

Drag forces and terminal velocity with calculus

AP Physics C (Mechanics and E&M, calculus-based) · Test answers (mark scheme)

Model answers with a marking guide for each question. Award method marks for correct formulae and substitution even if the arithmetic slips, and apply error carried forward where a later part uses an earlier wrong value. Units are required for the final answer.

Level: AP Physics C (Mechanics and E&M, calculus-based) · **Curriculum:** AP PC:M Unit 2

Question 1 Terminal velocity (2 marks)

a. The constant speed at which the drag force balances the driving force (weight). b. **Zero**.
Marking: 1 mark for each part; part b must say the net force is zero, not the drag.

Question 2 Linear drag calculation (3 marks)

a. $v_t = mg/b = (0.30 \times 9.81)/0.60 = \mathbf{4.9 \text{ m/s}}$. b. $\tau = m/b = \mathbf{0.50 \text{ s}}$. c. $v = 4.905(1 - e^{-2}) = 4.905 \times 0.8647 = \mathbf{4.2 \text{ m/s}}$.

Marking: 1 mark each; accept 4.9 m/s from 4.905.

Question 3 Acceleration (2 marks)

a. $dv/dt = v_t(1/\tau)e^{-t/\tau} = (mg/b)(b/m)e^{-t/\tau} = g e^{-t/\tau}$. b. At $t = 0$, $a = \mathbf{9.81 \text{ m/s}^2}$.

Marking: 1 mark for the derivative with the chain rule, 1 mark for g .

Question 4 Graph (3 marks)

a. **4.0 m/s**. b. $b = mg/v_t = (0.25 \times 9.81)/4.0 = \mathbf{0.61 \text{ kg/s}}$. c. The speed is 63 % of 4.0 m/s (2.5 m/s) at 0.40 s, and $m/b = 0.25/0.61 = 0.41 \text{ s}$, so $\tau \approx \mathbf{0.40 \text{ s}}$ agrees.

Marking: 1 mark per part; allow $\pm 0.1 \text{ s}$ on τ .

Question 5 Parachutist (3 marks)

a. $v_t = \sqrt{(mg/c)} = \sqrt{(637.65/0.22)} = \sqrt{2898} = \mathbf{54 \text{ m/s}}$. b. $v_t = \sqrt{(637.65/20)} = \sqrt{31.9} = \mathbf{5.6 \text{ m/s}}$.

Marking: 1 mark for part a; part b: 1 mark for the substitution, 1 for the result.

Question 6 Heavier object (2 marks)

At terminal speed drag equals weight. A heavier object needs a larger drag force to balance, and drag only grows with speed, so the speed must be larger before the forces balance.

Larger weight needs larger speed.

Marking: 1 mark for drag = weight; 1 mark for drag increasing with speed.

Question 7 Boat (3 marks)

a. $\tau = m/b = 250/40 = \mathbf{6.25\ s}$. b. $v = v_0 e^{-t/\tau}$, so $t = \tau \ln(5.0/1.0) = 6.25 \times 1.609 = \mathbf{10\ s}$.

Marking: 1 mark for τ ; 1 for the rearranged exponential; 1 for the result.

Question 8 Energy (2 marks)

a. $P = mg v_t = 0.30 \times 9.81 \times 4.905 = \mathbf{14\ W}$. b. It comes from the loss of gravitational potential energy, because the kinetic energy is constant.

Marking: 1 mark each.