AS Level Physics

Chapter 3 – Forces and Motions

3.4.2 Motion with Non-Uniform Acceleration

Worked Examples

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TERMINAL VELOCITY

Exam Style Question 1:

a) A student holds a golf ball and a table tennis ball out of an upper window of a tall building. The balls are released at the same time. Both balls have the same size. The golf ball has a greater mass than the table tennis ball. One of the balls reaches a greater terminal velocity.

i) State and explain the acceleration of the golf ball immediately after it is released.

ii) By referring to the forces acting on the golf ball, explain what is meant by terminal velocity.

iii) Explain which of the two balls reaches the greater terminal velocity.

Answer:

i) State and explain the acceleration of the golf ball immediately after it is released.

The Earth's gravitational pull causes objects to accelerate as they fall. Any object near the surface of the Earth, the acceleration caused by gravity has an approx. value of:
$g = acceleration\ of\ free\ fall = 9.81\ ms^{-2}$.
If a object is in free fall, the only force acting on the object is gravity; and therefore, acceleration is equal to g.

Applying this knowledge to the golf ball, the acceleration of the golf ball immediately after it is released is $9.81\ ms^{-2}$ because at that point the only force acting on the golf ball is its own weight caused by gravity and the drag force is zero.

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Exam Style Question 1:

Answer:

ii) By referring to the forces acting on the golf ball, explain what is meant by terminal velocity.

Terminal velocity is when the golf ball has reached its maximum velocity, and this is achieved when drag force = weight.

iii) Explain which of the two balls reaches the greater terminal velocity.

The golf ball experiences a greater drag force because it has a greater mass compared to the table tennis ball. This greater mass means a greater weight, and so a stronger drag force is required to achieve terminal velocity.

Therefore, the golf ball will accelerate for a longer time in order to reach a higher terminal velocity where the drag force can equal to the golf balls greater weight. As, the golf ball accelerates for a longer time, it achieves a higher velocity.

So, the golf ball has a greater terminal velocity.

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TERMINAL VELOCITY

Exam Style Question 2:

a) State two factors that affect the magnitude of the drag force acting on an object falling through air.

b) Fig 4.1 shows a skydiver of total mass $75\ kg$ falling vertically towards the ground.

The air resistance, or drag force, D in newtons (N) acting on the skydiver falling through the air is given by the equation:

$$D = 0.3v^2$$

Where v is the speed in ms^{-1} of the skydiver.

i) On Fig. 4.1, draw arrows to represent the weight (labelled W) and drag force (labelled D).

ii) Calculate the weight of the skydiver.

iii) At a particular instant, the speed of the skydiver is $20\ ms^{-1}$. Calculate the instantaneous acceleration of the skydiver.

iv) State the relationship between the forces W and D when the skydiver reaches terminal velocity.

v) Determine the terminal velocity of the skydiver.

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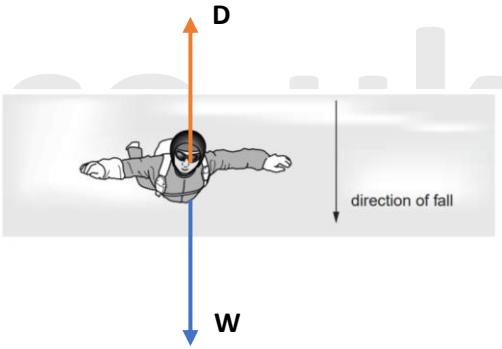
Exam Style Question 2:

Answer:

a) State two factors that affect the magnitude of the drag force acting on an object falling through air.

- Area (greater the area, greater the drag)
- Speed / velocity (greater the velocity, greater the drag)
- Aerodynamic shape (streamline) (more aerodynamic shaped an object, less frictional forces (drag) affects it)

bi) On Fig. 4.1, draw arrows to represent the weight (labelled W) and drag force (labelled D).



bii) Calculate the weight of the skydiver.

Use: $W = mg$

$$W = 75\ kg \times 9.81\ ms^{-2}$$

$$\therefore weight = 735.75\ N = 736\ N$$

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TERMINAL VELOCITY

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v) Determine the terminal velocity of the skydiver.

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Exam Style Question 2:

Answer:

biii) At a particular instant, the speed of the skydiver is $20\ ms^{-1}$. Calculate the instantaneous acceleration of the skydiver.

Step 1: Use the formula they gave us to calculate the drag force, D:

$$D = 0.3v^2$$

$$D = 0.30 \times (20)^2 = 120\ N$$

Step 2: Use $F = ma$ to find acceleration but first we need to calculate the net (resultant) force:

$$F = W - D = 736 - 120 = 616\ N$$

Step 3: Calculate the acceleration by rearranging $F = ma$

$$a = \frac{F}{m} = \frac{616\ N}{75\ kg} = 8.2133 = 8.2\ ms^{-2}$$

biv) State the relationship between the forces W and D when the skydiver reaches terminal velocity.

Terminal velocity is when an object or person reach their maximum velocity, and this is achieved when $D = W$.

bv) Determine the terminal velocity of the skydiver.

At terminal velocity $drag = weight = 736\ N$.

We know that drag is: $D = 0.3v^2$

$$\therefore\ 736\ N = 0.30 \times v^2$$

Now rearrange the formula to find v which in turn will give us the terminal velocity:

$$v^2 = \frac{736}{0.3}$$

$$v = \sqrt{\frac{736}{0.3}} = 49.5311\ \ldots = 49.5\ ms^{-1}$$

So, the terminal velocity of the skydiver is $49.5\ ms^{-1}$

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TERMINAL VELOCITY

Exam Style Question 3:

a) A skydiver jumps from a stationary hot-air balloon several kilometres above the ground.

In terms of acceleration and forces, explain the motion of the skydiver

i) Immediately after jumping

ii) At a time before terminal velocity is reached

iii) At terminal velocity.

b) In the final stage of the fall, the skydiver is falling through air at a constant speed. The skydiver's kinetic energy does not change even though there is a decreases in the gravitational potential energy. State what happens to this loss of gravitational potential energy.

c) Fig 3.1 shows a sketch graph of the variation of the velocity v of the skydiver with time t.

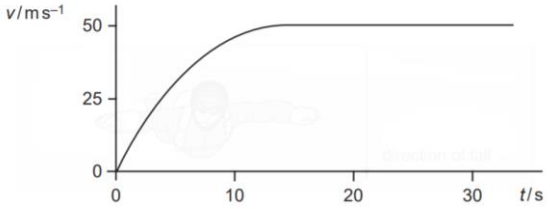

Fig. 3.1

Suggest the changes to the graph of Fig 3.1, if any, for a more massive (heavier) skydiver of the same shape.

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Exam Style Question 3:

Answer:

a) In terms of acceleration and forces, explain the motion of the skydiver

i) Immediately after jumping

Immediately after jumping the only force acting on the skydiver is his own weight and drag is zero. This means he will accelerate with an acceleration equal to $9.81\ ms^{-2}$.

ii) At a time before terminal velocity is reached

Before terminal velocity is reached drag increases gradually with speed and the net force decreases. Weight is still greater than drag but acceleration is less than $9.81\ ms^{-2}$.

iii) At terminal velocity.

Weight is equal to drag, net force is zero and acceleration is zero. The skydiver has reached his/hers maximum velocity and is falling at a constant velocity.

b) State what happens to this loss of gravitational potential energy.

The loss of GPE is transformed to heat/thermal energy.

c) Suggest the changes to the graph of Fig 3.1, if any, for a more massive (heavier) skydiver of the same shape.

1) The terminal velocity increases.
2) Initial gradient/slope is the same/equal to $9.81\ ms^{-2}$
3) Time taken to reach terminal velocity is longer.

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Please see the ‘3.4.1 Motion with Non-Uniform Acceleration notes’ pack for revision notes.

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