

Drag forces and terminal velocity with calculus

AP Physics C (Mechanics and E&M, calculus-based) · Lab

Name: _____ Date: _____ Class: _____

A stack of paper cupcake cases falls fast but not freely, because air drag is quadratic at these speeds. By timing the last metre of the fall for different masses, you test whether terminal speed squared is proportional to mass, as $v_t = \sqrt{(mg/c)}$ predicts.

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

Aim

Find how the terminal speed of a falling object depends on its mass when drag is quadratic, and estimate the drag constant c .

Equipment

- Paper cupcake cases, all identical (5 or more)
- Balance reading to 0.01 g
- Metre rule and tape, fixed vertically
- Phone with slow-motion video
- Stopwatch app or frame-by-frame viewer

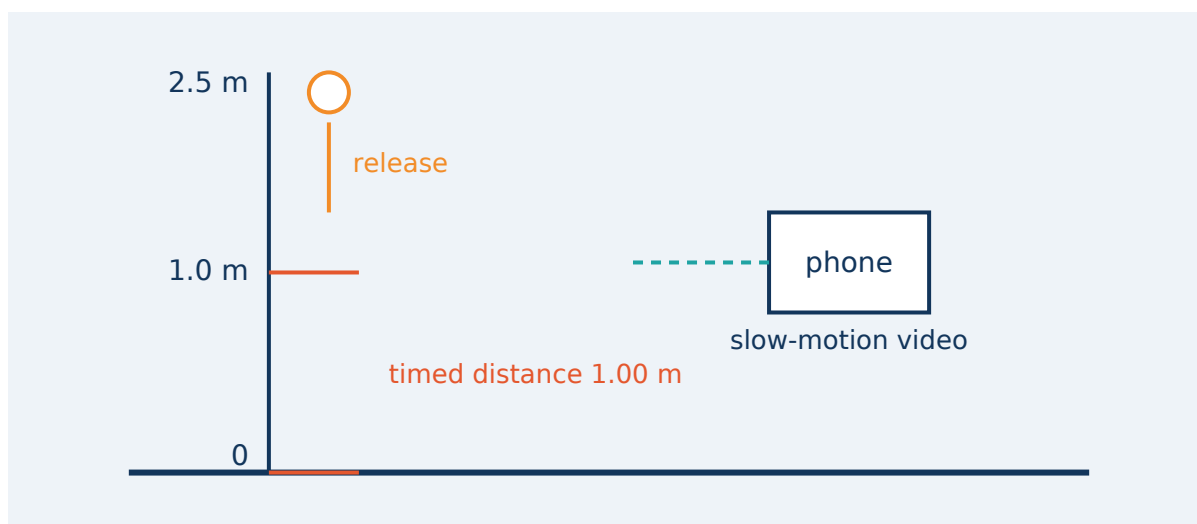
Safety

Safety

Work at floor level or from a low, stable step only. Clear the floor of bags, and tell others where you are dropping things so nobody trips or looks up into the falling cases.

Method

1. Weigh one case, then nest 1, 2, 3, 4 and 5 cases together so they fall as one open cup. Record the masses.
2. Mark two lines on the wall: one 1.00 m above the floor and one at the floor, as shown below.
3. Release the stack, open end up, from 2.5 m above the floor, so it has 1.5 m to reach a steady speed before the timed section.
4. Film the fall and find the time to cross the 1.00 m section. Repeat three times for each stack.
5. Calculate the mean time, then $v = 1.00 \text{ m}$ divided by the mean time.



Set-up for the cupcake case drops.

Results

Cases n	Mass m (g)	t ₁ (s)	t ₂ (s)	t ₃ (s)	Mean t (s)
1	0.80	0.68	0.66	0.67	0.67
2	1.60	0.47	0.48	0.46	0.47
3	2.40	0.39	0.37	0.38	0.38
4	3.20	0.33	0.34	0.32	0.33
5	4.00	0.30	0.31	0.29	0.30

Analysis questions

Question 1 Speeds and squares

Calculate $v = 1.00/t$ using each mean time, then v^2 . Complete a table of n, m, v and v^2 .

Question 2 Graph

Plot v^2 (vertical) against m in kg (horizontal). Draw the best-fit line through the origin and find its gradient.

Question 3 Drag constant

Use $v_t^2 = (g/c) m$ to find c from the gradient.

Question 4 Why the last metre?

Explain why the time is measured over the last metre instead of the whole fall.

Question 5 Uncertainty

The time for the 5-case stack is 0.30 s with an uncertainty of ± 0.02 s. Calculate the percentage uncertainty in v and in v^2 .

Question 6 Conclusion

State what the straight-line graph shows about the relation between v_t and m .

Question 7 Improvements

Propose two modifications to the drop that would make your value of c more reliable.