AS Level Physics

Chapter 5 – Mechanics

5.10.2 Newton's Laws of Motion

Worked Examples

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NEWTONS LAWS

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.

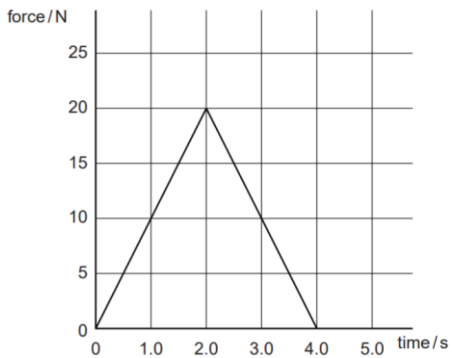

Fig. 1.1

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

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

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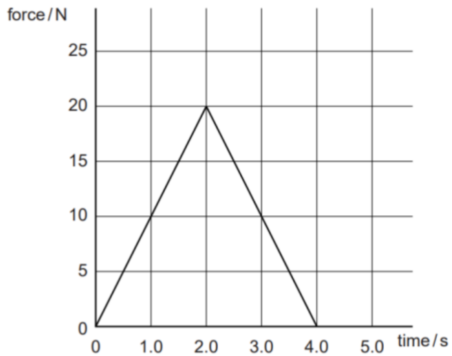

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NEWTONS LAWS

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

Exam Style Question 2

a) State Newton's second and third laws of motion.

b) A golfer uses a golf club to hit a stationary golf ball off the ground. Fig. 1.1 shows how the force F on the golf ball varies with time t when the club is in contact with the ball.

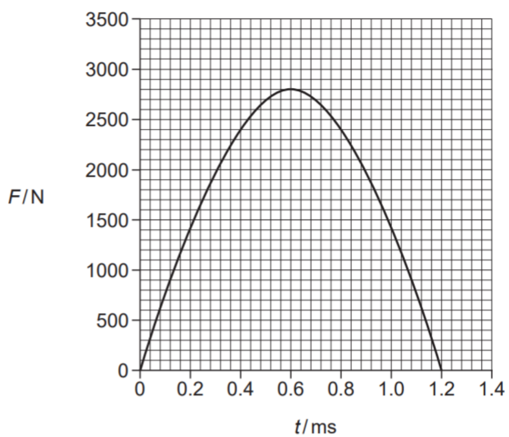

Fig. 1.1

i) Estimate the area under the graph.

ii) Name the physical quantity represented by the area under the graph in (i).

iii) Show that the speed of a golf ball, of mass $0.046\ kg$, as it leaves the golf club is about $50\ m\ s^{-1}$.

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NEWTONS LAWS

Exam Style Question 2

Answer

a) State Newtons second and third laws of motion.

- Newton's second law: Force is proportional to the rate of change of momentum.
- Newton's third law: When one body exerts a force on another the other body exerts an equal and opposite force on the first body.

bi) Estimate the area under the graph.

Step 1: Count the number of squares under the graph:

About 22 large squares = about 550 small squares

The question allows the estimation for the number of squares counted to be between a range of 500-600.

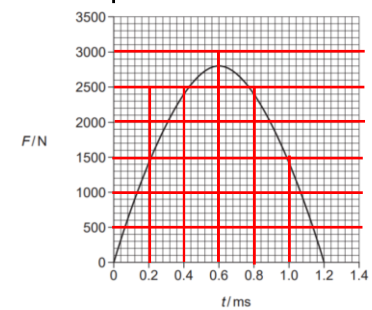

Fig. 1.1

Step 2: Find out the area of one square:

$$F \times t = 100\ N \times (0.04 \times 10^{-3}\ s) = 4 \times 10^{-3} N\ s$$

Step 3: Calculate the area under the graph:

$$550\ squares \times (4 \times 10^{-3}) = 2.2\ N\ s$$

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NEWTONS LAWS

Exam Style Question 2

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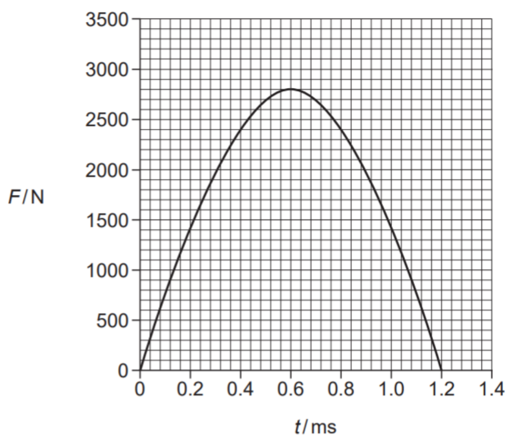

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NEWTONS LAWS

Exam Style Question 2

Answer

bii) Name the physical quantity represented by the area under the graph in (i).
Impulse.

biii) Show that the speed of a golf ball, of mass $0.046\ kg$, as it leaves the golf club is about $50\ m\ s^{-1}$.
Use: Impulse = change in momentum

$$F\Delta t = m\Delta v$$

We already calculated impulse $(= F\Delta t)$ is $2.2\ N\ s$.
Therefore:

$$2.2\ N\ s = (0.046\ kg)v$$

Rearrange for v:

$$v = \frac{2.2\ N\ s}{0.046\ kg} = 47.82608696\ m\ s^{-1} \approx 50\ m\ s^{-1}$$

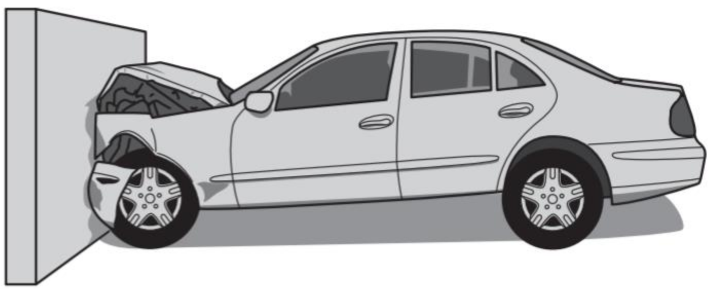
NEWTONS LAWS

Exam Style Question 3

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

Exam Style Question 3

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

Exam Style Question 3

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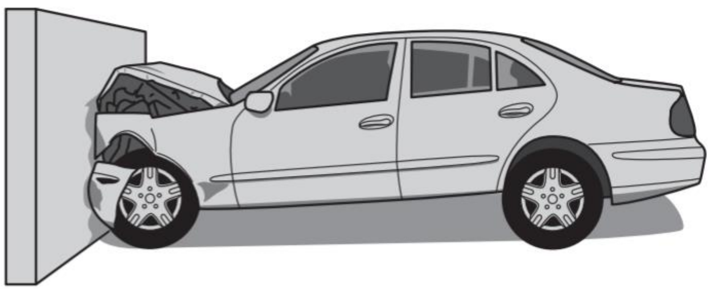

i) Calculate:

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NEWTONS LAWS

Exam Style Question 3

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 $33\ m\ s^{-1}$.

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Please see **'5.10.1 Newton's Law of Motion notes'** pack for revision notes.

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