Phone: (02) 8007 6824
Email: info@dc.edu.au
Web: dc.edu.au

2018 HIGHER SCHOOL CERTIFICATE COURSE MATERIALS

Preliminary Physics

Moving About

Term 1 – Week 3

Name ………………………………………………………….

Class day and time ……………………………………………

Teacher name ……………………………………………...

Term 1 – Week 3 – Theory

- **<u>Explain the need for a net external force to act in order to change the velocity of an object</u>**
- **<u>Define average acceleration as:</u>**

$$\boldsymbol{a_{av}} = \frac{\Delta \boldsymbol{v}}{\Delta \boldsymbol{t}}$$

<u>Therefore</u>

$$\boldsymbol{a_{av}} = \frac{\boldsymbol{v} - \boldsymbol{u}}{\boldsymbol{t}}$$

Acceleration

Acceleration refers to a **change in velocity over time**. Because velocity is a vector, it can change in two ways:

- Change in magnitude over time
- Change in direction over time
- (or both)

Acceleration refers to both of these cases. **Acceleration is also a vector** (since velocity is a vector), meaning it can have direction. It is measured in metres per second per second, or ms^{-2} (change in velocity, which is metres per second, each second).

Mathematically, acceleration is defined as:

$$a_{av} = \frac{\Delta v}{\Delta t}$$

Where

a_{av} is the average acceleration over the time interval Δt

Δv is the change in velocity in

Δt is the time interval in which all of this happens

The change in velocity Δv is given by the final velocity minus the initial velocity $v - u$

Therefore for a time interval t, we can also write a_{av} as:

$$\boxed{a_{av} = \frac{v - u}{t}}$$

This is the main equation you will use for acceleration in this module.

Calculus of motion (not in syllabus)

If we squeeze Δt such that it approaches 0, this happens:

$$\lim_{\Delta t \to 0} a = \lim_{\Delta t \to 0} \frac{\Delta v}{\Delta t} = \frac{dv}{dt}$$

From the discussion on velocity, we also know that:

$$v = \frac{dr}{dt}$$

So:

$$a = \frac{dv}{dt} = \frac{d\frac{dr}{dt}}{dt} = \frac{d^2r}{dt^2}$$

Basically this means if you integrate acceleration with respect to time once, you get velocity. If you integrate it with respect to time twice, you get displacement. This discussion is not required in the physics syllabus, but you will do this in detail in Maths Extension 1 and 2, so it is nice to see the connection between maths and physics.

Worked examples

Example 1: *suppose a car makes a 90° turn. It has an initial velocity of 15m/s north, and after turning, it has a velocity of 20m/s east. If the turn takes a total of 5 seconds, calculate the average acceleration during the turn.*

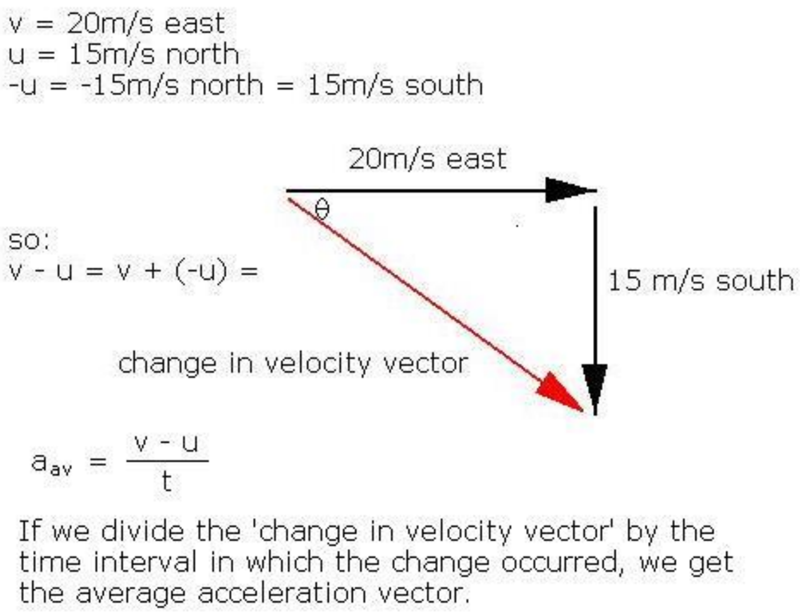
Notice that this is the same question as example 1 from subtracting vectors, except we are now asked to calculate the acceleration.

We have already calculated what $v - u$ is, and that is 25m/s at a true bearing of 126.87°.

Using the equation for average acceleration:

$$a_{av} = \frac{v - u}{t} = \frac{25}{5} = 5ms^{-2}$$

In the direction of the change in velocity: 126.87°.

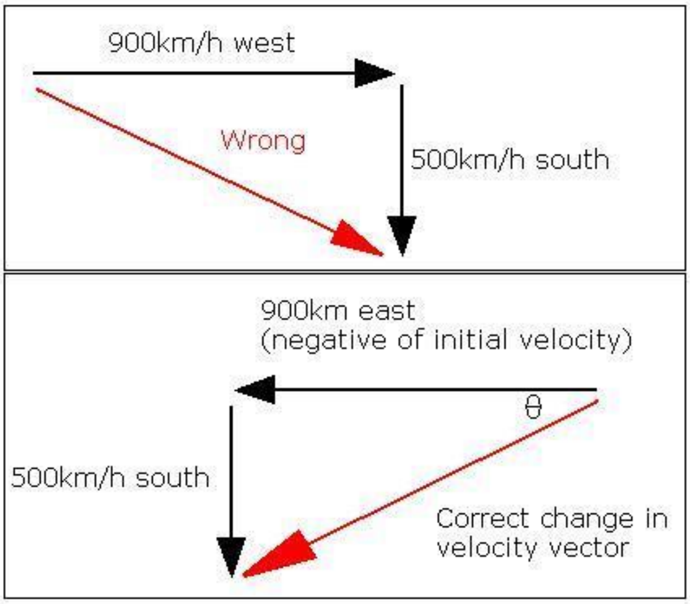


Example 2: *a plane is travelling west at a speed of 900km/h. It makes a right-angle turn for 60 seconds, and at the end of the turn, it is travelling south at a speed of 500km/h. Calculate the acceleration and the vector direction during the turn.*

Using the acceleration equation:

$$a_{av} = \frac{v-u}{t}$$

We see we need to subtract velocity vectors: the initial u from the final v.



Again, whenever you're subtracting vectors, remember to flip the direction of the negative vector (u in this case).

Magnitude of acceleration:

$$a = \frac{\sqrt{900^2+500^2} \times \frac{1000}{3600}}{60} = 4.766ms^{-2}$$

(remember to change km/h to m/s for the numerator, because we are dividing by time in seconds)

Direction:

$$\theta = \tan^{-1}\frac{5}{9} = 29.055°$$

$$\therefore \textit{true bearing} = 270° - \theta = 240.945°$$

Example 3: *a train moves at constant velocity of 40m/s over a circular track. As it travels a quarter of the circle, its direction changes from true north to true east. A complete revolution takes 600 seconds. What acceleration does the train experience?*

We know:

$$v = 40ms^{-1}north$$

$$u = 40ms^{-1}east$$

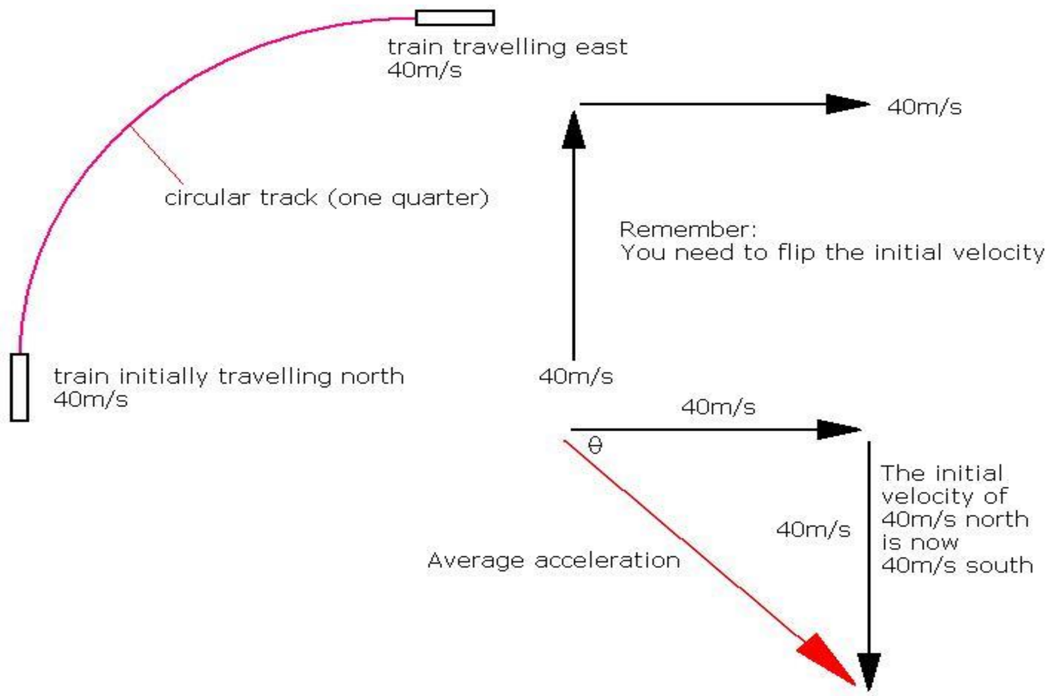
$$t = 600 \div 4 = 150s$$

Therefore the magnitude is:

$$a_{av} = \frac{v-u}{t} = \frac{\sqrt{40^2+40^2}}{150} = 0.377ms^{-2}$$

The direction:

It helps to draw a diagram for these types of questions.



$$\theta = \tan^{-1} 1 = 45°$$

$$\therefore true\ bearing = 90° + 45° = 135°$$

As you can see, this question demonstrates that even if the magnitude of velocity is not changing, there is still acceleration, because the **direction** of the velocity is changing.

Force and acceleration

For an object to experience a **change in its velocity** (e.g. from standing still to moving, speeding up, slowing down or changing directions), there must be a **net force acting on the object**. That is, acceleration requires a net external force to act upon an object. This is actually **Newton's first law** of motion.

Therefore, any object experiencing acceleration must have an external unbalanced (i.e. net) force acting upon it.

For example, when a car wants to accelerate and speed up, its engine must turn the wheels, which pushes against the ground. The reaction force from the ground pushes the car forward, and provides an unbalanced external force that accelerates the car.

When we hold a rock and let it fall to the ground, it falls because the Earth's gravity simply provides the external net force which pulls objects towards the ground.

If we use a fan to blow a leaf away, the leaf moves because moving air particles from the fan are hitting it. The transfer of momentum provides this external net force.

In all situations, whenever objects undergo a **change in velocity**, either in magnitude or direction or both (i.e. undergo acceleration), **there must be a net external force**.

- **<u>Describe the actions that must be taken for a vehicle to change direction, speed up and slow down</u>**
- **<u>Analyse the effects of external forces operating on a vehicle</u>**
- **<u>Describe the typical effects of external forces on bodies including:</u>**
  - **<u>Friction between surfaces</u>**
  - **<u>Air resistance</u>**

Forces on a vehicle

When a vehicle (such as a car) speeds up, slows down or turns, it is **undergoing acceleration**, which means there are **external forces acting upon it**.

In order to understand the exact mechanism by which vehicles move, we need to understand **Newton's third law** (loosely translated):

For every action, there is an equal and opposite reaction

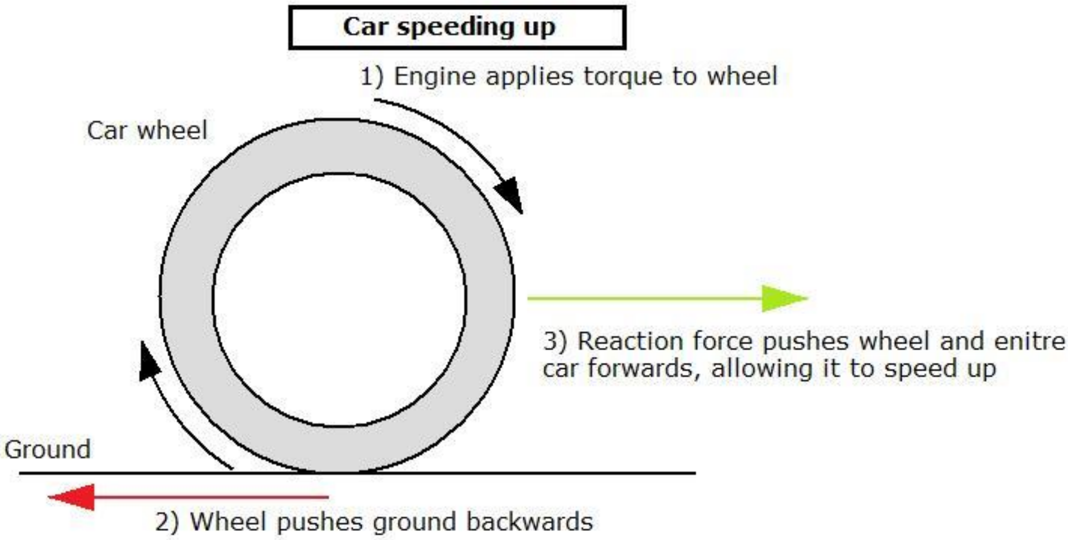
What this refers to is that for every force imparted, there exists a 'reaction force' which is equal in magnitude and opposite in direction to balance out the initial force.

For example, when we push a trolley, the trolley is pushing back at you. You feel this as the pressure between the trolley bar and your palms. The harder you push the trolley, the more it accelerates, but the more pressure will be felt in your palms. Another example is when we throw a ball. During the throw, as the ball speeds up in our hands, we feel the ball pressing against our palm. The harder we throw, the greater this pressure becomes.

In fact, all things that move rely on reaction forces. When we walk, for example, our legs are pushing laterally (sideways direction) against the ground, backwards, in order to create a forwards reaction force which pushes our body forwards, allowing us to walk. All forces come in action-reaction balanced pairs, because **momentum is always conserved**. That is, whenever we walk forwards, or our car speeds up, we are actually pushing the entire Earth backwards with as much momentum as we need for our forwards movement. Given that the Earth is massive compared to our body or car, the backwards push we give the Earth is unnoticeable.

Car speeding up

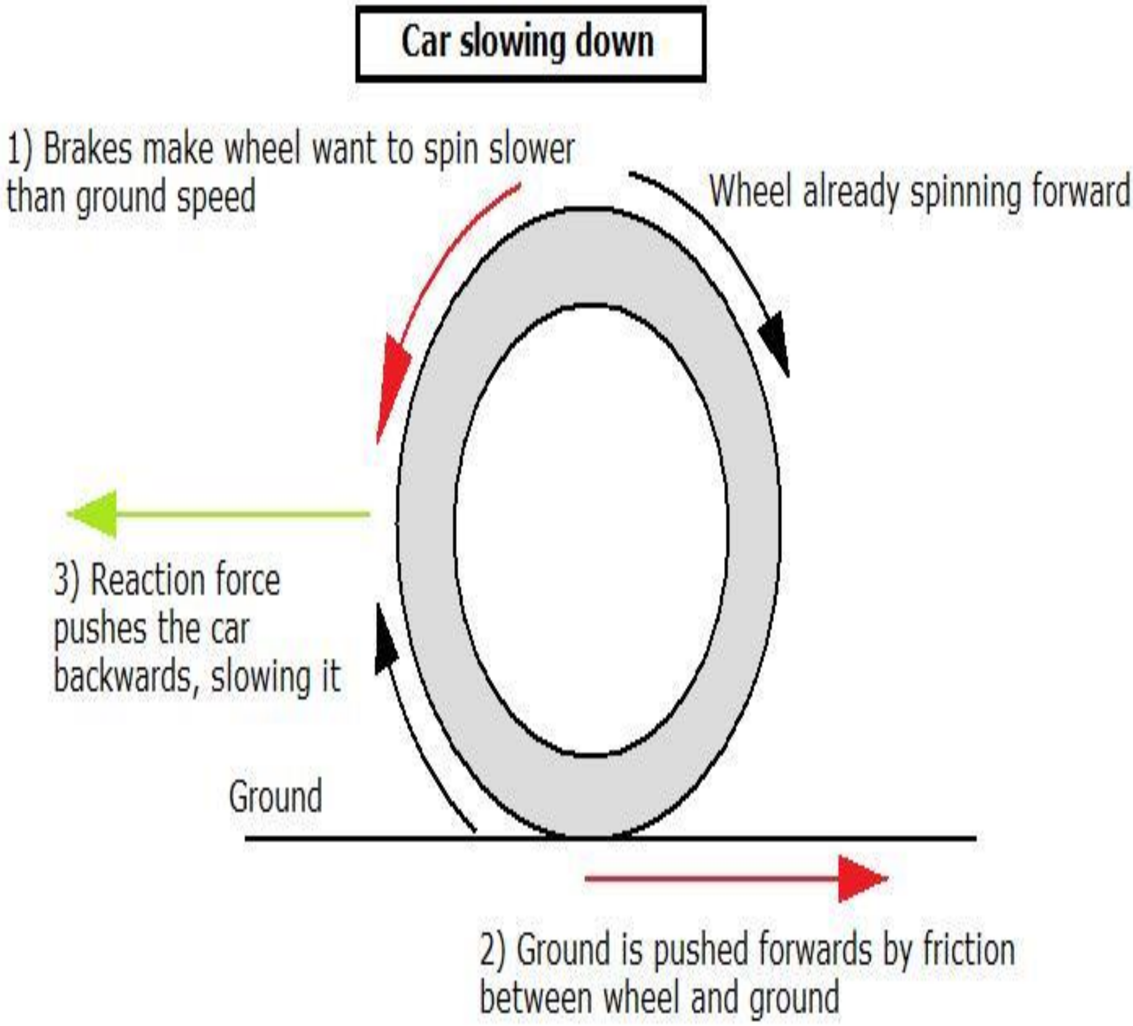
Much in the same way as walking, cars accelerate forward by using its wheels to create a forward reaction force. First the engine provides torque (turning force) to the wheels, which then turns, pushing the ground beneath it backwards. This force imparts a reaction force forwards (equal and opposite reaction force), pushing the car forwards.



In terms of friction between surfaces, the friction between the wheel and the ground is an example where friction between two surfaces can generate reaction force to propel a vehicle forward. Similarly when we walk forward, our shoes push the ground backwards in the same way, relying on friction between the sole of our shoes and the ground.

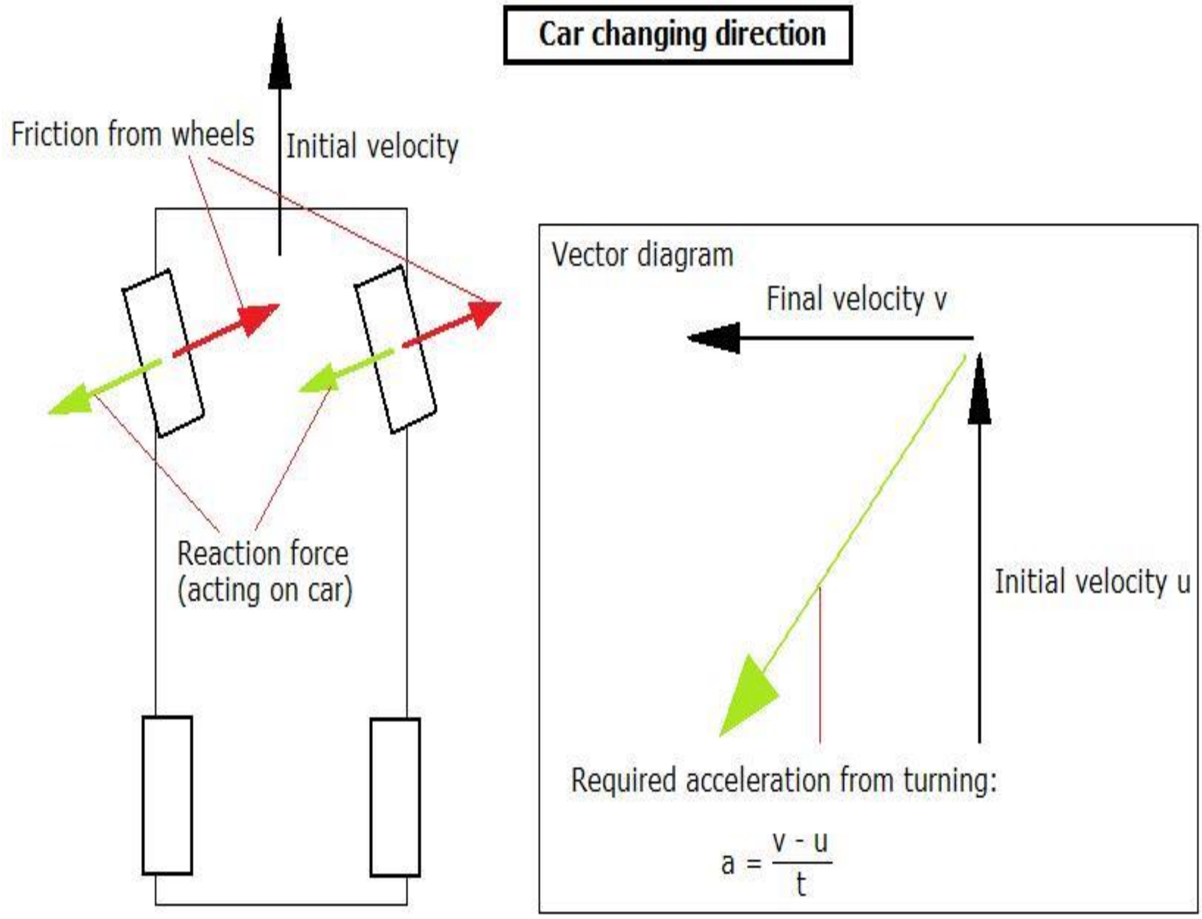
Slowing down

When the brakes are applied, the friction in the brake pads transfers its stopping force to the wheels, which wants to spin slower than its ground speed. The resultant friction between the wheels and the ground pushes the ground forward, creating a reaction force that pushes the car backwards, slowing it down.



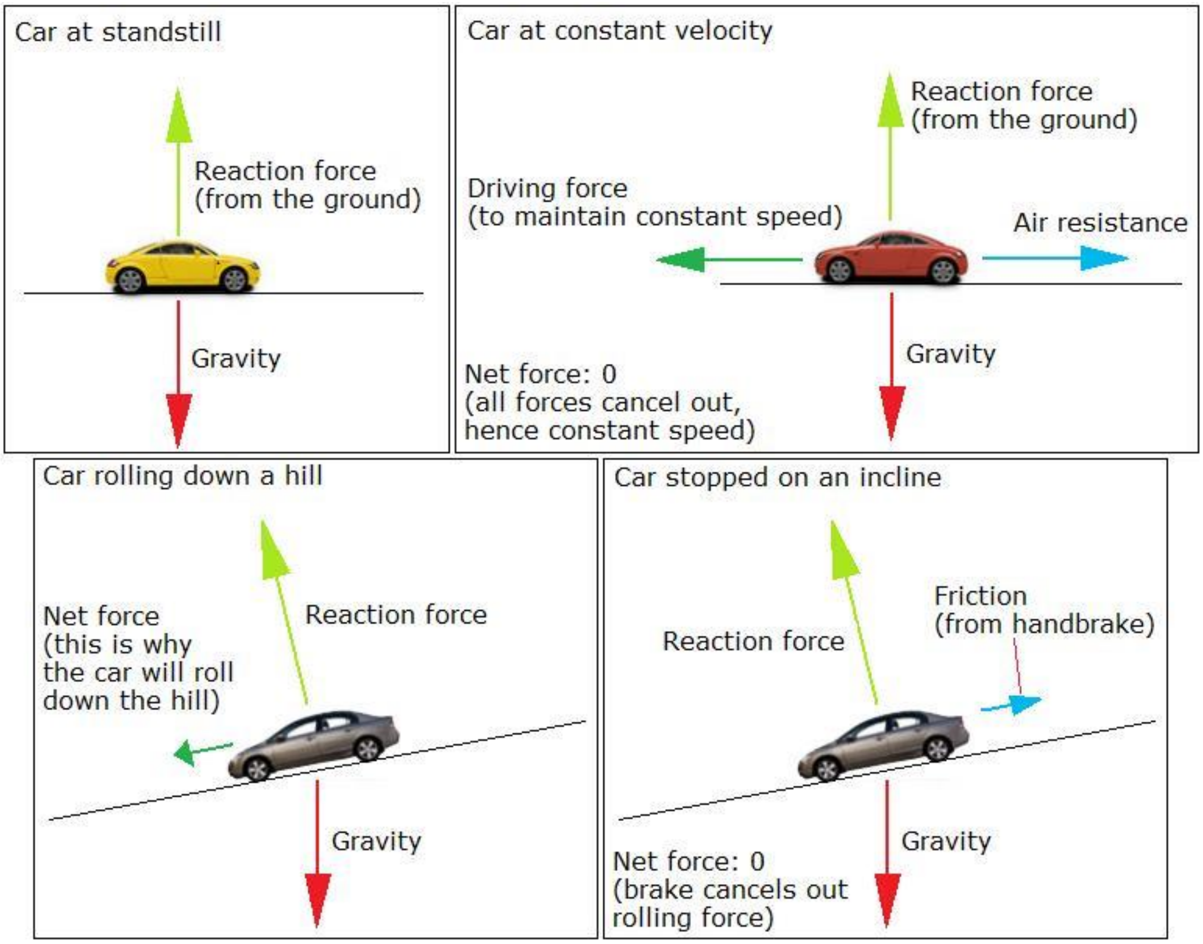
Changing direction

When a car wants to turn, it tilts its front wheels. This causes the wheels to generate lateral (sideways) friction with the ground, pushing the ground in one direction, and causing the reaction force to push the car into the other direction, which is where the car wants to turn.



From the diagram, a car changes direction by using the **reaction force** with the ground when its front wheels impart sideways friction onto the ground (note that the force towards the right is imparted onto the ground, so the car's front wheels experience a net force to turn left). The vector diagram shows the initial and final velocity vectors, and the acceleration vector required to allow the car to turn.

Other forces on a car



It is a good skill to be able to work out the force vectors and the net resultant force. In the four cases above, there's only one case (rolling down a hill) where the forces do not all cancel each other out, leaving a resultant force which causes the car to roll down the hill.

Air resistance

Air resistance in particular is a force which acts on all things which move in air. Air resistance is a force vector in the opposite direction to the velocity vector of the body, and its magnitude is proportional to the velocity of the body. That is, the faster a body moves, the more air resistance it will encounter.

Cars experience air resistance, and this is one reason why cars slow down automatically when we let go of the gas pedal (the other being rolling friction in the tires). When we throw a ball, it slows down due to air resistance. Bullets shot out of a gun experience extreme air resistance due to their high speed, and slow down significantly over long distances until it eventually become too slow to be harmful (given a long enough distance).

Term 1 – Week 3 – Homework

- **Explain the need for a net external force to act in order to change the velocity of an object**
- **Define average acceleration as:**

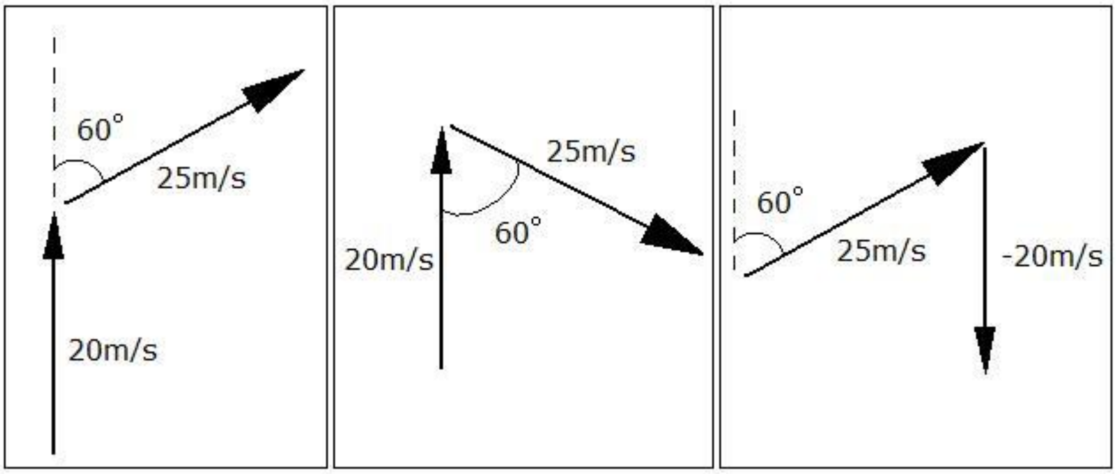
$$a_{av} = \frac{\Delta v}{\Delta t}$$

Therefore

$$a_{av} = \frac{v - u}{t}$$

1. Usain Bolt the sprinter can accelerate to 10.2m/s in 4 seconds. What is his average acceleration? **[1 mark]**

2. A car is travelling at 20m/s north and turns 60° to the left. After the turn, the car travels at a speed of 25m/s in its new direction.
   a. Identify the correct vector diagram to use if we wanted to find the average acceleration. (Hint: do we need to add or subtract vectors?) **[1 mark]**



   b. If the turn took 4.5 seconds to complete, calculate the average acceleration for the turn. **[2 marks]**

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3. A rock is sliding on a patch of ice at 5m/s east. With a single push lasting 3 seconds, we want the rock to head north at 8m/s. Calculate the direction of the push, as well as the acceleration needed during the push. **[3 marks]**

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4. A plane needs to make a sharp turn of 170° to the left. The plane was initially travelling north at 850km/h, and after the turn, the plane was travelling at 600km/h in its new direction. The turn took exactly one minute. Calculate the direction and magnitude of the average acceleration during this turn. (Remember to convert km/h to m/s and express your final answer as ms^{-2}) **[3 marks]**

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- **Describe the actions that must be taken for a vehicle to change direction, speed up and slow down**
- **Analyse the effects of external forces operating on a vehicle**
- **Describe the typical effects of external forces on bodies including:**
    - **Friction between surfaces**
    - **Air resistance**

1. Define Newton's Third Law of motion in terms of reaction force and give 2 real-world examples. **[2 marks]**

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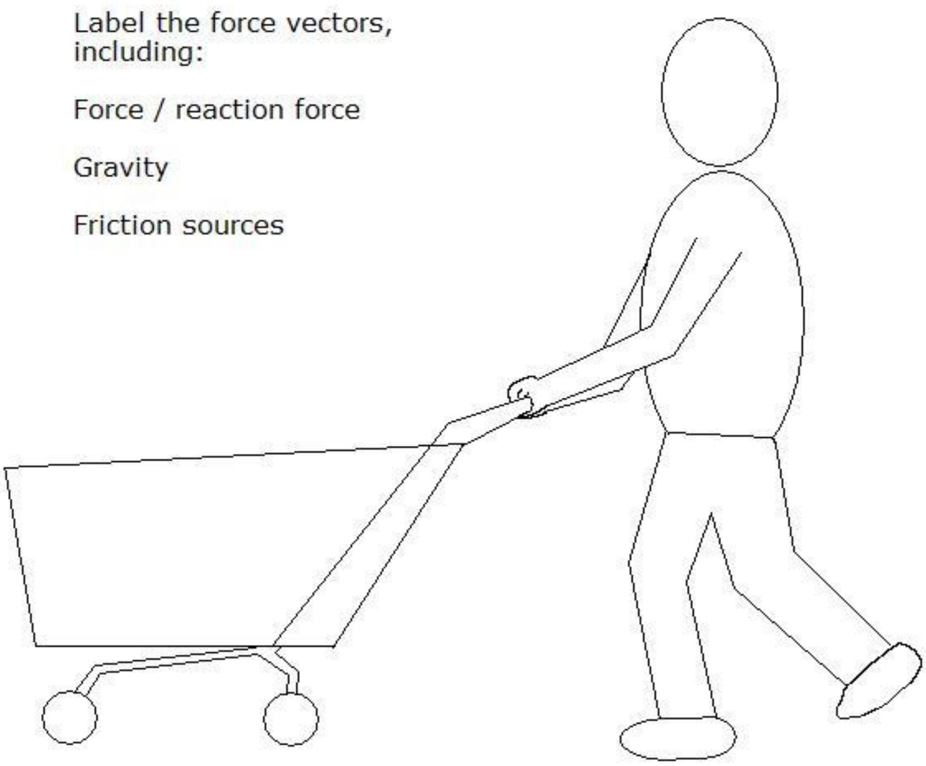
2. Below is a diagram of a person pushing a trolley. Draw the force vectors into the diagram and fully label all of them. Identify the net force vector which allows the person and the trolley to move forwards. **[4 marks]**



3. Describe the nature of air resistance as a force. In your answer, explain what makes air resistance stronger or weaker. **[3 marks]**

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4. Explain in terms of unbalanced forces why cars roll down inclined hills. **[3 marks]**

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End of homework