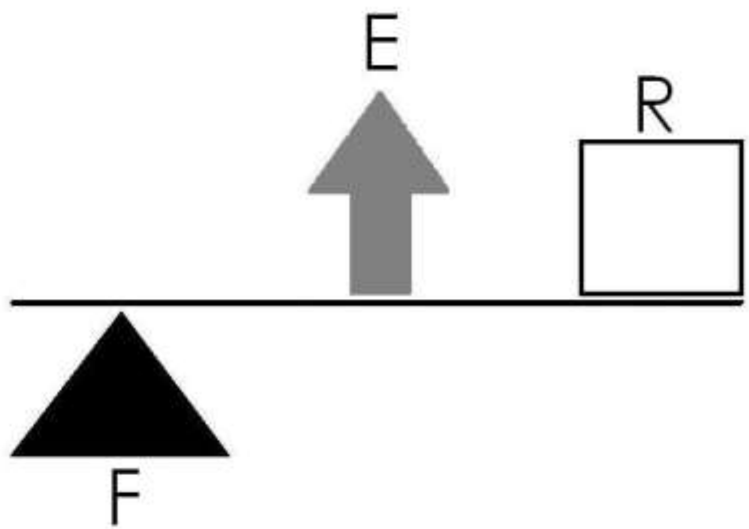
Second Class Levers

Pushing a wheel barrow.

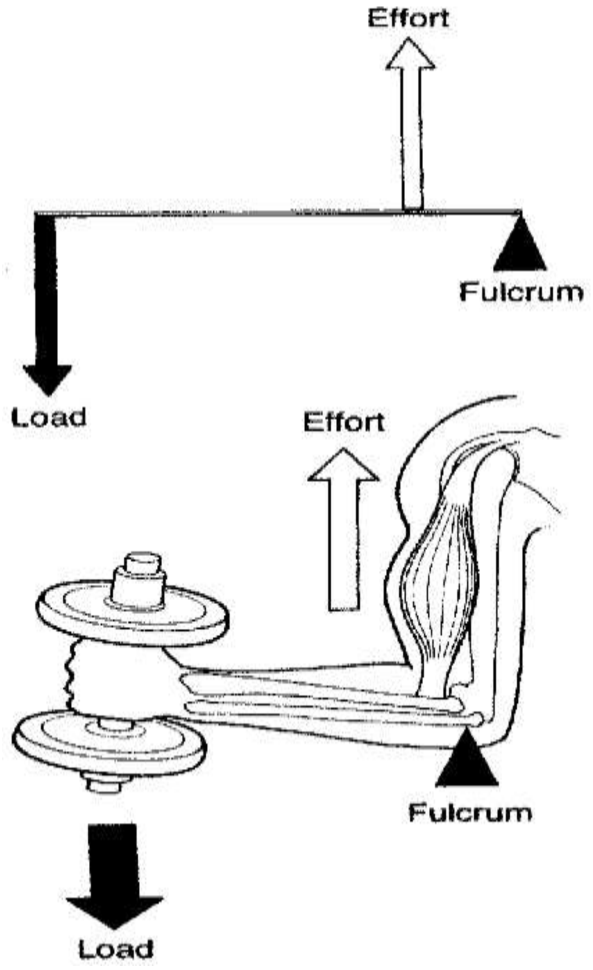


Third Class Levers

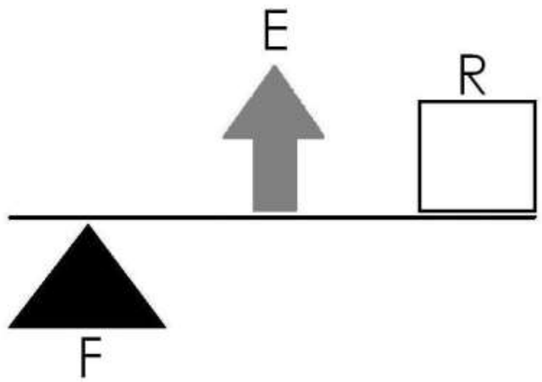
The effort lies between the load and the fulcrum.



Third Class Levers

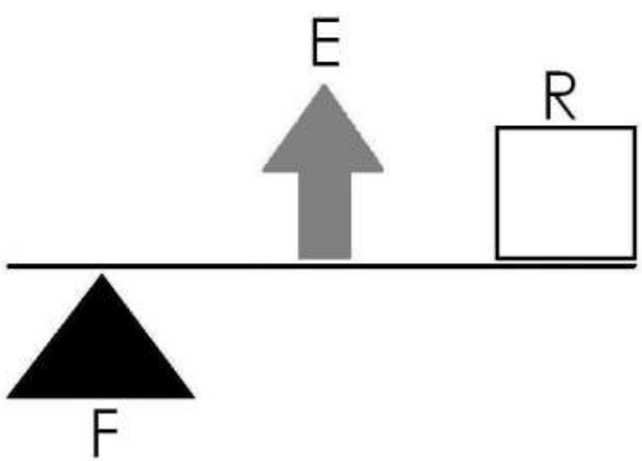


Biceps curl.

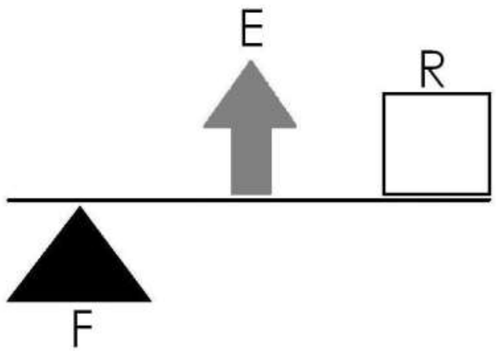


Third Class Levers

Fishing with a rod.



Third Class Levers



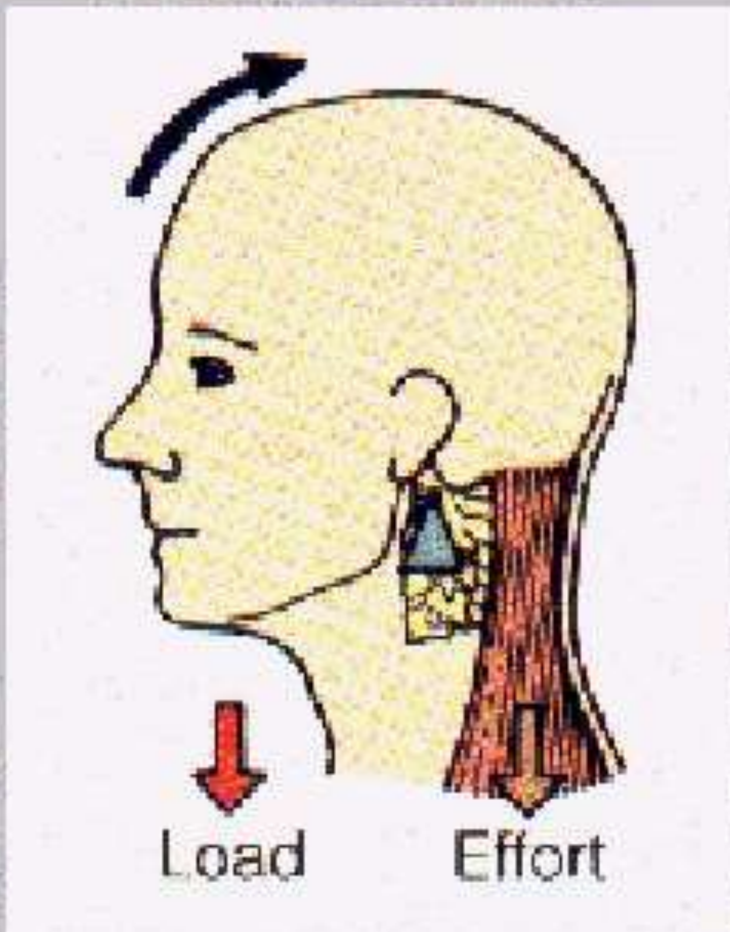
Swinging a bat to hit a ball.

Levers in the human body

- Levers are made up of the joints (fulcrum), and the bones that connect them to the objects being moved.
- Levers in the human body can be manipulated to improve speed, and apply large forces at the same time.

1st class body example:

First Class Levers (LFE)

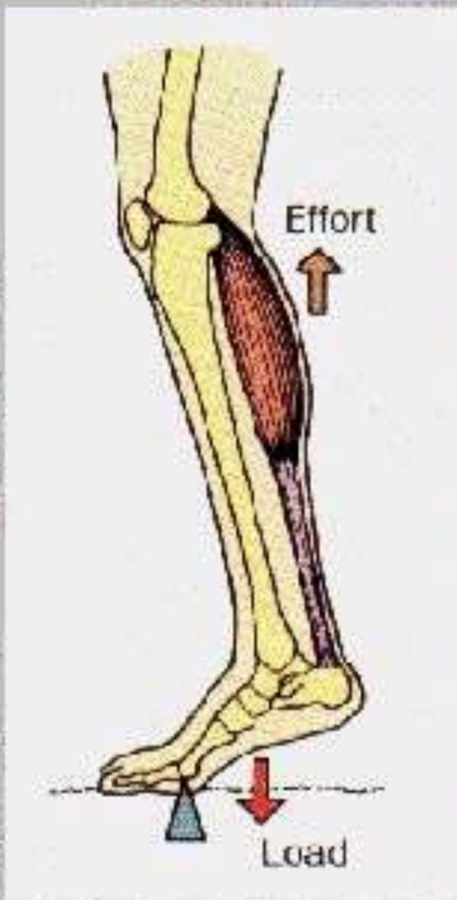


The best example of a first class lever in the body is found with the skull pivoting on the atlas vertebrae of the spine, with weight of the head held by the trapezius and sternocleidomastoid muscles of the neck.

1^{st} class sporting example: rowing oar

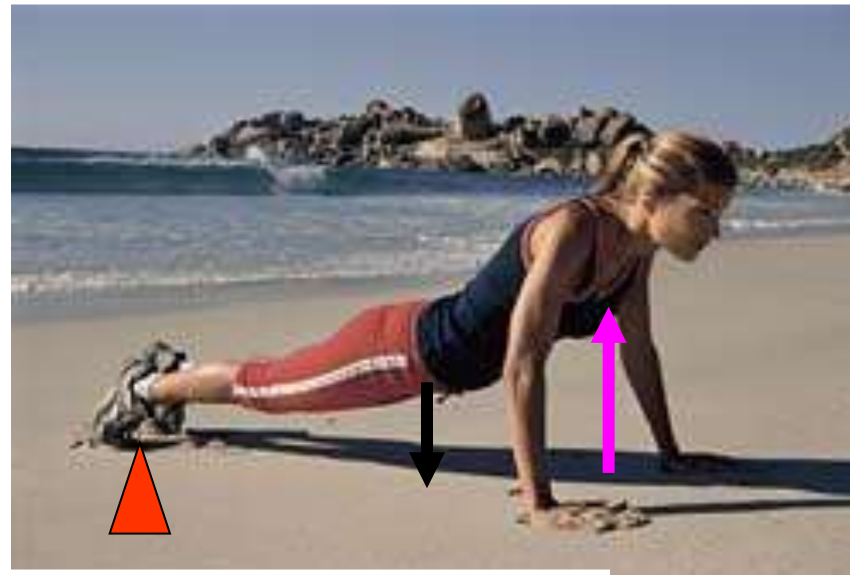
2nd class body example:

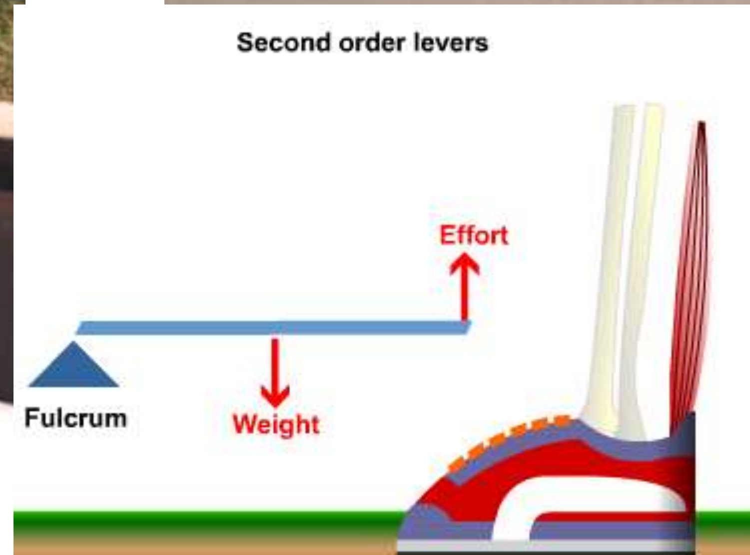
Second Class Levers (FLE)



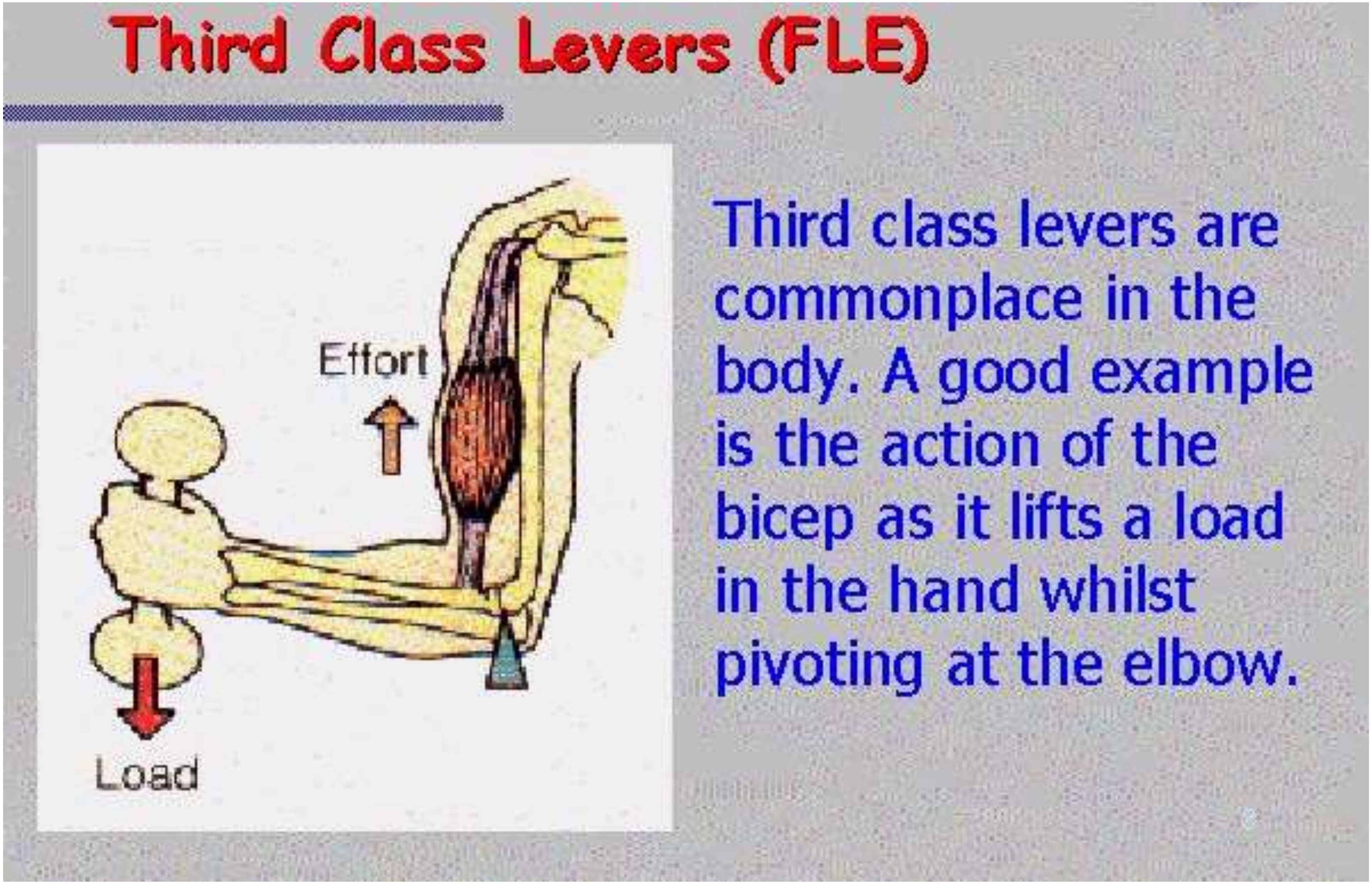
The best example of a second class lever is the action of the ball of the foot with the gastrocnemius and soleus muscles of the calf lifting the weight of the body, which is acting through the foot.

2nd class lever sporting examples: running and press-ups

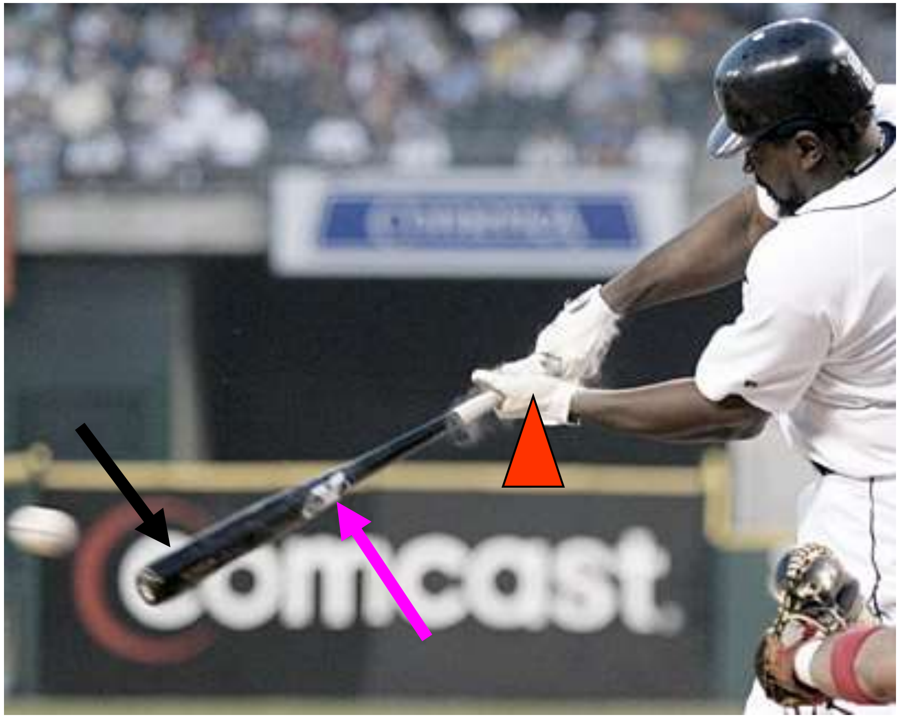




3rd class body example

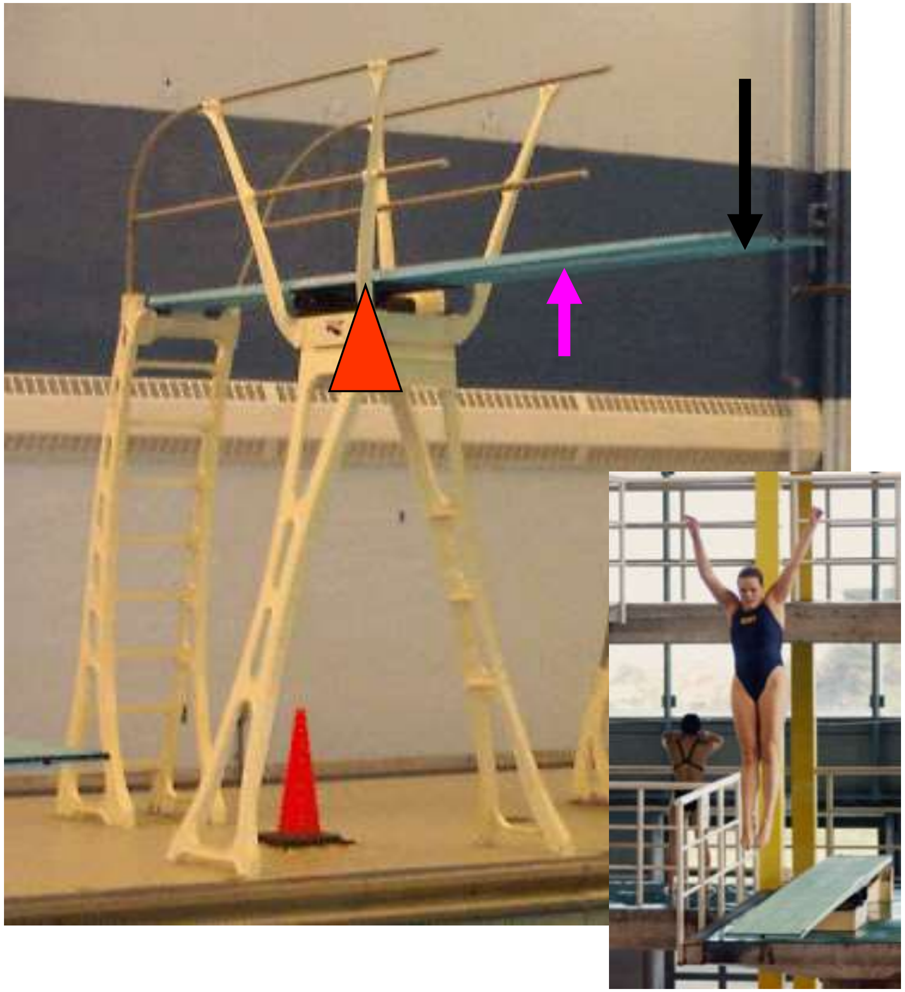


3rd class sporting examples: hockey stick and baseball bat



Individual Activity: Now try the individual activity in your workbook!

3rd class examples.: kayaking and diving board



Applications of levers in sport

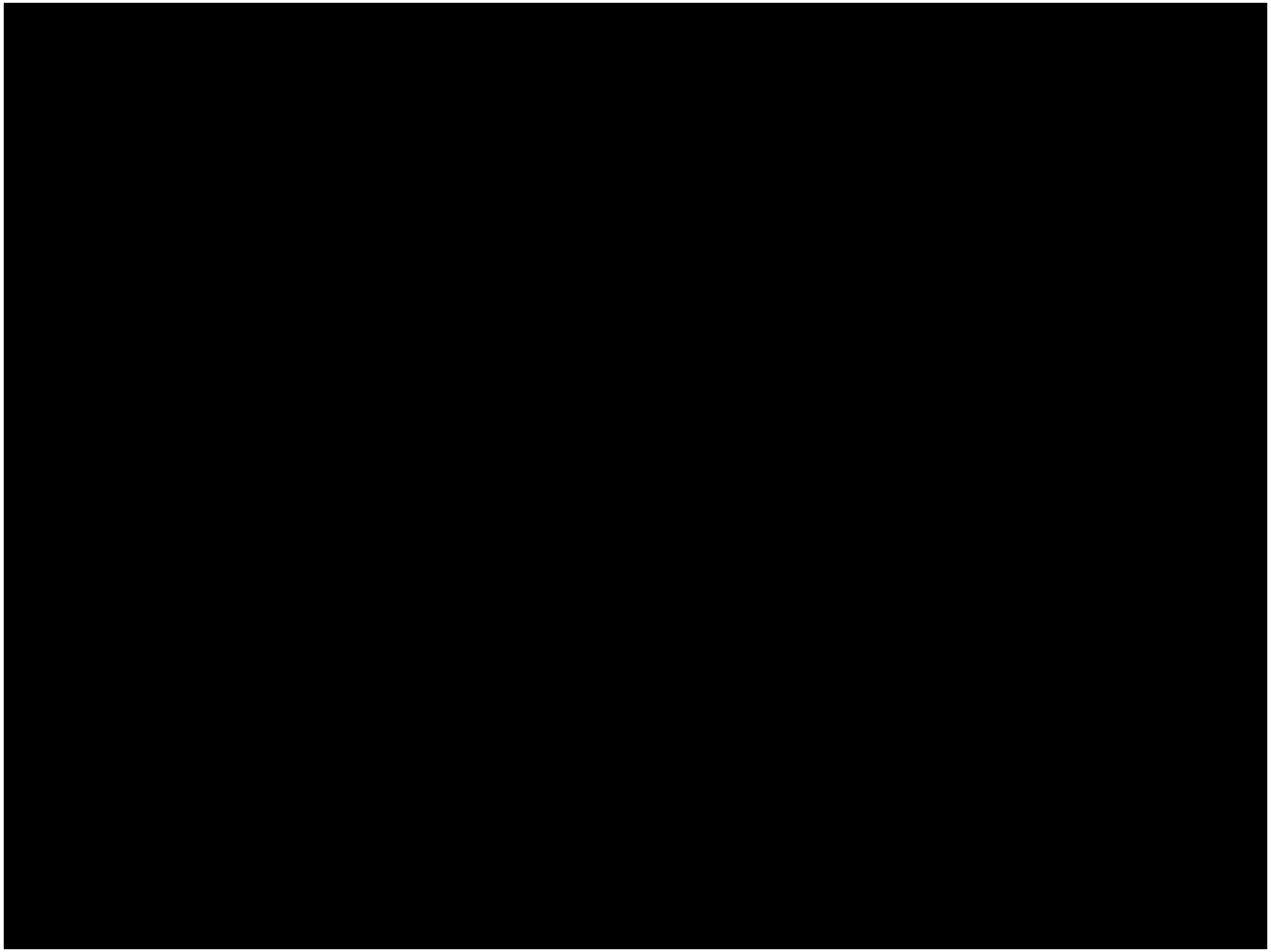
- Longer levers result in greater speed
- Good for throwing & striking.

- Shorter levers result in greater strength.
- Good for pulling, pushing and lifting.

The most common lever found in the human body is the 3rd class lever

Practical Activity: Now try the activity in your workbook in pairs!

STARTER: Answer the questions in your workbook using the video below



Learning Objectives

State the relationship between angular momentum, moment of inertia and angular velocity

Explain the concept of angular momentum in relation to sporting activities.

Individual Activity: Copy this definition into your workbook

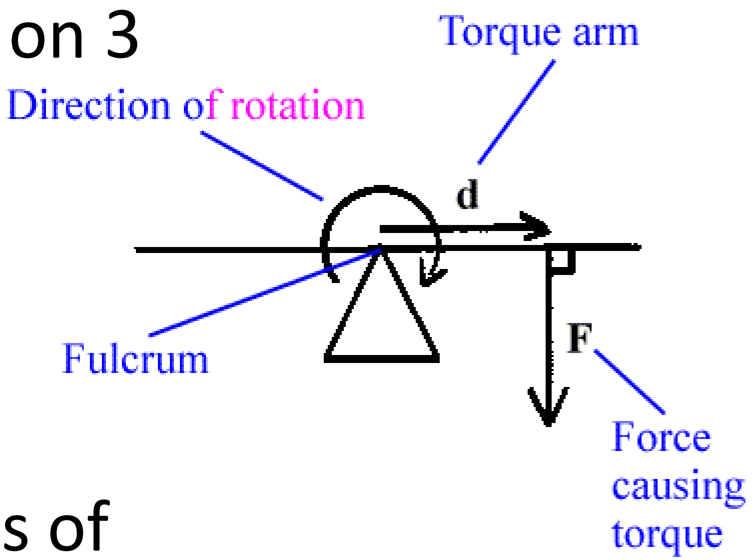
Torque

Torque (moment): The ability of a force to rotate a body about an axis.

$$T = (\text{force})(\text{distance})$$

The size of the torque created relies on 3 factors:

1. The size of the force
2. The direction of the force
3. How far it is applied from the axis of rotation



Demonstration of torque!

Linear vs Angular kinematics

Linear	Angular
•Mass	•Moment of inertia
•Force	•Torque
•Momentum	•Angular momentum
• Newton's Laws	•Newton's Laws (angular analogs)

Individual Activity: Copy these formulae into your workbook

Linear vs Angular Motion analogies

	Linear	**Angular**
Displacement	Distance (m)	θ (radians)
Velocity	V (m/s)	angular velocity ω
Acceleration	A (m/s/s)	Angular acceleration α
Inertia	Mass (kg)	Inertia
Newton's second law	F=ma	$\tau = I\alpha$
Momentum	p=mv	$H = I\omega$

Individual thought: What is momentum?

- Momentum is moving inertia.
- It is a product not only of an objects mass but also how fast it is moving.
- In rotation movements, inertia is due not only to mass but how mass is distributed about the axis of rotation.

Individual Activity: Copy these laws into your workbook

Angular Analog Newton's Laws

1) a rotating body will continue to turn about its axis of rotation with constant angular momentum, unless an external couple or eccentric force is exerted upon it

- linear momentum

  $M = m \cdot v$

- angular momentum

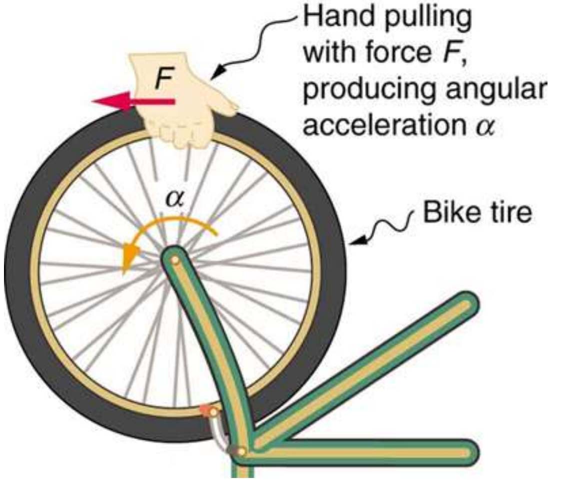
  $H = I \cdot \omega$

AKA - The principle of conservation of angular momentum

Can you remember Newton's Second Law?

Angular Analog

2) the rate of change of angular momentum of a body is proportional to the torque causing it and the change takes place in the direction in which the torque acts



What about Newton’s Third Law?

Angular Analog

3) for every torque that is exerted by one body on another there is an equal and opposite torque exerted by the second body on the first

Angular momentum

- When moment of inertia is high, angular velocity is low, and vice versa.

- E.g. if a sumo wrester did a somersault he would be quite slow

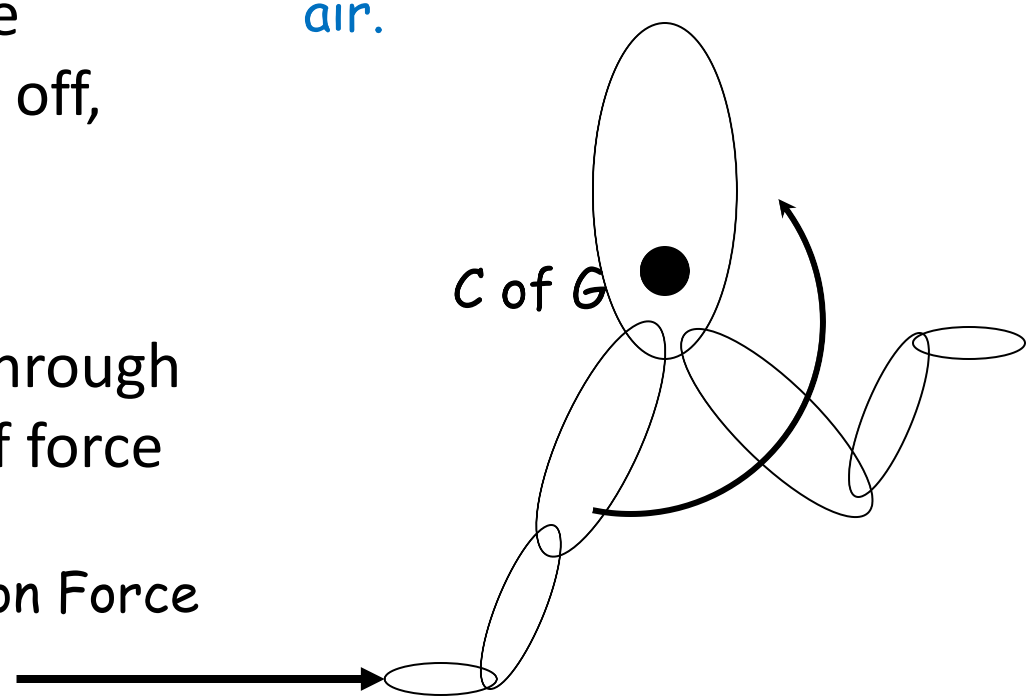
- But a capoeira fighter would be much faster!

Generation of angular momentum

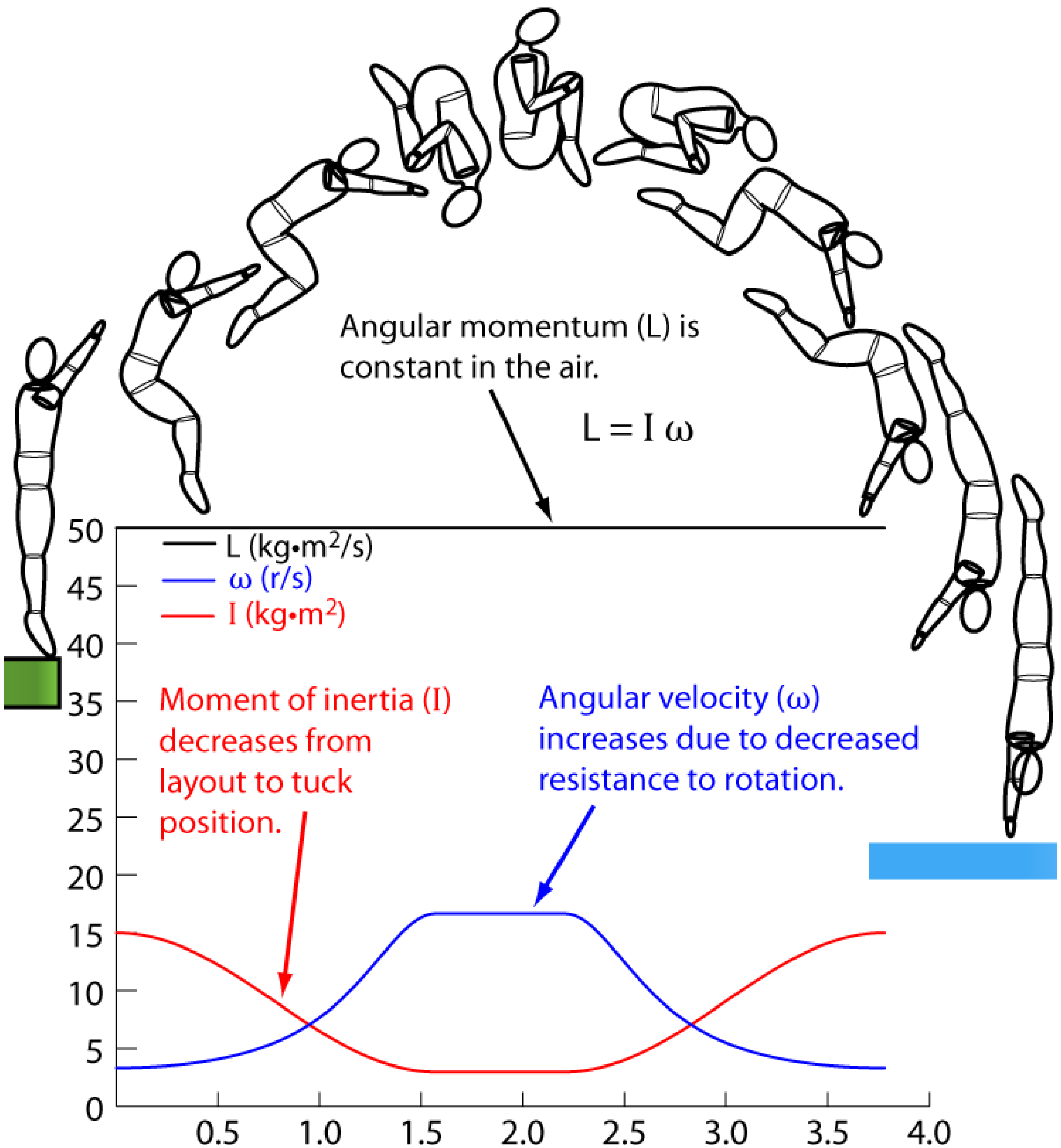
- On the ground angular momentum can affect speed and velocity through the legs, trunks, arms etc.
- In the air it needs to be produced prior to take off, such as in the run up
- This can be achieved through impulse (application of force over time).
-

The forces acting on the foot at take-off produce a torque about the jumper's CofG.

This torque will produce forward angular momentum causing the jumper to pitch forward in the air.



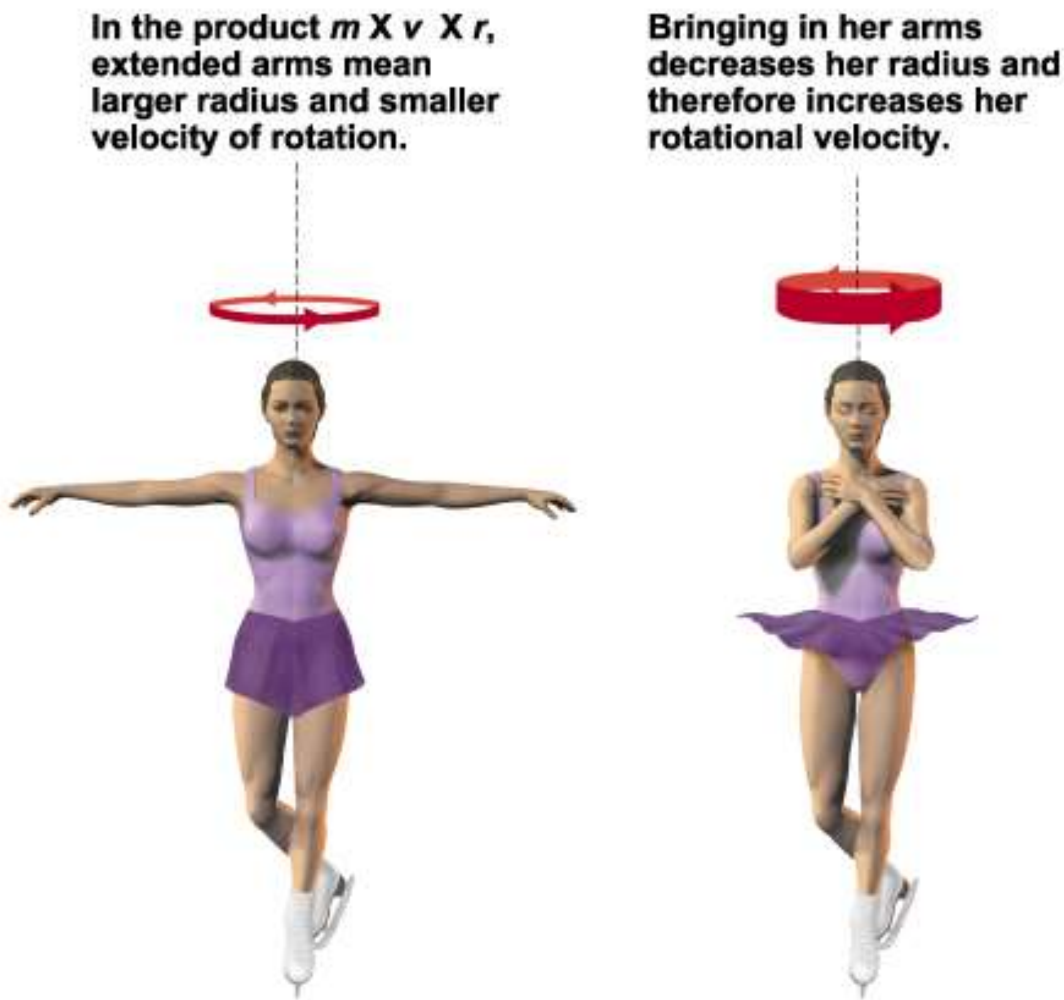
Conservation of angular momentum



Angular momentum is NOT angular speed.

A diver in the air can alter their moment of inertia and their angular speed, but they cannot change their angular momentum until another force is applied to it (hitting the water).

Group thought: Why does bringing in your arms during a spin make you spin faster?



Moment of inertia in the second phase varies in accordance with the angular velocity so as to conserve angular momentum.

When the diver first leaves the board, moment of inertia is high due the limbs i.e. the arms being outstretched and further away from the axis of rotation.

1. **Complete the individual activity in your workbook.**
2. **Use the statements on this slide to annotate the phases of a pike dive**

Towards the end of phase 1, the diver is assuming the pike position meaning that all body segments are pulled as close as possible to the axis of rotation thus decreasing the moment of inertia and increasing the angular velocity.

By the third phase the moment of inertia increases as the diver prepares to enter the water and releases from the pike position. This is because the arms are stretched over the head and are thus further away from the axis of rotation, similar to the initial position. The increased moment of inertia slows down the angular velocity and allows the diver to prepare for entry into the water in as straight a line as possible so as to produce minimum splash.

Pairs Activity – Past Paper Question

Why do shot-putters use either the glide or a spin technique prior to the release of the shot (4 marks)

- Angular momentum= angular velocity x moment of inertia
- If the mass moves closer to the axis of rotation, the moment of inertia decreases. If the moment of inertia decreases, then the angular velocity must increase, because angular momentum is conserved.
- Angular velocity and the moment of inertia have an inverse relationship.
- Therefore by spinning in a tucked position the shot putter will decrease their moment of inertia and thus increase the angular velocity applied to the shot.
- Both spin and slide techniques increase the impulse applied to the shot as the force is applied to it over a greater period of time.

Individual Activity – Extended Answer Question

Explain how a gymnast can alter the speed of rotation during flight. (7 marks)

A. Changing the shape of the body causes a change in speed

B. Change in moment of inertia leads to a change of angular velocity/speed/spin of rotation/ angular moment;

C. Angular momentum remains constant (during rotation)

D. Angular momentum = moment of inertia x angular velocity

E. Angular momentum - quantity of rotation/motion

F. Angular velocity - speed of rotation

G. Moment of inertia - spread/distribution of mass around axis/reluctance of the body to move

H. To slow down (rotation) gymnast increases moment of inertia

I. Achieved by extending body/opening out/or equivalent

J. To increase speed (of rotation) gymnast decreases moment of inertia

K. Achieved by tucking body/bringing arms towards rotational axis