ANSWERS TO FORCES – WORKSHEET 1

Question 1:

Describe the typical effects of external forces on bodies including:
- friction between surfaces
- air resistance

Let us consider how external forces affect the motion of cars. When dealing with friction and cars there are different types of friction to consider.

(i) Static friction: This is the friction between the tyre and the road when the car is stationary or when the tyre rolls without slipping. It is this static friction force that provides the reaction force that causes the wheel to roll and the car to move. When it is removed (e.g. a car bogged in mud or trying to drive on ice) the wheels rotate but because there is no reaction force between the tyres and the surface, the car will not move. Static friction is also the force that holds a car in place when it is parked on a slope.

(ii) Kinetic friction: This is the friction between two surfaces that are moving with respect to each other. It applies, for instance, when hard-braking stops the wheels from turning and the car skids to a stop.

(iii) Rolling friction: There is some loss of energy and some deceleration from friction for any real wheel in motion, and this is sometimes referred to as rolling friction. It is partly friction at the axle and can be partly due to flexing of the wheel which will dissipate some energy.

(iv) Internal friction: this is the friction that occurs between moving parts of a car such as the pistons and cylinders.

When an object moves through a fluid (liquid or gas) it has to push the particles of fluid out of the way. When the fluid is air this is known as air resistance. Air resistance opposes the motion of a car. Streamlining, i.e. sloping the shape of the car, so that air flows over it smoothly, greatly reduces air resistance. Air resistance includes the movement of a car through still air as well as the movement of air against the motion of the vehicle (wind).

Question 2:

Outline the forces involved in causing a change in the velocity of a vehicle when:
- coasting with no pressure on the accelerator
- pressing on the accelerator
- pressing on the brakes
- passing over an icy patch on the road
- climbing and descending hills
- following a curve in the road

Note that because you are only asked to outline the forces, your answers should be very brief. You need maybe a sentence or two and an appropriate diagram. I have supplied more of a description & explanation of the above forces in order to help your understanding.
In the diagrams that follow: \( F_E \) = force of engine, \( F_A \) = air resistance, \( F_f \) = force due to friction, \( F_g \) = force due to gravity, \( F_c \) = centripetal force and \( v \) = velocity.

(a) **Coasting with no pressure on the accelerator:** When there is no pressure on the accelerator there are no forward forces. If there were no backward forces then the car would keep moving forever at the same speed. However there is rolling friction, air resistance and friction between the moving parts of the car acting to oppose the motion of the car. Consequently the car will gradually slow down and stop.

(b) **Pressing on the accelerator:** Pressing on the accelerator increases the rate at which fuel is fed to the cylinders of the car. This in turn increases the rate of rotation of the wheels and increases static friction. The reaction force to this increases the forward force on the car allowing it to overcome the forces that retard the motion. If the accelerator is held in a position where it balances the forces opposing motion, the car will maintain constant speed. If the accelerator is pressed a little harder the car will increase its speed.

(c) **Pressing on the brakes:** The hydraulic system transfers pressure to the pads that grip the discs or drums. The pads exert a frictional force on the discs or drums that is in the opposite direction to the motion of the wheel. This slows the rate at which the wheels are rotating. This causes a forward force between the wheels and the road and the reaction force to this forward force causes the car to slow down and stop. If too much pressure is applied to the brakes they completely stop the rotation of the wheels. This causes the wheels to slide (skid) over the road and since sliding (kinetic) friction is less than static friction the car travels a much greater distance before stopping.
(d) **Passing over an icy patch on the road:** Ice reduces friction to a very low value so pressing on the accelerator would speed up the rate of rotation of the driving wheels but they would not be able to grip the road. The wheels would spin on the ice but the car would have no traction and would not increase its speed. The loss of friction would be disastrous for braking and steering. The brakes would stop the wheels from rotating but according to Newton’s first law, a car in motion continues in uniform motion unless acted on by a force. Hence the car would skid with little change in speed until it was clear of the icy patch or until it met an opposing force such as the back of the car in front. Also because of the lack of friction, turning the wheels would not be able to produce a centripetal force. Consequently the driver would not be able to steer and the car would continue in a straight line even if the road didn’t.

![Diagram of a car on ice](image)

**Climbing and descending hills:**
All objects on Earth have a gravitational force on them pulling them towards the centre of the Earth. This is true whether the object is on level ground or on a slope such as a hill. A car on a hill has a gravitational force acting vertically down. This applies whether the car is climbing (ascending), descending or parked on the hill. The gravitational force mg, can be divided into components perpendicular to the plane and parallel to the plane. The parallel component applies a force of mg sinθ downhill.

![Diagram of forces on a car on a hill](image)

The parallel component applies a force mg sinθ downhill.

(e) **Climbing a hill:**

![Diagram of forces on a car climbing a hill](image)
When a car is climbing a hill the driver has to press harder on the accelerator to overcome the gravitational force downhill.

(f) Descending a hill:

When the car is descending the hill the driver does not have to press the accelerator as hard since some of the downhill force is supplied by gravity. On steep hills the engine may have to supply no force at all and the car will coast down the hill. In these cases the car has to be slowed by the brakes. The problem is that constant hard braking can cause the brakes to overheat and become less effective. An alternative to constant braking is to choose a lower gear to descend the hill (eg “Steep Descent – Trucks Use Low Gear” signs on the road). Using a lower gear ensures that the wheels turn more slowly and are subject to less static friction.

(g) Following a curve in the road: A body will travel with uniform velocity unless acted on by a force (Newton’s first law). Therefore a force is required to change the direction of a car. When following a curve in the road, the necessary force is a “centripetal force”. This force always acts towards the centre of the motion i.e. towards the centre of the road’s curve. The force is supplied by the friction between the tyres and the road and has a value of: $F_c = \frac{mv^2}{r}$, where $F_c =$ centripetal force, $m =$ mass of car, $v =$ linear velocity of car, $r =$ radius of curve.

The centripetal force is always towards the centre.
Question 3:

Interpret Newton's Second Law of Motion and relate it to the equation $\Sigma F = ma$

Newton's second law states that the net force on an object is equal to the product of its mass and its acceleration and that the acceleration is in the direction of the force.

Thus, if a force of a given size is applied to several different masses we will find that the larger the mass the smaller the acceleration of the object.

The term "net force" refers to the sum of all the forces acting on the object. Hence the $\Sigma$ (capital sigma) in front of the $F$ in the formula. $\Sigma$ stands for "the summation of".

Examples: (i) At the school athletics carnival, athletes prefer to use a light shot put rather than a heavy one because they are able to give the light shot put a larger acceleration. This means that it will attain a larger velocity as it leaves the hand and so travel further before it hits the ground. (ii) In cars, if the same engine is installed in a heavy and a light car, the light car will attain the higher acceleration for the same applied force from the engine.

Question 4:

Identify the net force in a wide variety of situations involving modes of transport and explain the consequences of the application of that net force in terms of Newton's Second Law of Motion

Note the words "identify" and "explain"

Consider the forces acting in planes, trains and cars.

Planes: The physics of flight is extremely complex. Let us consider a plane just at take-off. There are two components of the net force that we have to consider. First there are the horizontal components of the motion that provide the plane's forward motion and secondly there are the vertical forces acting that cause the plane to lift from the ground.

The vertical motion of the plane is caused by dynamic lift (as opposed to static lift such as a balloon where the object rises in a more dense fluid). The dynamic lift of an aircraft is caused by two factors, both of which rely on the plane moving forward through the air.

![Diagram](image_url)

The first is caused by the wing sloping upward towards the direction of forward motion so that the air is deflected down. The second is due to the shape of the wing. The wing is curved
so that air travelling over the top of the wing travels a greater distance than air travelling underneath the bottom of the wing. This results in the air travelling over the top occupying a greater volume in the same time and so being less dense. While the difference in density would create very little lift for a stationary object, there is substantial lift for a moving object. This is due to the Bernoulli principle that is beyond the scope of the current HSC physics course. It used to be done in a Fluid Dynamics Half Elective some years ago.

The forward thrust of a jet plane is caused by the reaction force to the exhaust gases (Newton’s third law). A bigger engine or more engines gives a greater forward force. There is also the force of air resistance opposing the motion of the aircraft. The net force is forward and the acceleration is given by $a = F_{\text{net}}/m$.

Note that as a plane takes off, the net force acting on the plane at any point in time is the sum of the vertical & horizontal forces acting on the plane at that point in time. This would require a vector diagram to determine the net force on the plane at any point in time.

**Trains:** There are several different types (steam, diesel, electric) but all rely on the principle of a force causing the wheels to turn and the static friction between the wheels and the rail providing the forward (reaction) force to cause the train to move. There is friction between the moving parts of the train as well as air resistance but the overall result is a net force forward which results in the forward acceleration of the train. The train will attain a constant velocity when the forward force is equal to the sum of the backward forces.

**Cars:** These experience much the same forces as trains except that there is friction between the tyres and the road rather than between the wheels and rail. Tyres have a tread pattern, so the friction between the tyres and the road is usually greater than the corresponding friction between train wheels and the rails. There is friction between the moving parts of the car as well as air resistance but the overall result is a net force forward which results in the forward acceleration of the car. The car will attain a constant velocity when the forward force is equal to the sum of the backward forces.

**A Note on Friction for the Teacher**

Two types of friction can occur between a car tyre and the ground, a) static friction, and b) kinetic friction.

Static friction is when the tyre maintains grip or traction on the road surface, whereas kinetic friction (as the name implies) is when the tyre is moving relative to the ground. To illustrate static friction, consider for a moment a dot on the tyre's surface. Your vehicle is moving forward (let's say it's moving very slowly), and your tyre rotates so that the dot comes into contact with the ground at a certain point. Since a car tyre compresses a bit on the road's surface, there's approximately 10cm of tyre flat against the road at any given time. As your car moves forward, the tyre rotates, and once the dot touches the ground at a given point, the tyre and the ground move at the same rate relative to the car. That is, the dot on the tyre and the point on the ground remain in contact until the tyre reaches the end of that 10cm strip of contact, when it is pulled upward from the ground to rotate around top and back to the ground.
An example of kinetic friction from the illustration above would be that the dot on the tyre reaches a point on the ground, but the dot and point move away from one another. In real life this would be if you hit the brakes and skid, or if you hit the accelerator and burn out or spin your tires (e.g. in the snow or mud). The problem with kinetic friction is that it is weaker than static friction. Thus, when you hit the brakes, if your tyres lock up (you will hear the squealing tyres against the road) you are now in kinetic friction and your car will slow down less quickly compared to when your tyres were in static friction with the ground. That is why you pump your brakes... also why anti-lock braking systems (ABS) were developed.

Read more: http://wiki.answers.com/Q/How_does_friction_act_on_a_car#ixzz1y1iQA0Ku

**Question 5:**

The mass of an object is a measure of the amount of matter contained in the object. Mass is a scalar quantity. The weight of an object is the force due to gravity acting on the object. Weight is a vector quantity. $W = mg$, where $W$ = weight force, $m$ = mass, $g$ = acceleration due to gravity.
\[ F = ma \]
\[ a = \frac{F}{m} \]
\[ = \frac{48}{4} \]
\[ = 12 \text{ m s}^{-2}, \text{ West} \]

7. \( m = 2200 \text{ kg} \)
\( v_i = 25 \text{ m s}^{-1}, \hat{S} \)
\( v_f = 0 \text{ m s}^{-1} \)
\( t = 10 \text{ s} \)

(a) \[ a = \frac{\Delta v}{t} = \frac{v_f - v_i}{t} = \frac{0 - 25}{10} = -2.5 \text{ m s}^{-2} \]

- Acceleration of car is -2.5 m s\(^{-2}\), North

(b) \[ F = ma \]
\[ F = 2200 \times -2.5 \]
\[ = -5500 \text{ N} \]
- Force required to cause this acceleration is 5500 N, North.
8. Astronauts experience high g-forces during launch. Placing them horizontally minimizes the effect of these forces within the body. The astronauts' bodies are held firmly to the seat. However, the blood in their circulatory system is not. If they were standing upright during launch, the blood would be left behind in their veins and arteries as their bodies accelerated upwards. The blood would not experience the same upwards force as the body and as Newton's 1st law states: a body will remain at rest unless an external unbalanced force acts on it. The blood would be left behind as the body accelerated. Blood would drain from the brain and the astronauts would pass out.

9. Same pressure on accelerator will produce same engine force in both cases.

Force produced by engine on road, \( F = ma \)

\[
= 2600 \times 5
\]

\[
= 10000 \text{ N, forwards}
\]

In the sand, the van travels at constant speed — that is, zero acceleration. So, net force on van = 0 N.

\[ \text{Friction force supplied by sand} = 10000 \text{ N, } \]

\[ = 1 \times 10^4 \text{ N, opposing motion of van} \]
10. (a) \(m_c = 1200 \text{ kg}\)
\[V_c = 72 \text{ km h}^{-1} = \frac{(72 \times 1000) \text{ m}}{3600 \text{ s}} = 20 \text{ m/s South}\]
So, car is moving at a constant speed of 20 m/s South.

Safe Distance = speed \times time, from \(V = \frac{AS}{AT}\)
\[= 20 \times 2\]
\[= 40 \text{ m}\]

(b) \(F_c = 6400 \text{ N}, \text{ north}\)
\[x = ?\]
From \(F = ma\),
\[a = \frac{F}{m} = \frac{6400}{1200} = 5.33 \text{ ms}^{-2}, \text{ north}\]
So, acceleration of car = 5.3 ms\(^2\), north
\[= -5.3 \text{ ms}^{-2}, \text{ assuming south is } +\text{ve}\]

From \(a = \frac{\Delta V}{\Delta t} = \frac{V_f - V_i}{\Delta t}\)
We have \(-5.3 = \frac{0 - 20}{\Delta t}\)
\[\therefore \Delta t = 3.75 \text{ s}\]
\[\therefore \text{It takes car 3.75 s to stop.}\]
11. Reading = 3 \times 9.8 = 29.4 \text{ N}.

The 3kg mass on RHS of balance is like your hand when you held the balance vertically to measure a weight (force). In that case, your hand supplies 3kg force (29.4 N) upwards that holds the balance still while the 3kg mass whose weight you are measuring pulls the spring downwards. When the 3kg mass comes to rest, the balance will read 3kg force (29.4 N) provided the spring balance has been properly calibrated.