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Content Guidance

Questions & Answers

If the boys push each other, they will both move backwards away from each other. Using the principle of conservation of momentum, the change in the momentum of each boy must be equal and opposite. Because the time, Δt, taken for both pushes must be the same, it follows that:

the force of boy A on boy B = the rate of change in momentum of boy B

$$= \frac{\Delta p_B}{\Delta t}$$

the force of boy B on boy A = the rate of change in momentum of boy A

$$= \frac{\Delta p_A}{\Delta t}$$

As $\Delta p_B = -\Delta p_A$ it follows that the force exerted by boy A on boy B is equal and opposite to that exerted by boy B on boy A.

This shows that Newton's third law is an example of the principle of conservation of momentum.

Turning forces

When a force is applied to an object that is not a point mass it may rotate. The turning effect of a force is called its **moment**. The moment of a force depends on the size of the force and the perpendicular distance of its line of action from the axis of rotation.

The units of a moment are newton metres (N m). This is not the same as the unit of energy (the joule) because the force causing the moment does not actually move. The moment has a direction of rotation, clockwise or anticlockwise, and can be treated in a similar manner to a vector.

Principle of moments

When a body is acted upon by a number of forces, the resultant moment can be calculated by adding the total clockwise and anticlockwise moments.

If the body is in equilibrium there can be no resultant moment acting upon it; that means that the sum of the clockwise moments must equal the sum of the anticlockwise moments. This is known as the **principle of moments**.

Worked example

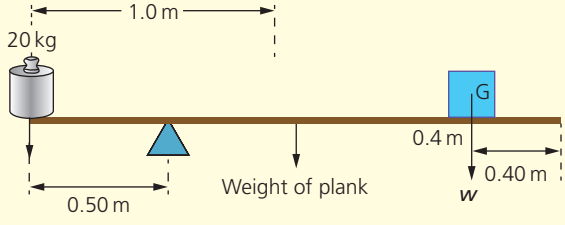


Figure 28

The **moment** of a force is the product of the force and the perpendicular distance of the line of action of the force from the point of rotation.

Knowledge check 13

Calculate the moment of a 12 N force acting at a perpendicular distance of 25 cm from the axis of rotation.

The **principle of moments** states that if a system is in equilibrium the sum of the clockwise moments about any point must equal the sum of the anticlockwise moments about that point.

Exam tip

Always indicate the direction of rotation by assigning a positive sign to the clockwise moments and a negative sign to the anticlockwise moments.

In Figure 28, a box is balanced on a uniform plank of length 2.0 m with a pivot 50 cm from one end, using a 20 kg mass placed at the end closest to the pivot. If the centre of gravity of the box is 40 cm from the other end of the plank and the mass of the plank is 5.0 kg, calculate:

a the weight, W, of the box

b the upward push, N, of the pivot on the plank

Answer

a Taking moments about the pivot:

Anticlockwise moments = $20\,\text{kg} \times 9.8\,\text{m s}^{-2} \times 0.50\,\text{m} = 98\,\text{N m}$

Clockwise moments = $W \times 1.1\,\text{m} + 5.0\,\text{kg} \times 9.8\,\text{m s}^{-2} \times 0.50\,\text{m}$

For equilibrium:

sum of the clockwise moments = sum of the anticlockwise moments

$W \times 1.1\,\text{m} + 5.0\,\text{kg} \times 9.8\,\text{m s}^{-2} \times 0.50\,\text{m} = 98\,\text{N m}$

$W = 67\,\text{N}$

b For equilibrium the resultant force acting on the system is zero

N – weight of (20 kg mass + box) = 0

$N = 20\,\text{kg} \times 9.8\,\text{N kg}^{-1} + 5\,\text{kg} \times 9.8\,\text{N kg}^{-1} + 67\,\text{N}$

$= 196\,\text{N} + 49\,\text{N} + 67\,\text{N}$

$= 312\,\text{N}$

Exam tip

Always start your answer by stating 'sum of the clockwise moments = sum of the anticlockwise moments'.

Summary

After studying this topic, you should be able to:

- state Newton's first law of motion
- draw free-body force diagrams for a body in a state of equilibrium
- state Newton's second law of motion for bodies of fixed mass
- determine the resultant force acting on a body, and use $F = ma$ to calculate its acceleration
- understand the concept of gravitational field strength, and the difference between mass and weight
- state Newton's third law of motion
- describe the nature and direction of pairs of forces on two interacting bodies
- define momentum and use the principle of conservation of linear momentum
- understand the meaning of the moment of a force and apply the principle of moments to systems in equilibrium

Work, energy and power

Work and energy are interrelated. When work is done on a body, the body will gain energy, and a body can transfer energy to do work. Power is the rate of doing work.

Work

- Work is done when the point of application of a force is moved.
- $\Delta W = F\Delta x$ is the equation defining the work done when the point of application of a force, F, is moved a distance Δx.
- 1 joule (J) of work is done when the point of application of a force of 1 newton (N) is moved through a distance of 1 metre (m).

Work done equals the product of the force *times* the distance moved *in the direction of the applied force*.

Question 16

A car of mass 1500 kg tows a trailer of mass 1000 kg along a level road. The driving force on the car is 2000 N and the total resistive forces on the car and trailer are 500 N and 300 N respectively.

e This question examines the application of Newton's second law of motion relating to a body of fixed mass.

(a) Calculate the resultant force acting on the combination. (1 mark)

(b) Determine the acceleration of the car and trailer. (3 mark)

e Many students lose marks on Newton's second law questions by failing to use the resultant force, and just including the driving force in the equation $F = ma$. You should also be aware that this force acts on the total mass of the combination.

(c) How long will it take the car and trailer to accelerate from 10 m s^{-1} to 20 m s^{-1} if the forces remain the same during this period? (2 marks)

(d) Draw a diagram of the trailer showing the forces acting upon it in the horizontal direction. (2 marks)

(e) Calculate the force the car exerts on the trailer through the coupling. (3 marks)

Total: 11 marks

e Once again, the key is to find an expression for the resultant force acting on the trailer alone. Since the acceleration of the trailer is the same as that of the combination, the value of the resultant force can be calculated and the pull on the trailer can be found.

Student answer

(a) resultant force = 2000 N – (500 N + 300 N) = 1200 N ✓

(b) By Newton's second law, for a fixed mass, $\Sigma F = ma$ ✓

$1200\,\text{N} = (1500\,\text{kg} + 1000\,\text{kg}) \times a$ ✓

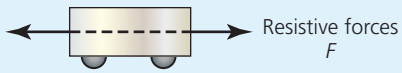
$a = 0.48\,\text{m s}^{-2}$ ✓

(c) Use $v = u + at$:

$20\,\text{m s}^{-1} = 10\,\text{m s}^{-1} + 0.48\,\text{m s}^{-2} \times t$ ✓

$t = 21\,\text{s}$ ✓

(d)



e Pull of car P ✓, resistive forces F ✓

(e) resultant force on trailer = 1000 kg × 0.48 m s^{-2} ✓ = 480 N ✓

pull of car on trailer = 480 N + 300 N = 780 N ✓

e These marks could be obtained from the diagram if the forces are quantified in the diagram.

Question 17

In metallic conductors an electric current is a flow of free electrons.

(a) What are free electrons? (1 mark)

(b) At normal room temperatures, the free electrons in a length of copper wire that is not connected to a power supply have an average speed of about 500 m s^{-1}, which is due to their thermal energy. Why is there no current in the wire? (1 mark)

(c) When the copper wire is part of a circuit connected to a battery, the current in the wire can be represented by the equation $I = nqvA$, where A is the area of cross-section of the wire and q is the charge carried by an electron (1.6×10^{-19} C). Explain the meanings of n and v in the equation. (2 marks)

e The question requires an explanation of the terms; simply stating 'carrier concentration' and 'drift velocity' will gain no marks.

(d) Show that the value of v is about 0.5 mm s^{-1} in a length of copper wire of cross-sectional area 0.085 mm^2 that is carrying a current of 0.50 A, given that n is 8.0×10^{28} m^{-3}. Comment on this value. (3 marks)

(e) The resistivities of three commonly used materials are given in Table 7. Use the equation $I = nqvA$ to explain why:

(i) silicon has a much greater resistivity than copper

(ii) the resistivity of copper increases with temperature while that of silicon decreases with temperature (3 marks)

Material	Resistivity/Ω m
Copper	1.7×10^{-8}
Constantan	4.9×10^{-7}
Silicon	2.4×10^{-3}

Table 7

e The question asks you to 'use the equation', so reference must be made to drift velocity in the first case and to carrier concentration in the second. Many students give good explanations without reference to the equation and thus lose the marks.

(f) A technician wishes to make a 1.0 Ω resistor. She has a reel of copper wire of cross-sectional area 0.085 mm^2.

(i) What length of wire will she need to make the resistor?

(ii) Why would it be better to use a length of constantan wire of the same diameter to make the resistor? (3 marks)

Total: 13 marks