AS Level Physics

Chapter 2 – Mechanics

2.9.2 Newton's Laws of Motion and Momentum

Worked Examples

Newtons Laws & Momentum

Exam Style Question 1

ai) State in words Newton's second law of motion.

aii) Show how this law leads to the expression $F = ma$ for an object of constant mass.

b) The graph in Fig. 1.1 shows the variation with time of a force acting on an object of mass $2.5\ kg$.

The force is acting in the direction of the object's motion.

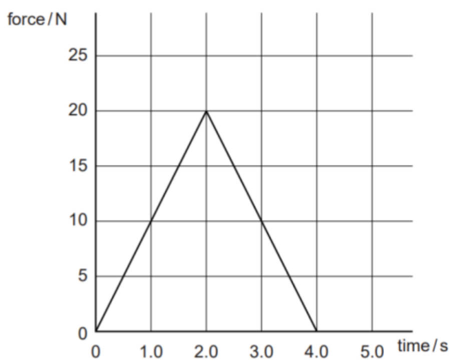


Fig. 1.1

Use Fig. 1.1 to

i) Determine the change in velocity of the object.

ii) Calculate the mean acceleration of the object.

iii) Describe how the acceleration of the object varies between 0 and 4.0 seconds.

Newtons Laws & Momentum

Exam Style Question 1

Answer

ai) State in words Newton's second law of motion.

Resultant force acting on an object is directly proportional to the rate of change of momentum and occurs in the same direction.

aii) Show how this law leads to the expression $F = ma$ for an object of constant mass.

Newton's second law states that the:

$$Resultant\ force\ (F) \propto rate\ of\ change\ of\ momentum\ (= \Delta(mv))$$

$$F = \frac{\Delta(mv)}{\Delta t}$$

$$F = m\frac{\Delta(v)}{\Delta t}\ (if\ m\ is\ constant)$$

$$F = ma$$

bi) Determine the change in velocity of the object.

Use: $F = \frac{m\Delta v}{\Delta t}$ which you can rearrange to give: $F\Delta t = m\Delta v$

But:

$$Impulse = F\Delta t = area\ under\ the\ graph$$

The area under the graph is simply the area of a triangle which is:

$$area\ under\ the\ graph = \frac{1}{2} \times 4\ s \times 20\ N$$

$$area\ under\ the\ graph = 40\ N\ s$$

$$\therefore impulse = F\Delta t = 40\ N\ s$$

So:

$$impulse = m\Delta v$$

Rearrange to get Δv:

$$\Delta v = \frac{impulse}{m} = \frac{40\ N\ s}{2.5\ kg} = 16\ m\ s^{-1}$$

So the change in velocity of the object is $16\ m\ s^{-1}$.

Newtons Laws & Momentum

Exam Style Question 1

ai) State in words Newton's second law of motion.

aii) Show how this law leads to the expression $F = ma$ for an object of constant mass.

b) The graph in Fig. 1.1 shows the variation with time of a force acting on an object of mass $2.5\ kg$.

The force is acting in the direction of the object's motion.

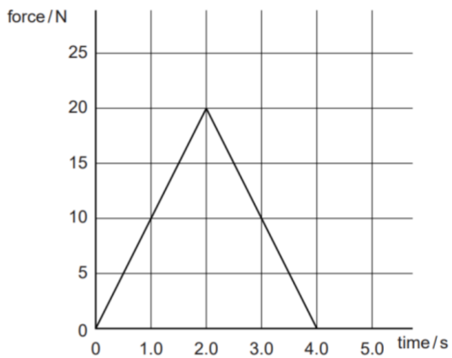


Fig. 1.1

Use Fig. 1.1 to

i) Determine the change in velocity of the object.

ii) Calculate the mean acceleration of the object.

iii) Describe how the acceleration of the object varies between 0 and 4.0 seconds.

Newtons Laws & Momentum

Exam Style Question 1

Answer

bii) Calculate the mean acceleration of the object.

Use $a = \frac{v-u}{t}$.

$$\therefore a = \frac{16\ m\ s^{-1} - 0\ m\ s^{-1}}{4\ s}$$
$$a = 4.0\ m\ s^{-2}$$

biii) Describe how the acceleration of the object varies between 0 and 4.0 seconds.

Acceleration increases to $2\ s$ and then decreases. The rate of change of acceleration is constant.

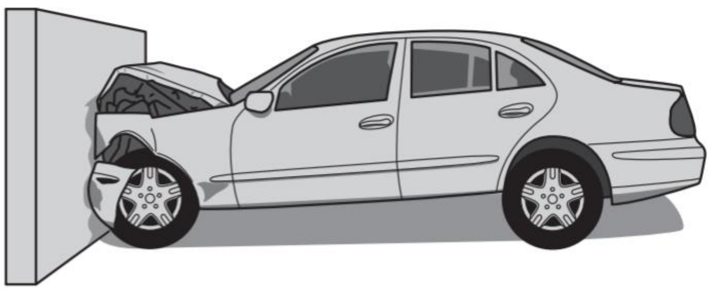
Newtons Laws & Momentum

Exam Style Question 2

ai) Define linear momentum.

aii) Linear momentum is a vector quantity. Explain why.

b) The crumple zone of a car is a hollow structure at the front of the car designed to collapse during a collision. In a laboratory road-test, a car of mass $850\ kg$ was driven into a concrete wall. A video recording of the impact showed that the car, initially travelling at $7.5\ m\ s^{-1}$, was brought to rest in $0.28\ s$ when it hit the wall.



i) Calculate:

1) The deceleration of the car, assuming it to be uniform.

2) The average force exerted by the wall on the car.

ii) The crumple zone of the car is designed to absorb $0.45\ MJ$ of energy before any distortion of the passenger cabin occurs. For this design of crumple zone, calculate the maximum speed of the car at impact.

Newtons Laws & Momentum

Exam Style Question 2

Answer

ai) Define linear momentum.

$$linear\ momentum = mass \times velocity$$

aii) Linear momentum is a vector quantity. Explain why.

Mass is a scalar quantity and velocity is a vector quantity. The product of a scalar and vector is a vector. Therefore, momentum is a vector quantity which has a magnitude and a direction.

bi) Calculate:

1) The deceleration of the car, assuming it to be uniform.

Use: $a = \frac{v-u}{t}$

$$a = \frac{0m\ s^{-1} - 7.5\ m\ s^{-1}}{0.28\ s}$$
$$a = -26.78571429\ m\ s^{-2}$$
$$a = -27\ m\ s^{-2}$$

Final velocity will be zero because after the collision the car will come to a stop. The initial velocity before the car collides with the wall is $7.5\ m\ s^{-1}$

The negative sign just indicates a deceleration.

2) The average force exerted by the wall on the car.

Use: $F = ma$

$$F = (850\ kg)(27\ m\ s^{-2})$$
$$F = 22950\ N$$
$$F = 2.3 \times 10^4\ N$$

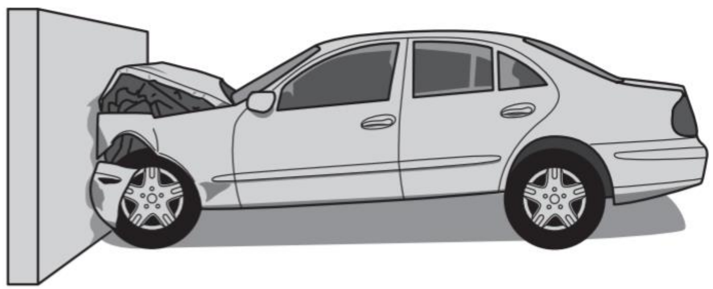
Newtons Laws & Momentum

Exam Style Question 2

ai) Define linear momentum.

aii) Linear momentum is a vector quantity. Explain why.

b) The crumple zone of a car is a hollow structure at the front of the car designed to collapse during a collision. In a laboratory road-test, a car of mass $850\ kg$ was driven into a concrete wall. A video recording of the impact showed that the car, initially travelling at $7.5\ m\ s^{-1}$, was brought to rest in $0.28\ s$ when it hit the wall.



i) Calculate:

1) The deceleration of the car, assuming it to be uniform.

2) The average force exerted by the wall on the car.

ii) The crumple zone of the car is designed to absorb $0.45\ MJ$ of energy before any distortion of the passenger cabin occurs. For this design of crumple zone, calculate the maximum speed of the car at impact.

Newtons Laws & Momentum

Exam Style Question 2

Answer

bii) Calculate the maximum speed of the car at impact.

Use: $KE = \frac{1}{2}mv^2$ and rearrange for v:

$$v^2 = \frac{2 \times KE}{m}$$

$$v^2 = \frac{2 \times (0.45 \times 10^6\ J)}{850\ kg}$$

$$v = \sqrt{\frac{2 \times (0.45 \times 10^6\ J)}{850\ kg}}$$

$$\therefore v = 32.53956867\ m\ s^{-1}$$

So the maximum speed of the car at impact was $33\ m\ s^{-1}$.

Please see '2.9.1 Newton's Law of Motion and Momentum notes' pack for revision notes.

For more revision notes, tutorials and worked examples please visit www.tutorpacks.co.uk.