AP® PHYSICS C: MECHANICS
2010 SCORING GUIDELINES

General Notes

1. The solutions contain the most common method of solving the free-response questions and the allocation of points for the solution. Some also contain a common alternate solution. Other methods of solution also receive appropriate credit for correct work.

2. Generally, double penalty for errors is avoided. For example, if an incorrect answer to part (a) is correctly substituted into an otherwise correct solution to part (b), full credit will usually be awarded. One exception to this may be cases when the numerical answer to a later part should be easily recognized as wrong — for example, a speed faster than the speed of light in vacuum.

3. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth 1 point and a student's solution contains the application of that equation to the problem but the student does not write the basic equation, the point is still awarded. However, when students are asked to derive an expression it is normally expected that they will begin by writing one or more fundamental equations, such as those given on the AP Physics Exams equation sheet. For a description of the use of such terms as "derive" and "calculate" on the exams and what is expected for each, see "The Free-Response Sections — Student Presentation" in the *AP Physics Course Description*.

4. The scoring guidelines typically show numerical results using the value $g = 9.8 \text{ m/s}^2$, but use of 10 m/s^2 is of course also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

5. Strict rules regarding significant digits are usually not applied to numerical answers. However, in some cases answers containing too many digits may be penalized. In general, two to four significant digits are acceptable. Numerical answers that differ from the published answer due to differences in rounding throughout the question typically receive full credit. Exceptions to these guidelines usually occur when rounding makes a difference in obtaining a reasonable answer. For example, suppose a solution requires subtracting two numbers that should have five significant figures and that differ starting with the fourth digit (e.g., 20.295 and 20.278). Rounding to three digits will lose the accuracy required to determine the difference in the numbers, and some credit may be lost.

Question 1

15 points total | **Distribution of points**

(a) 2 points

Starting with Newton's second law:

$F_{net} = mg - Cv^2 = ma$

For correctly indicating that at terminal velocity ($v = v_T$), the net force and acceleration are zero — 1 point

$mg - Cv_T^2 = 0$

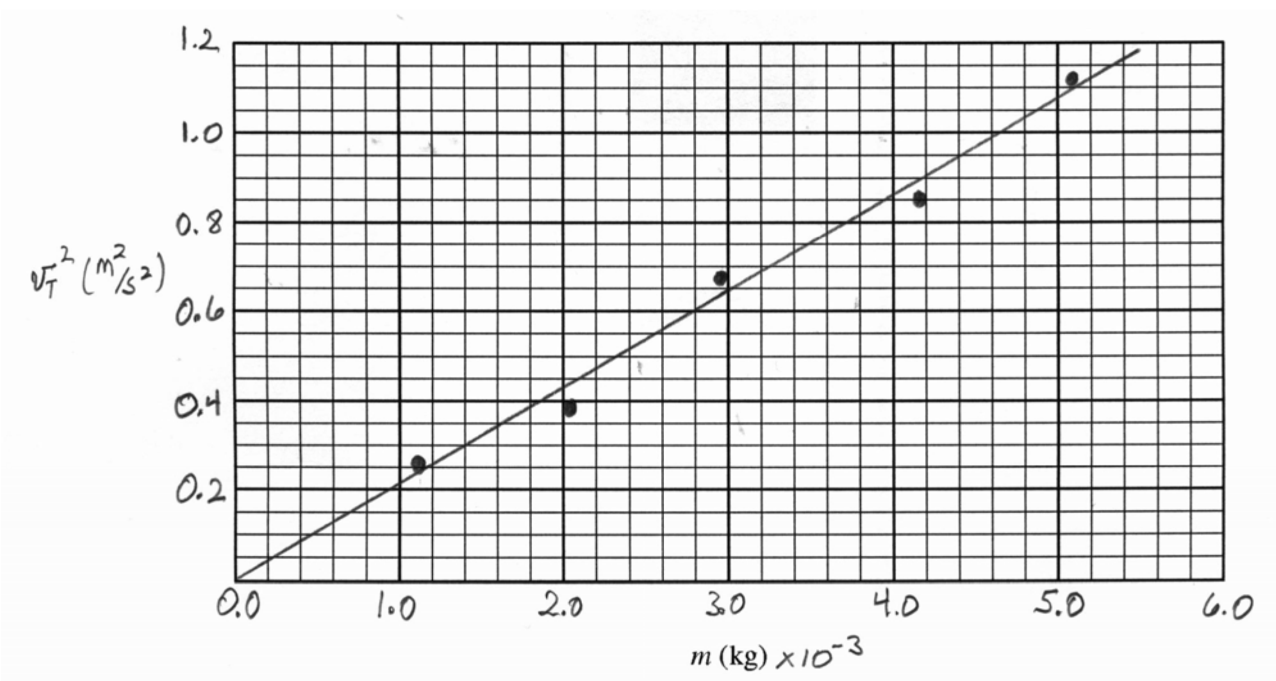
For a correct relationship between v_T and m — 1 point

$v_T^2 = \frac{g}{C}m$

(b)

(i) 4 points

Mass of the stack of filters, m (kg)	1.12×10^{-3}	2.04×10^{-3}	2.96×10^{-3}	4.18×10^{-3}	5.10×10^{-3}
Terminal speed, v_T (m/s)	0.51	0.62	0.82	0.92	1.06
v_T^2 (m^2/s^2)	0.26	0.38	0.67	0.85	1.12



Question 1 (continued)

Distribution of points

(b) (i) (continued)

For recording in the table a row of calculated data points that involve only v_T or a combination of v_T and g — 1 point

For graphing v_T^2 (or the equivalent) on the vertical axis to obtain a linear graph — 1 point

For including an appropriate linear scale on both axes — 1 point

For drawing a reasonable best-fit straight line — 1 point

Note: Correct graphs of v_T versus $\sqrt{m}$ are given credit provided the quantities being plotted are clearly indicated.

(ii) 3 points

For a correct calculation of the slope, using points on the student's best-fit line (not points from the data table) — 1 point

Using the example graph shown:

$$\text{slope} = \frac{(0.95\ - 0.30\ )\text{m}^2/\text{s}^2}{\left[(4.4 - 1.4)\times 10^{-3}\right]\text{ kg}} = 217\ \text{m}^2/\text{kg}\bullet\text{s}^2$$

For a correct expression relating the slope to C — 1 point

$$\text{slope} = 217\text{m}^2/\text{kg}\bullet\text{s}^2 = \frac{g}{C}$$

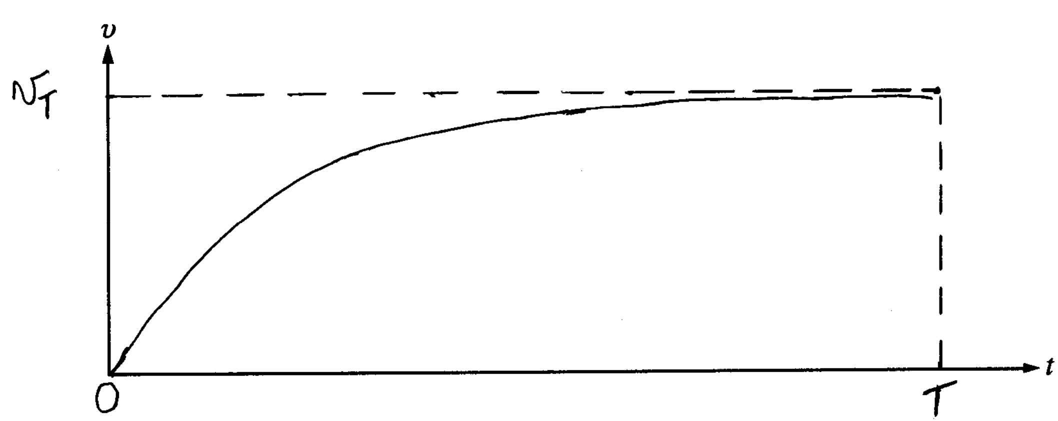
$$C = \frac{g}{\text{Slope}} = \frac{9.8\ \text{m}/\text{s}^2}{217\ \text{m}^2/\text{kg}\bullet\text{s}^2}$$

For correct units on C — 1 point

$C = 0.045\ \text{kg}/\text{m}$ $\quad(0.046\ \text{kg}/\text{m}$ using $g = 10\ \text{m}/\text{s}^2)$

(c)

(i) 3 points



For a graph that starts at the origin with an initial positive slope — 1 point

For a graph that is concave down throughout — 1 point

Question 1 (continued)

	Distribution of points
For labeling υ_T and T at a point where the slope of the graph approaches zero	1 point

(c) (continued)

(ii) 1 point

For a verbal statement that clearly indicates the distance Y is the area under the curve between times $t = 0$ and $t = T$	1 point

Or an equivalent statement referring to the area under the curve when the υ versus t graph ends at T

Or an equivalent mathematical expression with limits: $Y = \int_0^T \upsilon(t)\, dt$

(d) 2 points

For a correct indication that the mechanical energy dissipated is the change in mechanical energy during the time the stack falls a distance y	1 point

$\Delta E = \left(U_{final} + K_{final}\right) - \left(U_{initial} + K_{initial}\right) \qquad \left(\text{or } \Delta E = \int_0^y C\upsilon^2 dy\right)$

$\Delta E = \Delta U + \Delta K$

For correct substitutions of y, m, and υ_T	1 point

$\Delta U = -mgy$

$\Delta K = \frac{1}{2}m\upsilon_T^2$

$\Delta E = \frac{1}{2}m\upsilon_T^2 - mgy$ (or any equation with an additional negative sign that has the correct relative signs for potential and kinetic energies)

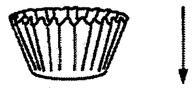
PHYSICS C: MECHANICS

SECTION II

Time—45 minutes

3 Questions

Directions: Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part, NOT in the green insert.



Mech. 1.

Students are to conduct an experiment to investigate the relationship between the terminal speed of a stack of falling paper coffee filters and its mass. Their procedure involves stacking a number of coffee filters, like the one shown in the figure above, and dropping the stack from rest. The students change the number of filters in the stack to vary the mass m while keeping the shape of the stack the same. As a stack of coffee filters falls, there is an air resistance (drag) force acting on the filters.

(a) The students suspect that the drag force F_D is proportional to the square of the speed v : $F_D = Cv^2$, where C is a constant. Using this relationship, derive an expression relating the terminal speed v_T to the mass m.

$\Sigma F = F_D - mg = ma = 0$ @ terminal speed

$F_D = mg$

$Cv_T^2 = mg$

$\boxed{V_T = \sqrt{\frac{mg}{C}}}$

The students conduct the experiment and obtain the following data.

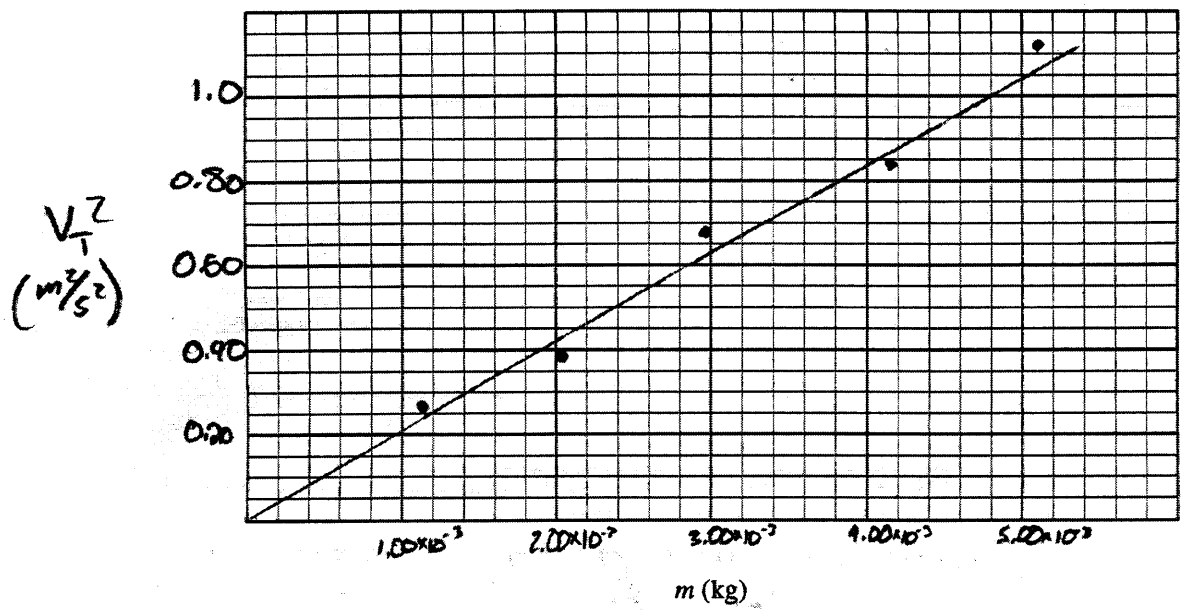
Mass of the stack of filters, m (kg)	1.12×10^{-3}	2.04×10^{-3}	2.96×10^{-3}	4.18×10^{-3}	5.10×10^{-3}
Terminal speed, v_T (m/s)	0.51	0.62	0.82	0.92	1.06
V_T^2 (m^2/s^2)	0.2601	0.3844	0.6724	0.8464	1.1236

$V_T^2 = \frac{mg}{C}$ so if we graph

V_T^2 with respect to m we obtain $\frac{g}{C}$ as the slope.

(b)

(i) Assuming the functional relationship for the drag force above, use the grid below to plot a linear graph as a function of m to verify the relationship. Use the empty boxes in the data table, as appropriate, to record any calculated values you are graphing. Label the vertical axis as appropriate, and place numbers on both axes.



(ii) Use your graph to calculate C.

It goes through the points (m, v_T^2):

$(0,0)$ and $(4.80\times10^{-3}, 1.0)$

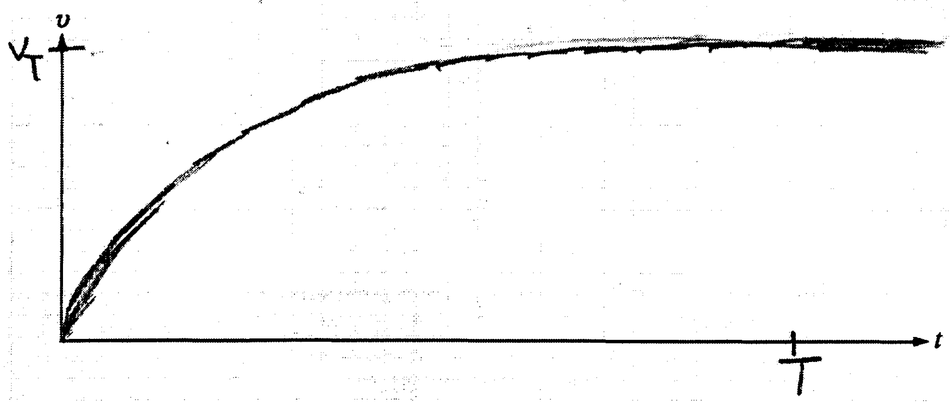
$$\frac{g}{C} = \frac{1.0-0}{4.80\times10^{-3}-0} = 208.3$$

$$C = \frac{g}{208.3} = \frac{10}{208.3} = \boxed{0.048\ \text{kg/m}}$$

A particular stack of filters with mass m is dropped from rest and reaches a speed very close to terminal speed by the time it has fallen a vertical distance Y.

(c)

(i) Sketch an approximate graph of speed versus time from the time the filters are released up to the time $t = T$ that the filters have fallen the distance Y. Indicate time $t = T$ and terminal speed $v = v_T$ on the graph.



(ii) Suppose you had a graph like the one sketched in (c)(i) that had a numerical scale on each axis. Describe how you could use the graph to approximate the distance Y.

Y is equal to the area under a velocity vs. time curve, so you would need to find the area under that curve from t=0 to t=T.

(d) Determine an expression for the approximate amount of mechanical energy dissipated, ΔE, due to air resistance during the time the stack falls a distance y, where $y > Y$. Express your answer in terms of y, m, v_T, and fundamental constants.

$$\Delta E = \Delta U + \Delta K$$

$$= U_f - U_o + K_f - K_o$$

$$= -mgy + \frac{1}{2}v_T^2 - 0$$

$$= \boxed{\frac{1}{2}v_T^2 - mgy}$$

M1-B-1

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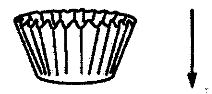

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(a) The students suspect that the drag force F_D is proportional to the square of the speed v : $F_D = Cv^2$, where C is a constant. Using this relationship, derive an expression relating the terminal speed v_T to the mass m.

$$mg - Cv^2 = 0$$

$$V_T = \sqrt{\frac{mg}{C}}$$

$$mg = Cv^2$$

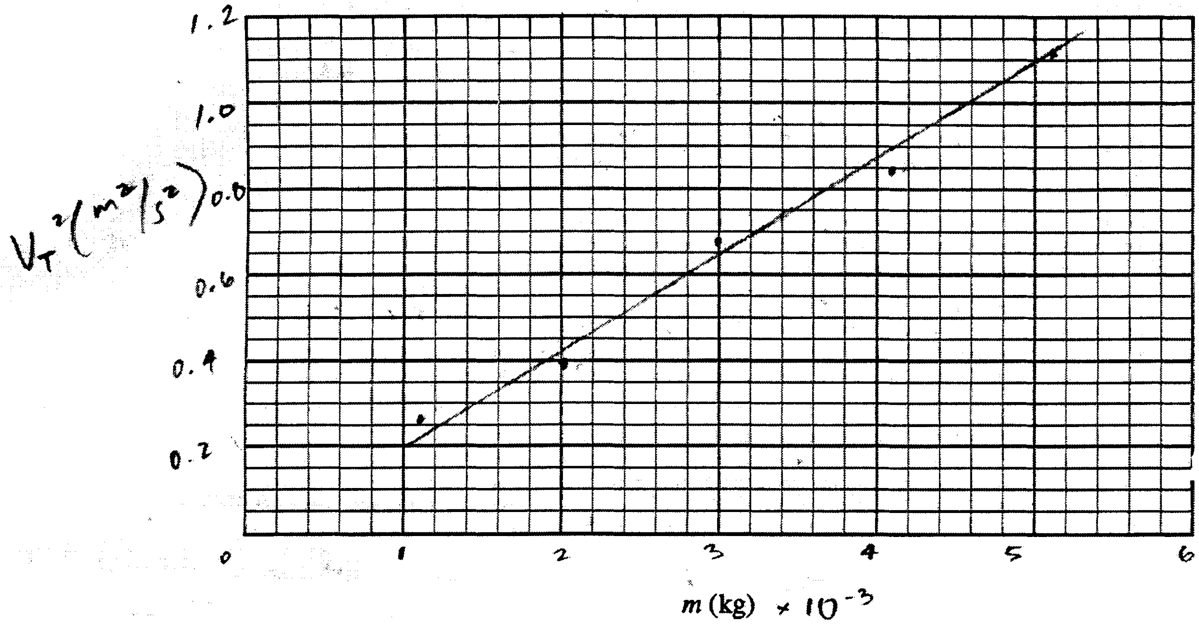
$$\frac{mg}{C} = v^2$$

The students conduct the experiment and obtain the following data.

Mass of the stack of filters, m (kg)	1.12×10^{-3}	2.04×10^{-3}	2.96×10^{-3}	4.18×10^{-3}	5.10×10^{-3}
Terminal speed, v_T (m/s)	0.51	0.62	0.82	0.92	1.06
V_T^2 (m^2/s^2)	0.2601	0.3844	0.6724	0.8464	1.1236

(b)

(i) Assuming the functional relationship for the drag force above, use the grid below to plot a linear graph as a function of m to verify the relationship. Use the empty boxes in the data table, as appropriate, to record any calculated values you are graphing. Label the vertical axis as appropriate, and place numbers on both axes.



(ii) Use your graph to calculate C.

$g = 10\,m/s^2$

$$C = \frac{mg}{v^2}$$

$$\frac{1}{C} = \frac{v^2}{mg}$$

$$\frac{1}{C} = \frac{v^2}{10m}$$

$$\frac{1}{C} = \frac{1.1236 - 0.2601}{10(5.10\times10^{-3} - 1.12\times10^{-3})}$$

$$\frac{1}{C} = 21.696$$

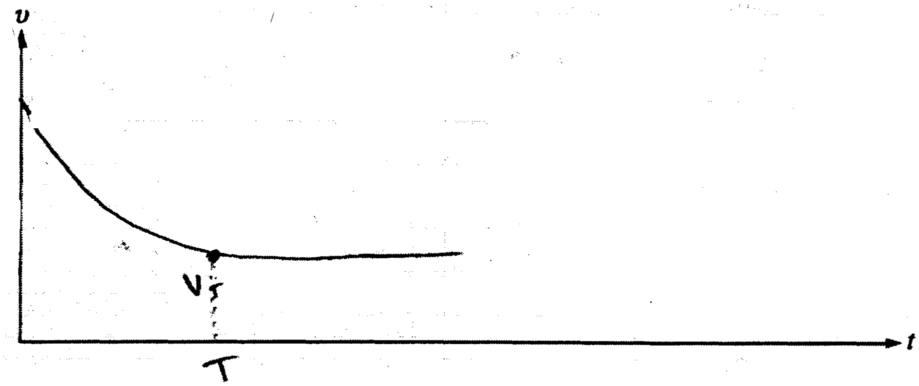
$$C = 0.0461\ m/kg$$

$$\frac{\frac{m^2}{s^2}}{\frac{m}{s^2}\cdot kg} \quad m^2 \cdot \frac{1}{kg \cdot m}$$

A particular stack of filters with mass m is dropped from rest and reaches a speed very close to terminal speed by the time it has fallen a vertical distance Y.

(c)

(i) Sketch an approximate graph of speed versus time from the time the filters are released up to the time $t = T$ that the filters have fallen the distance Y. Indicate time $t = T$ and terminal speed $v = v_T$ on the graph.



(ii) Suppose you had a graph like the one sketched in (c)(i) that had a numerical scale on each axis. Describe how you could use the graph to approximate the distance Y.

You would find the area of a set limit from $t=0$ to $t=T$.
~~It~~ is an integral
of $\int_0^T v(t)\,dt$
which would give Y.

(d) Determine an expression for the approximate amount of mechanical energy dissipated, ΔE, due to air resistance during the time the stack falls a distance y, where $y > Y$. Express your answer in terms of y, m, v_T, and fundamental constants.

$$\frac{1}{2}mv^2 - \frac{1}{2}mv_T^2 = \Delta E$$

$$mgy = \frac{1}{2}mv^2$$

$$\sqrt{2gy} = v$$

$$\frac{1}{2}m(\sqrt{2gy})^2 - \frac{1}{2}mv_T^2 = \Delta E$$

$$mgy - \frac{1}{2}mv_T^2 = \Delta E$$

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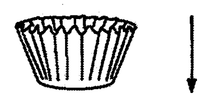

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(a) The students suspect that the drag force F_D is proportional to the square of the speed v : $F_D = Cv^2$, where C is a constant. Using this relationship, derive an expression relating the terminal speed v_T to the mass m.

$F = ma \quad a = \frac{V}{t}$

$F_D = m\left(\frac{V_t}{t}\right)$

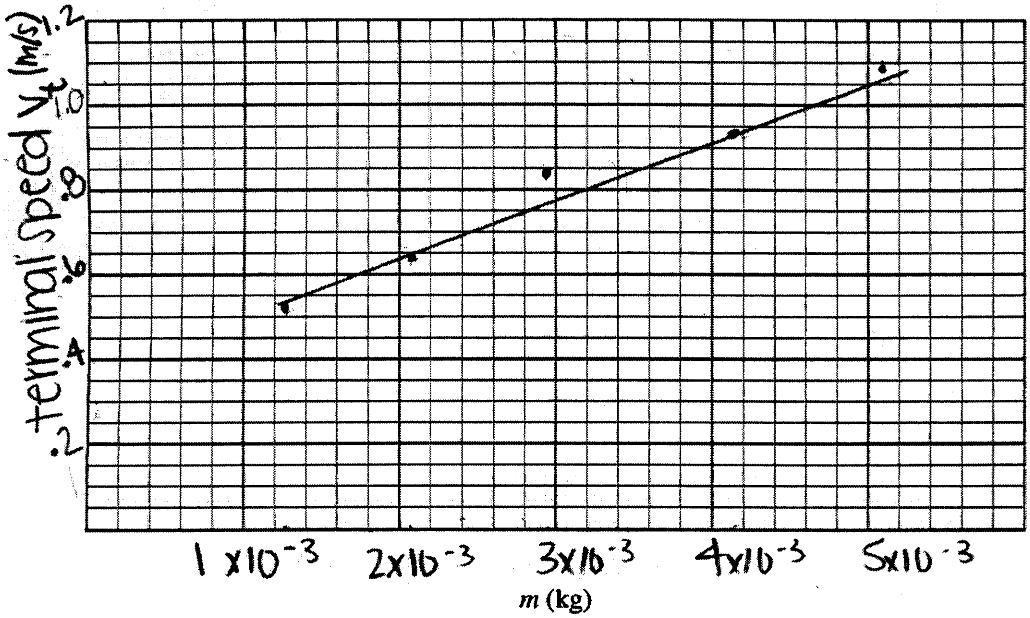
$FD = CV^2$

The students conduct the experiment and obtain the following data.

Mass of the stack of filters, m (kg)	1.12×10^{-3}	2.04×10^{-3}	2.96×10^{-3}	4.18×10^{-3}	5.10×10^{-3}
Terminal speed, v_T (m/s)	0.51	0.62	0.82	0.92	1.06
V^2	.2601	.3844	.6724	.8464	1.1236

(b)

(i) Assuming the functional relationship for the drag force above, use the grid below to plot a linear graph as a function of m to verify the relationship. Use the empty boxes in the data table, as appropriate, to record any calculated values you are graphing. Label the vertical axis as appropriate, and place numbers on both axes.



(ii) Use your graph to calculate C.

$F_D = CV^2$

F_d = slope

$\frac{.11}{9.2 \times 10^{-4}}$

$F_d = 119.6$

$119.6 = C(.2601)$

$C = 459.7$

M1-C-3

A particular stack of filters with mass m is dropped from rest and reaches a speed very close to terminal speed by the time it has fallen a vertical distance Y.

(c)

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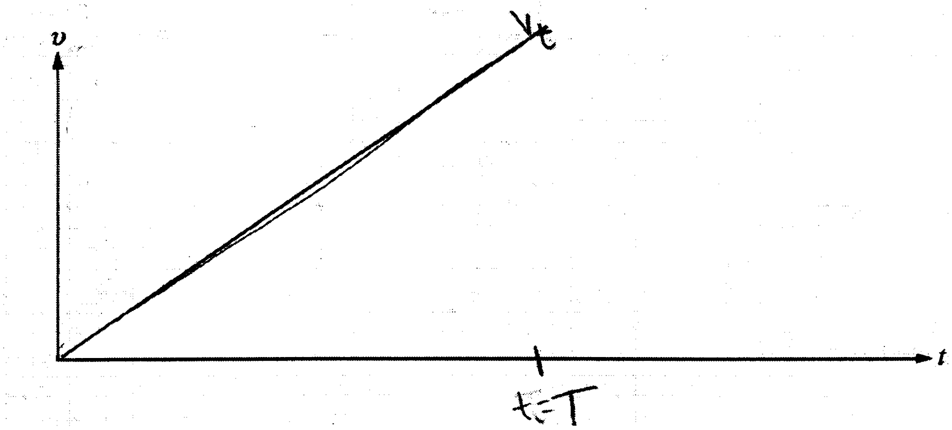

(ii) Suppose you had a graph like the one sketched in (c)(i) that had a numerical scale on each axis. Describe how you could use the graph to approximate the distance Y.

you would take the velocity value and divide by the time to get distance

$V = \frac{m}{s}$ $V = \frac{d}{t}$ $\frac{V}{t} = d$

(d) Determine an expression for the approximate amount of mechanical energy dissipated, ΔE, due to air resistance during the time the stack falls a distance y, where $y > Y$. Express your answer in terms of y, m, v_T, and fundamental constants.

$K = \frac{1}{2}mv^2$ $K = \frac{1}{2}m\left(\frac{Y}{t}\right)(V_t)$

Question 1

Overview

This question assessed students' understanding of forces in equilibrium. It also tested their ability to create a linear relationship from nonlinear data, to graph the linear relationship in order to determine a constant, to graphically represent the velocity of a falling body when air resistance is not neglected, to describe how distance could be calculated using that graph, and finally to determine an expression for the amount of mechanical energy dissipated during the fall owing to air resistance.

Sample: M1-A
Score: 14

The only point lost by this response was in part (d), where the kinetic energy term is missing the m. Note the explicit explanations throughout the response. When students use (0, 0) as a point on the line for a slope calculation, their written work most often just shows the other point used. It is better to specifically mention (0, 0), as in part (b)(ii) of this response, to clearly indicate the use of two points.

Sample: M1-B
Score: 10

Parts (a) and (b)(i) earned full credit. Part (b)(ii) received 1 point. It uses data points to calculate the slope, one of which is clearly not on the line drawn, and the units on the answer are inverted. Part (c)(i) earned nothing because the label of v_T near the data point leaves understanding of the value of the asymptote ambiguous. Parts (c)(ii) and (d) earned full credit.

Sample: M1-C
Score: 4

Part (a) earned no credit. Part (b)(i) earned only 3 points because it is a graph of v_T and not v_T^2. Part (b)(ii) earned no credit. Part (c)(i) earned 1 point for a graph starting at the origin with a positive slope. Parts (c)(ii) and (d) earned no credit.