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SESSION 2: NEWTON'S LAWS

Key Concepts

In this session we
- Examine different types of forces
- Review and apply Newton's Laws of motion
- Use Newton's Law of Universal Gravitation to solve problems

X-planation

THE NATURE OF FORCES

Forces can be divided into two categories: **contact forces and non-contact forces.**

- The following are non-contact forces:

  o **Gravitational forces** – between a planet and an object on the planet

  o **Electrostatic forces** – between charged objects

  o **Magnetic forces** – between magnets

- Examples of contact forces include **normal, frictional, tensional and applied forces**

NEWTON'S THIRD LAW

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

Please note the following, regarding Newton's 3rd Law:

- in every interaction, there is a pair of forces acting on the two interacting objects.

- the size of the force on the first object **equals** the size of the force on the second object.

- the direction of the force on the first object is **opposite** to the direction of the force on the second object.

- these forces are referred to as action-reaction pairs.

- **These forces are acting on separate objects**.

NEWTON'S FIRST LAW

A body will remain in its state of rest or uniform motion in a straight line unless acted upon by an external resultant force.

- In other words, unless a resultant force acts on an object, that object will remain in its state of rest, or if it were moving, it will continue moving at a constant velocity in a straight line.

Example: A passenger sitting in a vehicle that is moving at a constant velocity will be thrown forwards if the vehicle suddenly had to break. This is because the passenger wishes to continue moving at that constant velocity in a straight line.

- The property of matter which maintains an object's state of rest or uniform motion in a straight line, is called **inertia.**

- Therefore, **inertia is the resistance of an object to change its state of motion.**

NEWTON'S SECOND LAW

- **It states that when a resultant force acts on an object, it causes that object to accelerate in the direction of the resultant force (net force). This acceleration is directly proportional to the resultant force and inversely proportional to the mass of the object.**

a α F_{net}

a

Fres

m

a α 1/m

a

1/m

a
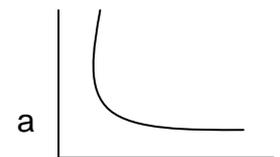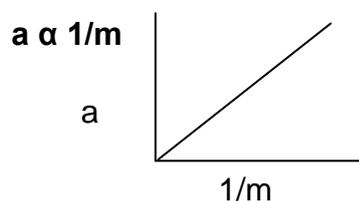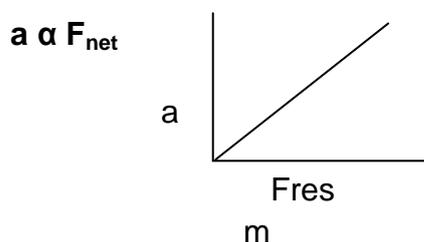
Equation: **F_{net} = m.a**

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NEWTON'S SECOND LAW TYPES OF QUESTIONS

Newton's Second Law questions come in many different forms and the forms are listed below, but please take note of the following points when solving Newton's Second Law questions:

- It helps to draw a force diagram labelling all the forces acting **on** the object, even if the question does not require you to do that.

- According to Newton's Second Law: F_{net} = ma, but also mathematically F_{net} = algebraic sum of all the forces acting on an object and in most cases you will need to combine those two statements to solve a given problem.

- In the case of more than one object within the same question, it is advisable to let the examiner know which object you are considering in you calculations.
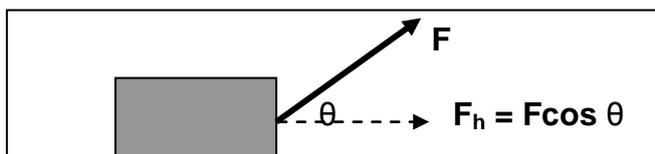
Following are the types of question you can expect:

Horizontal plane

1. One force acting : Applied force **F = F$_{net}$ = ma**
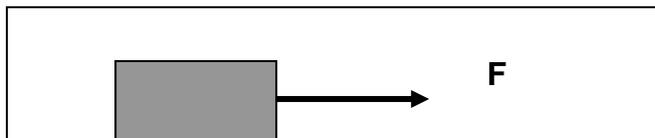
2. One force actions at an angle θ to the horizontal.

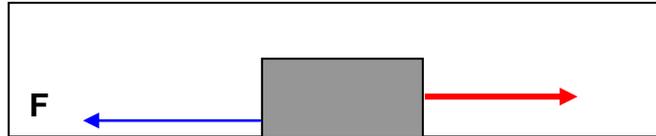   **Horizontal Component of the force F$_h$ = F$_{net}$ = F cos θ**

3. More than one force acting

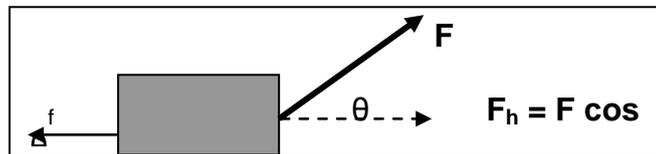$\mathbf{F_{net} = ma}$ = **algebraic sum of all the forces in the horizontal plane**
Example: $F_{net} = ma = F + (-f)$
[if you consider the direction to the right as positive]

F

4. More than one force acting with a force at an angle θ to the horizontal

$\mathbf{F_{net} = ma}$ = **algebraic sum of all the forces acting in the horizontal plane including F_h**
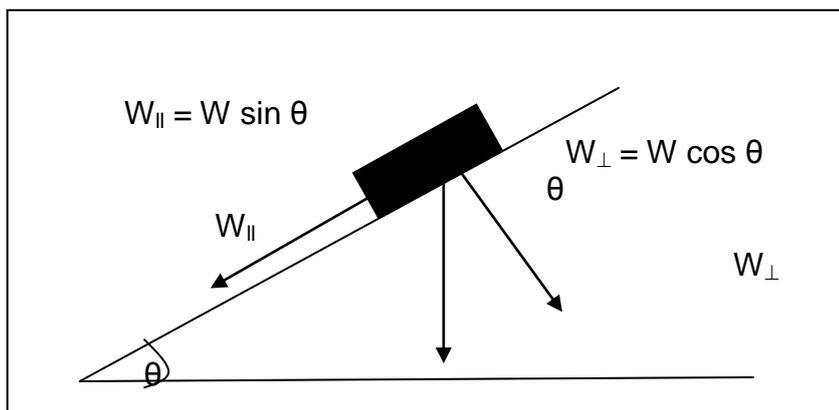

F

f

θ

$\mathbf{F_h = F\ cos}$

$\mathbf{F_{net} = ma = Fh + (-f)}$ [considering the direction to the right as positive]

Inclined Plane

1. On a frictionless plane, the object rolls down the slope due to $W_{\parallel}$

2. If there is an upward force (friction or tension by a rope):

$F_{net} = ma$ = algebraic sum of all the forces acting in that plane.

$W_{\parallel} = W \sin \theta$

$W_{\perp} = W \cos \theta$

θ

$W_{\parallel}$

$W_{\perp}$

θ

NEWTON'S LAW OF UNIVERSAL GRAVITATION

- The gravitational attraction of the earth on an object (weight) depends on the mass of the object, i.e.

$$W \text{ or } F_g = mg$$

- The masses of the attracting objects affect the force of attraction, therefore, the gravitational force is directly proportional to each mass

i.e. **$F \propto m_1$ and $F \propto m_2$**

Therefore, **$F \propto m_1 m_2$**

- Another factor affecting the force is the distance (**r**) between the objects
- The force of attraction is inversely proportional to the square of the distance

i.e. $F \propto 1/r^2$

Therefore : **$F \propto \dfrac{m_1 m_2}{r^2}$**

if you introduce a proportionality constant G

$F = \dfrac{Gm_1 m_2}{r^2}$

G: proportionality constant = $6{,}7 \times 10^{-11} \text{ N.m}^{-2}.\text{kg}^{-2}$

- **Newton's Law of Universal Gravitation states that every body attracts every other body in the universe with a force that is directly proportional to the product of the masses of the two bodies, and inversely proportional to the square of the distance between their centers.**

GRAVITATIONAL ACCELERATION 'g' – INDEPENDENT OF THE MASS OF THE OBJECTS

- an object, mass **m** experiences a force of attraction by the earth and this is the **weight** of the object

$$W = mg$$

- the same force represents the force of gravitational attraction between the object and the earth

$$F = \frac{GmM}{r^2} \qquad M : \text{mass of the earth}$$

Therefore, $\cancel{m}g = \dfrac{Gm M}{r^2}$

$$g = \frac{GM}{r^2}$$

- From the above equation it is clear that the gravitational acceleration is independent of the mass (**m**) of the object but dependant on the mass of the earth (or planet) **M**.

X-ample Questions

Question 1
An aircraft flies in a straight line with a constant speed of 450 km.h^{-1}

What is the magnitude of the resultant force acting on the aircraft?
Explain your answer

Question 2
A car of mass 2000 kg accelerates from rest to a velocity of 25m.s^{-1} in 5s.
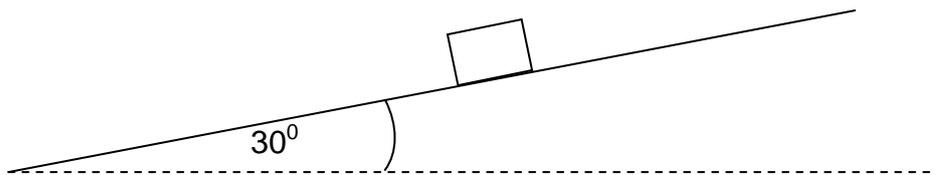
2.1   Calculate the acceleration of the car.   (4)

2.2   Calculate the resultant force acting on the car while it is accelerating.   (3)

Question 3
A 5kg block slides down a slope. The inclination of the slope is 30° to the horizontal. The force of kinetic friction acting on the block is 4,5N.
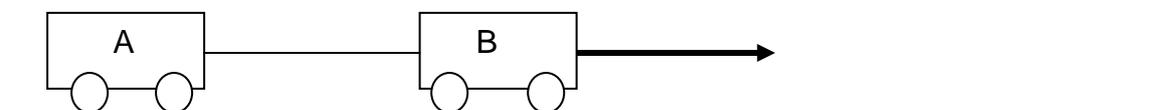

3.1   Calculate the acceleration of the block

3.2   What is the co-efficient of kinetic friction for these surfaces?

Question 4
A learner pulls two trolleys, which are connected with a string, by applying a 12 N horizontal force. Trolley A has a mass of 1kg and Trolley B has a mass of 3kg. You can ignore the force of friction acting on the system.

4.1   Calculate the acceleration of the trolleys

4.2   Determine the tension in the string joining the trolleys

Question 5
The diameter of a planet is 9,8 x 10^3 km and it has a mass of 7,3 x 10^{24} kg.

A 10 kg object falls from rest 10 m above the surface.

6.1   What is the acceleration of the object?

6.2 What force would be exerted on the 10 kg object if it was placed a distance of $4{,}9 \times 10^3$ km above the surface of the planet?

X-ercises

Question 1

Consider a box on the back of a truck as shown in the following diagram. The floor of the truck is smooth and the truck is moving at a constant velocity when suddenly the driver notices an obstruction, a large rock, on the road 100m away and he applies brakes.

Direction of motion
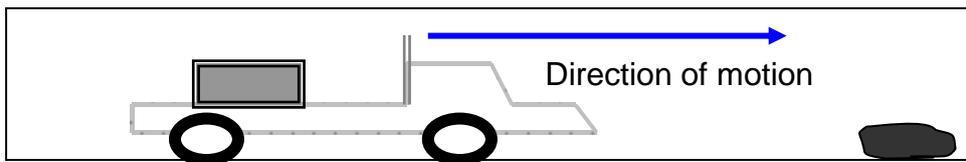
1.1 What happens to the box when the brakes are applied? Describe fully.
1.2 Explain your observations using Newton's Laws.

Question 2

A 10 N force is used to pull a toy train, which has an engine and on other cart attached. The train engine has a mass of 1 kg and the cart has a mass of 500g. The track is smooth, therefore there is no friction.
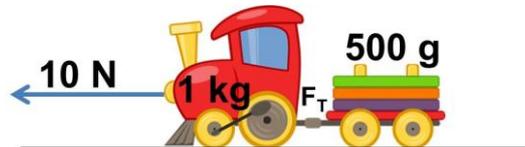
2.1 Calculate the acceleration of the train
2.2 Calculate the tension (F_T) in the link between the train engine and the cart.

Question 3

A helicopter lifts a load vertically off the ground. It accelerates at 5 m.s^{-2} vertically upwards.

3.1 Draw a labelled free body diagram to show the forces acting on the load
3.2 Calculate the lifting force exerted by the rope on the load, if the mass of the load is 100 kg.

Question 4

An object is on the surface of a planet.
4.1 Name three factors that affect its weight on the planet.
4.2 Explain how the factors in 2.1 affect the weight of the object.
4.3 Two metal spheres of masses 100kg and 60 kg respectively are placed 5m apart. Calculate the force of gravitational attraction that acts between them

Question 5

The earth and the moon attract each other with a force of 2×10^{26} N. Calculate the mass of the moon if, in its orbit, the magnitude of its acceleration towards the earth is 3×10^3 m.s^{-2}

Answers to X-ercises

1.1   The box will slide forward at the velocity that the truck was moving at. It will collide with the front of the cab of the truck. The cab of the truck will exert a force on the box. If you ignore friction, the box will then slide towards the back of the truck in the direction of the applied force at constant velocity.

1.2   When the truck applies brakes there is no force acting on the box so according to Newton's 1st Law it will continue at constant velocity until it collides with the cab of the truck. When the box collides with the cab, it will exert a force on the cab of the truck and the cab of the truck will exert a force of the same magnitude on the box (Newton's 3rd Law) but in the opposite direction. When the cab exerts a force on the box, there will be a change in velocity and the box will accelerate in the direction of the applied force (Newton's 2nd Law). In the absence of friction, the box will move away from the cab of the truck and continue moving at constant velocity towards the back of the truck (Newton's 1st Law) until it experiences another force – the force due to gravity and fall off the truck!

2.1   a = 6,67 m.s^{-2} forward

2.2 F_T = 3,33 N

3.1
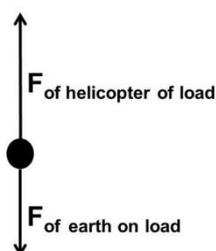
3.2 F_{app} = 1 480 N upward

4.1   Mass of object, mass of planet, radius of planet

4.2   Increasing the mass of planet or object will increase the weight, Increasing the radius will decrease the weight.

4.3   F = 1,61 x 10^{-8}N towards each other

5. M_{moon} = 6,67 x 10^{22}kg