AP Physics C: Mechanics
2000 Student Samples

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Mech 2.

A rubber ball of mass m is dropped from a cliff. As the ball falls, it is subject to air drag (a resistive force caused by the air). The drag force on the ball has magnitude bv^2, where b is a constant drag coefficient and v is the instantaneous speed of the ball. The drag coefficient b is directly proportional to the cross-sectional area of the ball and the density of the air and does not depend on the mass of the ball. As the ball falls, its speed approaches a constant value called the terminal speed.

(a) On the figure below, draw and label all the forces on the ball at some instant before it reaches terminal speed.

F_d = drag force

(b) State whether the magnitude of the acceleration of the ball of mass m increases, decreases, or remains the same as the ball approaches terminal speed. Explain.

The magnitude of the acceleration decreases as the ball approaches terminal speed because the drag force will increase until it is equal to the force due to gravity. Once $F_d = mg$, the ball will be at terminal speed because the acceleration will be zero.

(c) Write, but do NOT solve, a differential equation for the instantaneous speed v of the ball in terms of time t, the given quantities, and fundamental constants.

$$\Sigma F_y = ma = m\frac{dv}{dt}$$

$$F_d - mg = m\frac{dv}{dt}$$

$$\frac{bv^2 - mg}{m} = \frac{dv}{dt}$$

(d) Determine the terminal speed v_t in terms of the given quantities and fundamental constants.

$$\Sigma F_y = ma = 0$$
$$F_d - mg = 0$$
$$F_d = mg$$
$$bv_t^2 = mg$$
$$v_t^2 = \frac{mg}{b}$$
$$\boxed{v_t = \sqrt{\frac{mg}{b}}}$$

(c) Determine the energy dissipated by the drag force during the fall if the ball is released at height h and reaches its terminal speed before hitting the ground, in terms of the given quantities and fundamental constants.

Energy dissipated $= E_A - E_B$
$$= mgh - \frac{1}{2}mv_t^2$$
$$= mgh - \frac{1}{2}m\left(\frac{mg}{b}\right)$$
$$= \boxed{mg\left(h - \frac{1}{2}\frac{m}{b}\right)}$$

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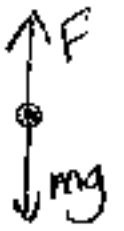
$f = bv^2$ $\quad v_T = \sqrt{\frac{mg}{b}}$

(a) On the figure below, draw and label all the forces on the ball at some instant before it reaches terminal speed.



(b) State whether the magnitude of the acceleration of the ball of mass m increases, decreases, or remains the same as the ball approaches terminal speed. Explain.

a will decrease to zero as the ball approaches terminal speed

increases

Let's compare $g - \frac{bv^2}{m} = a$ & $g - gv_T = a$

In the first equation, a bigger number is being subtracted from

$mg - F = ma$

$mg - bv^2 = ma$

$\frac{mg - bv^2}{m} = a$

$g - \frac{bv^2}{m} = a$

$g - gv = a$

$g - b\frac{\sqrt{mg/b}^2}{m} = a$

$g - \frac{bmg}{bm} = a$

$g - g = a$

$a = 0$

$g - \frac{b\left(\sqrt{\frac{mg}{b}}\right)^2}{m} = a$

$g - \frac{b\frac{mg}{b}}{m} = a$

$g - \frac{m^2g^2}{b^2m} = a$

$g - \frac{mg^2}{b} = a$

$g - \left(\frac{mg}{b}\frac{v_T}{g}\right)g = a$

$g(1 - v_t) = a$

(c) Write, but do NOT solve, a differential equation for the instantaneous speed v of the ball in terms of time t, the given quantities, and fundamental constants.

$mg - bv^2 = ma$

$mg = ma + bv^2$

$mg = m\frac{dv}{dt} + bv^2$

$mg = m\frac{dv}{dt} + \frac{mg}{v_T^2}v^2$

$g = \frac{dv}{dt} + gv$

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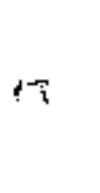
(d) Determine the terminal speed v_t in terms of the given quantities and fundamental constants.



$$mg - bv_t^2 = ma$$

$$mg = bv_t^2$$

$$\frac{mg}{b} = v_t^2$$

$$v_t = \sqrt{\frac{mg}{b}}$$

(e) Determine the energy dissipated by the drag force during the fall if the ball is released at height h and reaches its terminal speed before hitting the ground, in terms of the given quantities and fundamental constants.

$$\frac{1}{2}mv_t^2 + mgh$$

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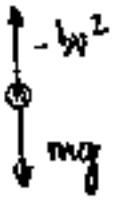

(b) State whether the magnitude of the acceleration of the ball of mass m increases, decreases, or remains the same as the ball approaches terminal speed. Explain.

The acceleration decreases due to the drag force.

(c) Write, but do NOT solve, a differential equation for the instantaneous speed v of the ball in terms of time t, the given quantities, and fundamental constants.

$$mg - bv^2 = ma$$

$$mg - bv^2 = m\frac{dv}{dt}$$

$$\left(\frac{mg}{m} - \frac{bv^2}{m}\right)dt = dv$$

$$\int\left(g - \frac{bv^2}{m}\right) = v$$

(d) Determine the terminal speed v_t in terms of the given quantities and fundamental constants.

$Vt = \frac{mg}{b}$

$mg - bv^2 = ma$

$mg - bv^2 = m\frac{dv}{dt}$

(e) Determine the energy dissipated by the drag force during the fall if the ball is released at height h and reaches its terminal speed before hitting the ground, in terms of the given quantities and fundamental constants.

At top $\Rightarrow$ Total Energy = mgh

IF energy is conserved Then $= mgh$