Tutor Packs

AS Level Physics

Chapter 4 – Materials

4.2.2 Drag (Edexcel Only)

Worked Examples

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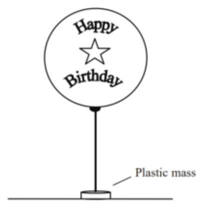
Exam Style Question 1

A child's birthday balloon is filled with helium to make it rise. A ribbon is tied to it, holding a small plastic mass designed to prevent the balloon from floating away.



a) Add labelled arrows to the diagram of the balloon to show the forces acting on the balloon.

b) The balloon is approximately a sphere, of diameter $30\ cm$. Show that the upthrust on the balloon is about $0.2\ N$.

The density of the surrounding air $\rho = 1.30\ kg\ m^{-3}$.

c) The ribbon is cut and the balloon begins to rise slowly.

i) Sketch a diagram to show the airflow around the balloon as it rises.

ii) What is the name of this type of airflow?

d) A student suggests that if the balloon reaches terminal velocity, its motion could be described by the relationship

$$mg + 6\pi r\eta v = \frac{4}{3}\pi r^3 \rho g$$

where $\eta = viscosity\ of\ air$, $m = mass\ of\ the\ balloon$, $r = radius\ of\ the\ balloon$ and $v = the\ terminal\ velocity$ reached.

i) Write the above relationship as a word equation.

ii) The balloon has a total weight of $0.17\ N$. Use the equation given above to calculate the corresponding value for the terminal velocity of the balloon. $Viscosity\ of\ air = 1.8 \times 10^{-5}\ N\ s\ m^{-2}$.

iii) Suggest a reason why the balloon is not likely to reach the calculated velocity.

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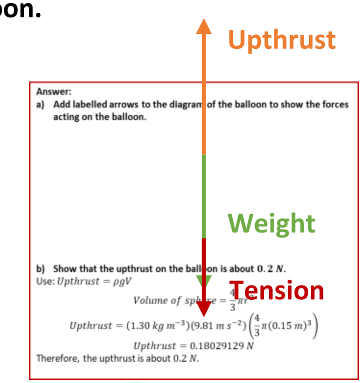
Exam Style Question 1

Answer:

a) Add labelled arrows to the diagram of the balloon to show the forces acting on the balloon.



b) Show that the upthrust on the balloon is about $0.2\ N$.

Use: $Upthrust = \rho g V$

$$Volume\ of\ sphere = \frac{4}{3}\pi r^3$$

$$Upthrust = (1.30\ kg\ m^{-3})(9.81\ m\ s^{-2})\left(\frac{4}{3}\pi(0.15\ m)^3\right)$$

$$Upthrust = 0.18029129\ N$$

Therefore, the upthrust is about $0.2\ N$.

Upthrust is the upward force in a fluid (such as air or liquid). You can calculate upthrust (U) using the formula below: $U = \rho g V$.

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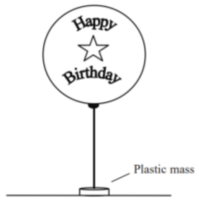

a) Add labelled arrows to the diagram of the balloon to show the forces acting on the balloon.

b) The balloon is approximately a sphere, of diameter $30\ cm$. Show that the upthrust on the balloon is about $0.2\ N$.

The density of the surrounding air $\rho = 1.30\ kg\ m^{-3}$.

c) The ribbon is cut and the balloon begins to rise slowly.

i) Sketch a diagram to show the airflow around the balloon as it rises.

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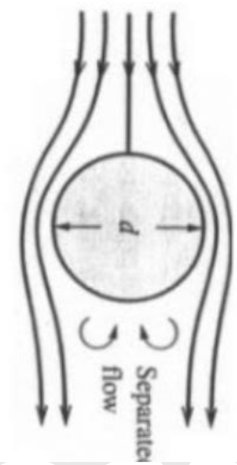
Exam Style Question 1

Answer:

ci) Sketch a diagram to show the airflow around the balloon as it rises.



cii) What is the name of this type of airflow?

Laminar.

di) Write the above relationship as a word equation.

$$mg + 6\pi r\eta v = \frac{4}{3}\pi r^3 \rho g$$

$$weight + viscous\ drag = upthrust$$

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Exam Style Question 1

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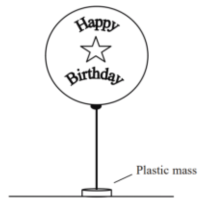

a) Add labelled arrows to the diagram of the balloon to show the forces acting on the balloon.

b) The balloon is approximately a sphere, of diameter $30\ cm$. Show that the upthrust on the balloon is about $0.2\ N$.

The density of the surrounding air $\rho = 1.30\ kg\ m^{-3}$.

c) The ribbon is cut and the balloon begins to rise slowly.

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where $\eta = viscosity\ of\ air$, $m = mass\ of\ the\ balloon$, $r = radius\ of\ the\ balloon$ and $v = the\ terminal\ velocity$ reached.

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ii) The balloon has a total weight of $0.17\ N$. Use the equation given above to calculate the corresponding value for the terminal velocity of the balloon. $Viscosity\ of\ air = 1.8 \times 10^{-5}\ N\ s\ m^{-2}$.

iii) Suggest a reason why the balloon is not likely to reach the calculated velocity.

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Exam Style Question 1

Answer:

dii) Use the equation given above to calculate the corresponding value for the terminal velocity of the balloon.

Use: $mg + 6\pi r\eta v = \frac{4}{3}\pi r^3 \rho g$

But we know that:

$$\frac{4}{3}\pi r^3 \rho g = upthrust = 0.18029 \ldots\ N$$

and:

$$mg = weight\ of\ the\ ballon = 0.17\ N$$

Therefore:

$$0.17\ N + 6\pi r\eta v = 0.18\ N$$

Rearrange for v to find the terminal velocity:

$$v = \frac{0.18\ N - 0.17\ N}{6\pi r\eta}$$

$$v = \frac{0.18029 \ldots\ N - 0.17\ N}{6\pi\left(\frac{0.30\ m}{2}\right)(1.8 \times 10^{-5}\ N\ s\ m^{-2})}$$

$$v = 202.2110709\ m\ s^{-1}$$

Therefore, the terminal velocity of the balloon is $202\ m\ s^{-1}$.

Terminal velocity of an object is the steady speed (or the maximum velocity) achieved by an object when the driving force (e.g. weight) is equal to the drag force (e.g. air resistance or upthrust). This can be achieved when the resultant force and acceleration is zero.

diii) Suggest a reason why the balloon is not likely to reach this calculated velocity.

Air pressure also acts on the balloon and is reduced as the balloon gains height.

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Exam Style Question 2

Volcanoes vary considerably in the strength of their eruptions. A major factor in determining the severity of the eruption is the viscosity of the magma material. Magma with a high viscosity acts as a plug in the volcano allowing very high pressures to build up. When the volcano finally erupts it is very explosive. Once magma is out of the volcano it is called lava.

a) How would the flow of high viscosity lava differ from that of lava with a low viscosity?

b) What would need to be measured to make a simple comparison between the viscosities of two lava flows?

c) When the lava is exposed to the atmosphere it cools rapidly. What effect would you expect this cooling to have on the lava's viscosity?

d) When lava is fast flowing, changes to its viscosity disrupt the flow, making it no longer laminar. Use labelled diagrams to show the difference between laminar and turbulent flow

e) Different types of lava have different viscosities. The least viscous type has a viscosity of about $1 \times 10^3\ N\,s\,m^{-2}$ whereas a silica-rich lava has a viscosity of $1 \times 10^8\ N\,s\,m^{-2}$. What type of scale would be used to display these values on a graph?

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Exam Style Question 2

Answer:

a) How would the flow of high viscosity lava differ from that of lava with a low viscosity?

High viscosity lava is slower than the low viscosity lava and therefore takes a greater time to flow the same distance.

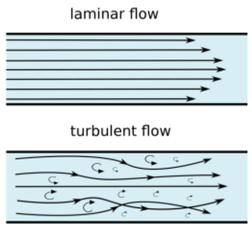
b) What would need to be measured to make a simple comparison between the viscosities of two lava flows?

Time taken to travel a set distance.

c) When the lava is exposed to the atmosphere it cools rapidly. What effect would you expect this cooling to have on the lava's viscosity?

Viscosity increases.

d) Use labelled diagrams to show the difference between laminar and turbulent flow



e) What type of scale would be used to display these values on a graph?

Power of 10 scale.

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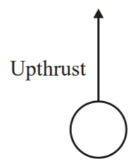
Exam Style Question 3

After wine has been fermenting it contains many small particles. These particles are allowed to settle so that they can be separated from the liquid.

a) Add labelled arrows to this diagram showing the other two forces on a particle falling downwards within the wine.



The upthrust can be calculated using the expression $U = \frac{4}{3}\pi r^3 \rho_w g$ where ρ_w is the density of wine and r is the radius of the falling particle.

b) Explain how the above expression for upthrust is derived.

c) Write down the equation relating the three forces acting on the particle when it reaches terminal velocity.

d) Show that the terminal velocity v of a particle of density ρ_s is given by the following expression:

$$v = \frac{2r^2 g(\rho_s - \rho_w)}{9\eta}$$

Where η is the viscosity of the wine.

e) Explain how you would expect the velocity of this particle to change if the temperature of the wine was increased.

f) Stokes's law is valid only provided the flow is laminar. Using a diagram, explain what is meant by the term laminar flow.

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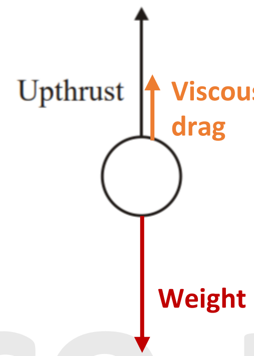

b) Explain how the above expression for upthrust is derived.

Remember $Upthrust = \rho g V$

Where:

$$V = volume\ of\ sphere = \frac{4}{3}\pi r^3$$

$$\rho = density\ of\ wine = \rho_w$$

Therefore, substitute the above into the upthrust formula to get:

$$U = \frac{4}{3}\pi r^3\ \rho_w\ g$$

c) Write down the equation relating the three forces acting on the particle when it reaches terminal velocity.

Remember terminal velocity is achieved when $weight = drag$ therefore:

$$Upthrust + viscous\ drag = weight$$

Drag

Exam Style Question 3

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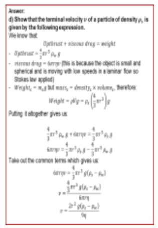

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Drag

Exam Style Question 3

Answer:

d) Show that the terminal velocity v of a particle of density ρ_s is given by the following expression.

We know that:

$$Upthrust + viscous\ drag = weight$$

- $Upthrust = \frac{4}{3}\pi r^3\ \rho_w\ g$
- $viscous\ drag = 6\pi r\eta v$ (this is because the object is small and spherical and is moving with low speeds in a laminar flow so Stokes law applied)
- $Weight_s = m_s g$ but $mass_s = density_s \times volume_s$, therefore:

$$Weight = \rho V g = \rho_s\left(\frac{4}{3}\pi r^3\right)g$$

Putting it altogether gives us:

$$\frac{4}{3}\pi r^3\ \rho_w\ g + 6\pi r\eta v = \frac{4}{3}\pi r^3\ \rho_s\ g$$

$$6\pi r\eta v = \frac{4}{3}\pi r^3\ \rho_s\ g - \frac{4}{3}\pi r^3\ \rho_w\ g$$

Take out the common terms which gives us:

$$6\pi r\eta v = \frac{4}{3}\pi r^3\ g(\rho_s - \rho_w)$$

$$v = \frac{\frac{4}{3}\pi r^3\ g(\rho_s - \rho_w)}{6\pi r\eta}$$

$$v = \frac{2r^2\ g(\rho_s - \rho_w)}{9\eta}$$

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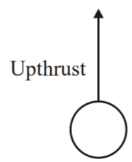

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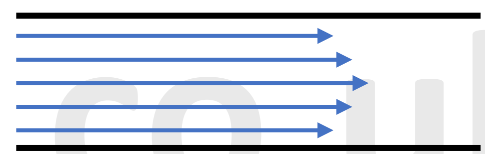
Exam Style Question 3

Answer:

e) Explain how you would expect the velocity of this particle to change if the temperature of the wine was increased.

If the temperature of the wine was increased, viscosity of the wine would decrease therefore the velocity of the particle will increases.

f) Stokes's law is valid only provided the flow is laminar. Using a diagram, explain what is meant by the term laminar flow.



Laminar flow is where the particles in a fluid move by flowing smoothly or in regular paths with no abrupt change in direction or whorls.

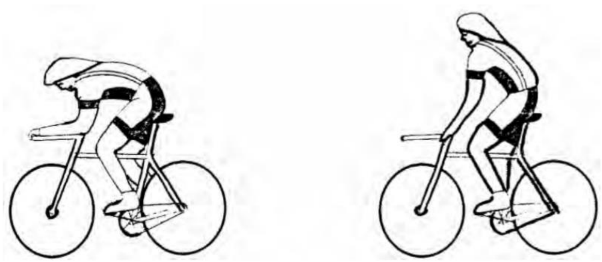
Drag

Exam Style Question 4

Speed cyclists need to reach very high speeds when competing.

a) What word describes the preferred airflow around the body of a speed cyclist?

b)Draw the possible airflow above and behind the body of a speed cyclist.



(i) in racing position (ii) when sitting upright.

c)What is the advantage to speed cyclists of travelling very close together as shown in the photograph?

Drag

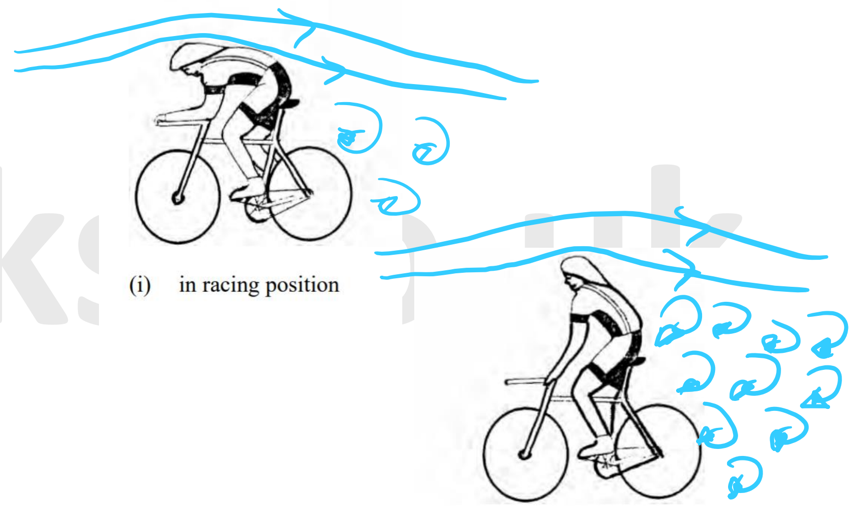
Exam Style Question 4

Answer:

a) What word describes the preferred airflow around the body of a speed cyclist?

Streamlined/ laminar flow.

b)Draw the possible airflow above and behind the body of a speed cyclist.



(i) in racing position

(ii) when sitting upright.

c)What is the advantage to speed cyclists of travelling very close together as shown in the photograph?

Less drag on cyclist behind.

Please see **'4.2.1 Drag notes'** pack for revision notes.

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