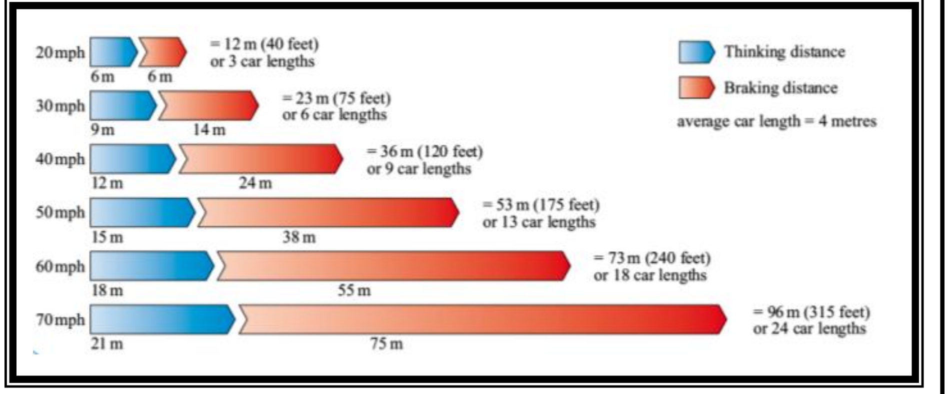
- ***Candidates should be able to :***

    - *Define **thinking distance, braking distance** and **stopping distance.***
    - ***Analyse** and **solve** problems using the terms thinking distance, braking distance and stopping distance.*
    - *Describe the **factors that affect** thinking distance and braking distance.*
    - *Describe and explain how **air bags, seat belts** and **crumple zones** in cars reduce impact forces in accidents.*
    - *Describe **how air bags work**, including the triggering mechanism.*
    - *Describe how the **trilateration technique** is used in **GPS (Global Positioning System)** for cars.*

- *VEHICLE STOPPING DISTANCE*

- *The diagram and the table below show the **HIGHWAY CODE** data on **MINIMUM STOPPING DISTANCES** for cars travelling at different speeds.*

    *These are the **shortest** distances in which a **well maintained** car can be brought to rest from a given speed, assuming **good weather** and **road conditions** as well as an **ideal driver** (i.e. rested, sober, drug-free and completely focussed).*



SPEED (in mph and m s^{-1})	THINKING DISTANCE (m)	BRAKING DISTANCE (m)	STOPPING DISTANCE (m)
20 (8.9)	6	6	**12**
30 (13.3)	9	14	**23**
40 (17.8)	12	24	**36**
50 (22.2)	15	38	**53**
60 (26.7)	18	55	**73**
70 (31.1)	21	75	**96**

- The **total stopping distance** for a vehicle can be calculated using the following equation :

STOPPING DISTANCE = THINKING DISTANCE + BRAKING DISTANCE

THINKING DISTANCE

- **THE DISTANCE TRAVELLED BY THE VEHICLE DURING THE TIME TAKEN BY THE DRIVER TO REACT TO A HAZARDOUS SITUATION (i.e. THE REACTION TIME).**
- It is **increased by anything which causes the driver's reaction time to increase** (**e.g.** alcohol, drugs, old age, tiredness, distractions).
- For a given reaction time :

THINKING DISTANCE IS DIRECTLY PROPORTIONAL TO VEHICLE SPEED.

BRAKING DISTANCE

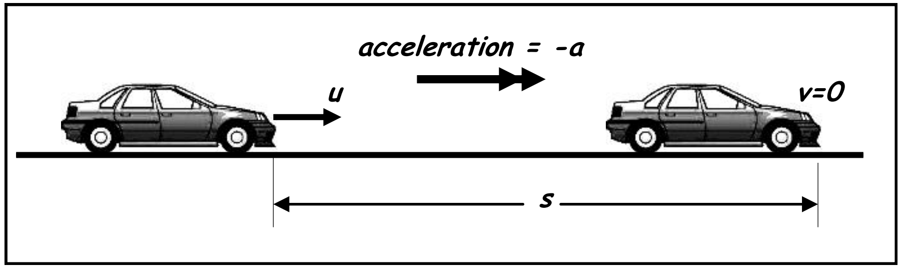
- **THE DISTANCE TRAVELLED DURING THE VEHICLE'S DECELERATION TO REST WITH THE BRAKES APPLIED.**
- It is increase when :
  - The **MASS** of the vehicle is increased.
  - The road surface is **WET, ICY or OILY** causing a reduction in the frictional grip between the tyres and the road.
  - The vehicle's brakes are **worn down** or **defective.**
  - The vehicle's tyres have **little or no tread .**
- **BRAKING DISTANCE IS DIRECTLY PROPORTIONAL TO (VEHICLE SPEED)^2.**

- **THINKING DISTANCE = VEHICLE SPEED x REACTION TIME**

So, since reaction time is constant (≈ 0.67 s), thinking distance is directly proportional to vehicle speed (i.e. if the vehicle is moving at 2 x the speed, the thinking distance will be doubled etc..). This can be verified by analysing the figures given in the table on page 1. as shown below.

VEHICLE SPEED (mph)	20	40	60
THINKING DISTANCE (m)	6	12	18

- The diagram below shows a car moving at a **speed (u)** which is brought **to rest** with a constant **deceleration (a)** over a **braking distance (s)** when the brakes are applied.



Using $v^2 = u^2 + 2as$ (and noting that v = 0)

Then : $2(-a)s = -u^2$

From which : $s = \dfrac{-u^2}{-2a}$

So, braking distance is directly proportional to (vehicle speed)^2.

UNIT G481	Module 2	1.2.4	Car Safety

- *The fact that the braking distance is directly proportional to the square of the vehicle speed can be verified by analysing the figures given in the table on page 1 as shown below.*

According to the table :

VEHICLE SPEED	*20 mph = 8.9 m s^{-1}*	*40 mph = 17.8 m s^{-1}*	*60 mph = 26.7 m s^{-1}*
BRAKING DISTANCE	*6*	*24*	*55*

Since ***BRAKING DISTANCE (s) is proportional to (VEHICLE SPEED)^2 :***

$$\frac{s_2}{s_1} = \frac{(v_2)^2}{(v_1)^2}$$

Then, if s(20), the braking distance at 20 mph (8.9 ms^{-1}) is 6m, the braking distance at 40 mph (17.8 m s^{-1}), s(40) can be calculated from :

$$\frac{s(40)}{s(20)} = \frac{(17.8)^2}{(8.9)^2} = 4$$

From which : $s(40) = 4 \times 6 = \boxed{24\ m}$ *(as shown in the table).*

- **PRACTICE QUESTIONS (1)**

1 A motorist is driving his BMW in the fast lane of a motorway. *The* car is travelling at a speed of ***100 mph (≈ 44.5 m s^{-1})*** when the careless driver suddenly realises that there is a stationary lorry directly ahead. At that moment, the distance between the BMW and the lorry is ***165 m*** and the traffic density is such that the BMW driver is unable to steer his car into another lane.
Given that his reaction time is ***0.70 s*** and that the BMW decelerates at ***6.5 m s^{-2}*** when the brakes are applied, calculate the car's ***total stopping distance*** (assume all other conditions to be ideal).
Will the BMW crash into the lorry ?

2 Using the figures shown in the table on page 1, plot a graph of ***THINKING DISTANCE (m)*** against ***VEHICLE SPEED (m s^{-1}).*** 3
Use the graph to estimate the ***REACTION TIME.***

3 Use the figures shown in the table on page 1 to do this question.

(a) Create your own table of ***(VEHICLE SPEED)^2 (u^2) in ($m^2 s^{-2}$)*** and ***BRAKING DISTANCE (s) in (m).***

(b) Plot a graph of ***(u^2)*** against ***(s).***

(c) Rearranging the equation ***$s = u^2/2a$*** gives ***$u^2 = 2as$.*** Compare this equation with the equation for a straight line ***(y = mx + c)*** and hence use the graph of ***(u^2)*** against ***(s)*** to determine the size of the ***deceleration (a)*** of a vehicle as it comes to a halt in an emergency.

4 The frictional force between a lorry's tyres and the road it is travelling along is ***0. 65 x the lorry's weight*** when the road is level. For a lorry of mass ***14000 kg,*** travelling at ***25 m s^{-1}*** calculate :

(a) The ***maximum deceleration*** of the lorry.

(b) The ***braking distance.***

(Assume ***g = 9.81 m s^{-2}***)

5 (a) (i) Explain the term ***THINKING DISTANCE.***

(ii) The thinking distance of a person driving a car at ***25.5 m s^{-1}*** is ***18 m.*** Calculate the person's ***REACTION TIME.***

(b) (i) Explain the term ***BRAKING DISTANCE.***

(ii) The driver of a car travelling at a speed of ***25.5 m s^{-1}*** applies the brakes and the car comes to rest in a braking distance of ***50 m.*** Calculate the car's ***deceleration.***

- ***CAR SAFETY FEATURES***

- ***SEAT BELTS***

When a car crashes it decelerates to rest very rapidly. The driver and passengers will obey Newton's first law and so continue to move forward at the car's impact velocity until a force changes their motion. This force is provided by collisions with each other, the steering wheel, dashboard or windscreen and generally results in serious injuries, even at low impact velocities.

Although a ***SEAT BELT*** *keeps you in your seat during a crash, it does not hold you rigidly in position. The end of the belt is wound over an* ***inertia reel*** *which clamps the belt firmly whenever there is a sudden force on it, but allows it to be pulled out slowly when it is being fastened. More importantly, the belt is also designed to stretch by about 0.25 m in a crash and this allows the force holding you in place to act over a longer time.*

Newton's second law **($F = \Delta(mv)/\Delta t$)** *shows that for a given* **momentum decrease $\Delta(mv)$**, *the* **restraining force (F)** *is smaller if the* **time (Δt)** *over which the force acts is longer.*

Seat belts are also relatively wide so that the **force (F)** *acts over a larger* **area (A)**, *reducing the* **pressure ($p = F/A$)** *Which might otherwise cause injury.*

- ***AIR-BAGS***

The purpose of an air-bag is to provide a soft, yielding cushion between the person's upper body (mainly the head) and the steering wheel or dashboard.

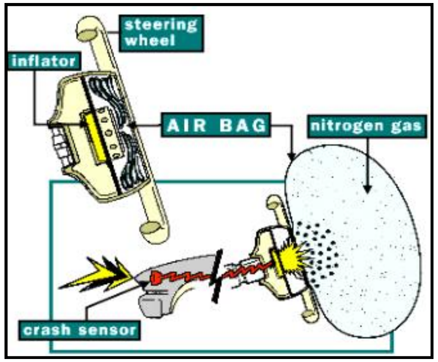
The injuries (mainly to the face and chest) which could result in the event of a crash are virtually eliminated by the deployment of an air-bag. This is because the air-bag :

- *Dramatically reduces the* **impact force (F)** *by extending the* **impact time (Δt)**. *According to Newton's second law,* **$F = \Delta(mv)/\Delta t$** *and so for a given* **momentum decrease $\Delta(mv)$**, *an increase in the* **impact time (Δt)** *means a decrease in the* **impact force (F)**.

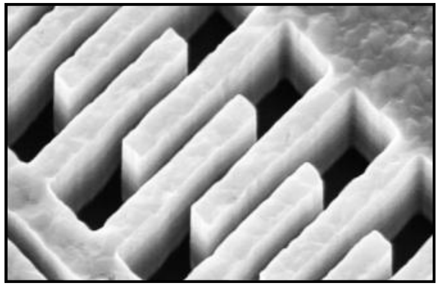
- *Significantly reduces the* **pressure ($p = F/A$)** *on the face or chest by providing a* **larger impact area (A)** *for a given* **impact force (F)**.

- *In the event of a crash and without an air-bag, the person's head would hit the steering wheel or dashboard about* **80 ms** *after impact. To prevent this, the* **onset of the crash needs to be detected** *and the* **air-bag must be inflated in less than 50 ms**.

A tiny **accelerometer*** *is used to detect the very large deceleration which occurs in any vehicular collision and then to trigger the very rapid, explosive inflation of the air-bag.*



** The* **accelerometer** *consists of two rows of interlocking teeth which will move relative to each other when subjected to the large deceleration produced in a collision. This movement generates a voltage which is used to trigger the inflation of the air-bag.*



- *The air-bag will only be triggered to inflate when the car is involved in a collision and not when it is heavily braked. To understand why, we need to realise that the deceleration produced in a collision is many times greater than that due to the heaviest braking and the accelerometer is only designed to operate with extremely large decelerations.*

First, let's calculate the deceleration produced when the brakes are used to bring a car to rest from **70 mph (≈ 31 m s^{-1}).** *Using the data given on page 1, the* **braking distance** *for this speed is* **75 m.**

Then using $v^2 = u^2 + 2as$ *and knowing that* $v = 0$

The deceleration (a) is given by :

$$a = \frac{-u^2}{2s} = \frac{-31^2}{2 \times 75} = \boxed{-6.4 \text{ m s}^{-2}}$$

Now let's calculate the deceleration produced when a car moving at **70 mph (≈ 31 m s^{-1})** *crashes and is brought to rest in a very short time* **(t ≈ 100 ms = 0.01 s).**

The deceleration (a) is given by :

$$a = \frac{v - u}{t} = \frac{0 - 31}{0.01} = \boxed{-3100 \text{ m s}^{-2}}$$

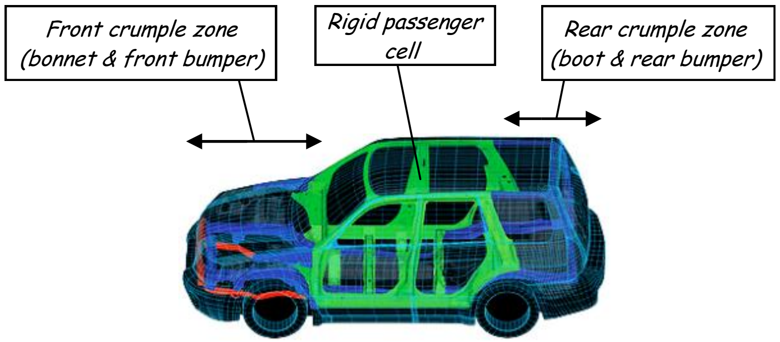
This deceleration is 480 times greater than the deceleration produced by slamming on the brakes to bring the car to a halt from 31 m s^{-1} in a braking distance of 75 m.

It should also be noted that the air-bag deflates rapidly after impact so as to prevent whiplash injury due to bounce or the possibility of suffocation.

CRUMPLE ZONES

- ***A* CRUMPLE ZONE** *is a part of a car which has been specifically designed so as to squash up or crumple easily in the event of a crash.*

The effect of this crumpling is to increase the time (Δt) for the car to come to rest when it is involved in a collision. According to Newton's second law, $F = \Delta(mv)/\Delta t$ *and so for a given* **momentum decrease $\Delta(mv)$**, *an increase in the* **impact time (Δt)** *means a decrease in the* **impact force (F)** *which acts on the car and passengers.*

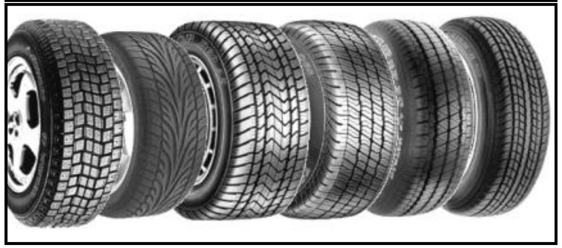


- *Other parts of the car, such as the* **passenger cell**, *are designed as a very strong, rigid compartment so as to maximise passenger protection in the event of a collision.*

- *Another interesting feature is the design of the engine support brackets which will shear in the event of a crash, directing the heavy engine downwards and so preventing it from penetrating the passenger compartment.*

TYRE TREAD

- *The* **TREAD** *on a car tyre is designed to ensure good grip between the tyre and the road (i.e. enough friction so that there is no slip) in wet as well as dry conditions.*



A tyre having a tread depth which is **less than 1.6 mm over the centre ¾ of its breadth** *is deemed to be 'illegal' and constitutes a motoring offence.*

On a **wet** *road, water moves up into the tread gaps and is thrown outwards from the tyre as the wheel rotates. This does not happen if the tyres are* **bald** *and if the brakes had to be applied, the car would slide along on a virtually frictionless water film between the tyres and the road surface. This could double or even treble the car's braking distance.*

- **GLOBAL POSITIONING SYSTEM (GPS)**

- *The GP system has about 30 satellites placed in high orbits around the Earth such that at any point on the surface of the Earth, three to six of these satellites are above the horizon.*

- *Each satellite sends out signals giving the satellite's* **identity, transmission time and the precise position at the time of transmission.**

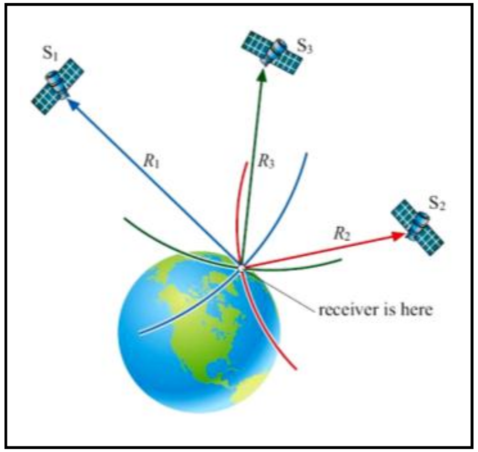
- *The receiver on Earth compares these signals with its own clock, measures the time lag and so measures the* **time from transmission to reception.** *Using this time and the speed of radio waves in space (3.0×10^8 m s^{-1}) the receiving system can determine* **its distance from the satellite.**

- *Then, using this distance and the satellite's position at the time of transmission, the receiving system calculates* **its own position.**

- *Because this requires information from three satellites, the process is called* **TRILATERATION**.

- **HOW DOES TRILATERATION WORK ?**

The diagram opposite shows three GPS satellites S_1, S_2 and S_3 *at distances* R_1, R_2 and R_3 *respectively from the receiver.*



So the receiver must lie somewhere on a sphere of radius R_1 *centred on* S_1.
It must also lie somewhere on a sphere of radius R_2 *centred on* S_2.

The receiver's position is somewhere on the circle produced by the intersection of the two spheres. It is the distance R_3 *from satellite* S_3 *which pinpoints the receiver's actual location on the circle.*

This gives the receiver's position on Earth to within a few metres, but a signal from a fourth satellite can make the positioning even more precise.

USES OF THE GLOBAL POSITIONING SYSTEM	
Navigation	*GPS is used in cars, boats and aircraft.*
Vehicle Tracking	*Stolen cars can be located when a beacon in the car is activated.*
Geological Surveying	*Geologists searching for mineral deposits make use of GPS.*
Mobile Phones	*Many mobile phones have GPS built in and this means that they can be located in an emergency.*

- HOMEWORK QUESTIONS

1 A car is travelling at a constant speed of ***25 m s⁻¹*** and the driver's reaction time is ***0.62 s.***

(a) Calculate the ***thinking distance*** when the car is travelling at this speed.

(b) The ***overall stopping distance*** of the car is ***75 m.*** Calculate :

(i) The ***braking distance*** of the car.

(ii) The ***deceleration*** of the car when braking. Assume that the deceleration is uniform.

(OCR AS Physics - Module 2821 - January 2004)

2 The diagram below shows a crate resting on the flat bed of a moving lorry.

(a) The lorry brakes and decelerates to rest.

(i) ***Describe*** and ***explain*** what happens to the crate if the flat bed of the lorry is ***smooth.***

(ii) A ***rough*** flat bed allows the crate to stay in the same position on the lorry when the brakes are applied. State the ***direction of the force*** that acts on the crate to allow this.

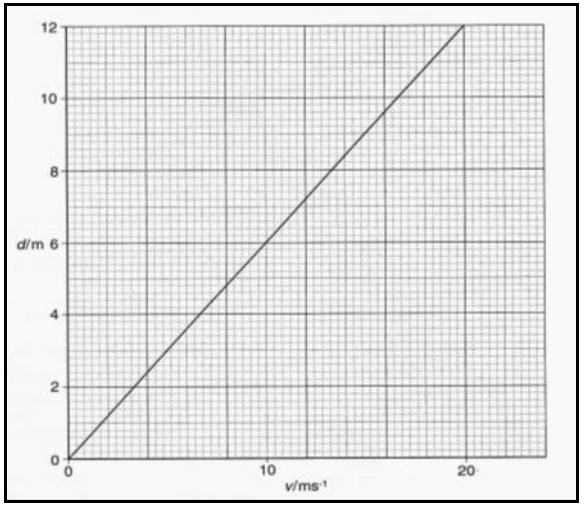
(b) Using your answers to (a) or otherwise, ***explain*** how seat belts worn by rear seat passengers can reduce injuries when a car is involved in a head-on crash.

(OCR AS Physics - Module 2821 - June 2005)

3 (a) Explain the following terms when associated with driving a car.

(i) ***Thinking distance,*** (ii) ***Braking distance.***

(b) The graph below shows the variation with ***speed (v)*** of the ***thinking distance (d)*** for the driver of a car.



(i) Explain why the graph is a straight line through the origin.

(ii) Use the graph to determine the ***time taken*** for the driver to react when the car is travelling at ***16 m*** s^{-1}.

(iii) The driver is travelling at ***30 m*** s^{-1} in a car which brakes with an acceleration of ***- 6.5 m*** s^{-2}. Calculate :

1. The ***thinking distance,*** 2. The ***overall stopping distance.***

(c) Explain the effect of the ***road conditions and tyre tread*** on the stopping distance.

(OCR AS Physics - Module 2821 - May 2002)

4 (a) Explain the term ***braking distance*** in relation to the motion of a road vehicle. *9*

The table below how the ***braking distance*** for a car of mass ***800 kg*** varies with its ***initial speed*** when a constant braking force is applied.

Speed / m s^{-1}	0	10	20	30	40
Braking distance / m	0	6	24	54	

(b) Calculate the ***kinetic energy*** of the car when it is travelling at ***20 m*** s^{-1}.

(c) Explain why the braking distance is ***NOT proportional*** to the speed of the car when the braking force is constant.

(d) Calculate the ***braking distance*** for this car when it is travelling at ***40 m*** s^{-1}, assuming the same braking force is applied.

(e) Discuss in terms of the force acting on the driver of a car, how a ***seat belt*** can help to protect the driver from injury in a head-on collision.

Suggest how an ***air-bag*** gives additional protection to the driver.

(OCR AS Physics - Module 2821 - June 2003)