
AP[®] Physics C: Mechanics

Sample Student Responses and Scoring Commentary Set 1

Inside:

Free Response Question 1

- Scoring Guideline
- Student Samples
- Scoring Commentary

AP[®] PHYSICS

2019 SCORING GUIDELINES

General Notes About 2019 AP Physics Scoring Guidelines

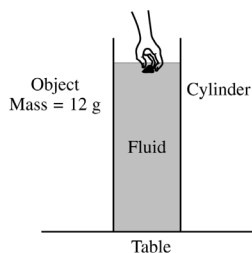
1. The solutions contain the most common method of solving the free-response questions and the allocation of points for this solution. Some also contain a common alternate solution. Other methods of solution also receive appropriate credit for correct work.
2. The requirements that have been established for the paragraph-length response in Physics 1 and Physics 2 can be found on AP Central at <https://secure-media.collegeboard.org/digitalServices/pdf/ap/paragraph-length-response.pdf>.
3. 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, e.g., a speed faster than the speed of light in vacuum.
4. 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 embeds the application of that equation to the problem in other work, 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 exam 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; Physics C: Mechanics, Physics C: Electricity and Magnetism Course Description* or “Terms Defined” in the *AP Physics 1: Algebra-Based Course and Exam Description* and the *AP Physics 2: Algebra-Based Course and Exam Description*.
5. The scoring guidelines typically show numerical results using the value $g = 9.8 \text{ m/s}^2$, but the use of 10 m/s^2 is of course also acceptable. Solutions usually show numerical answers using both values when they are significantly different.
6. 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.

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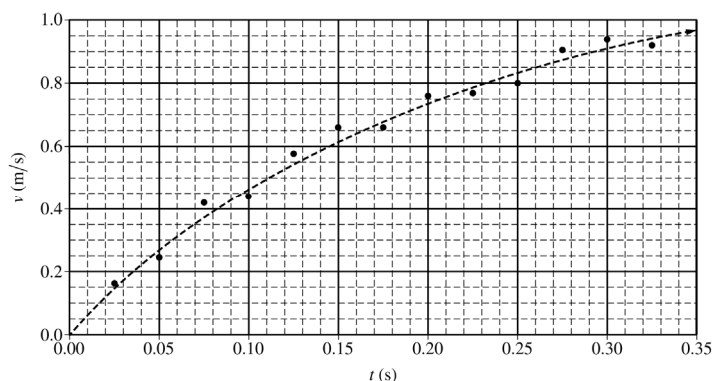
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Question 1

15 points



In an experiment, students used video analysis to track the motion of an object falling vertically through a fluid in a glass cylinder. The object of $m = 12\text{ g}$ is released from rest at the top of the column of fluid, as shown above. The data for the speed v of the falling object as a function of time t are graphed on the grid below. The dashed curve represents the best fit chosen by the students for these data.



(a)

- i. LO CHA-1.C, SP 7.A
1 point

Does the speed of the object increase, decrease, or remain the same?

Increase Decrease Remain the same

For selecting “Increase”		1 point
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- ii. LO CHA-1.C, SP 4.D
2 points

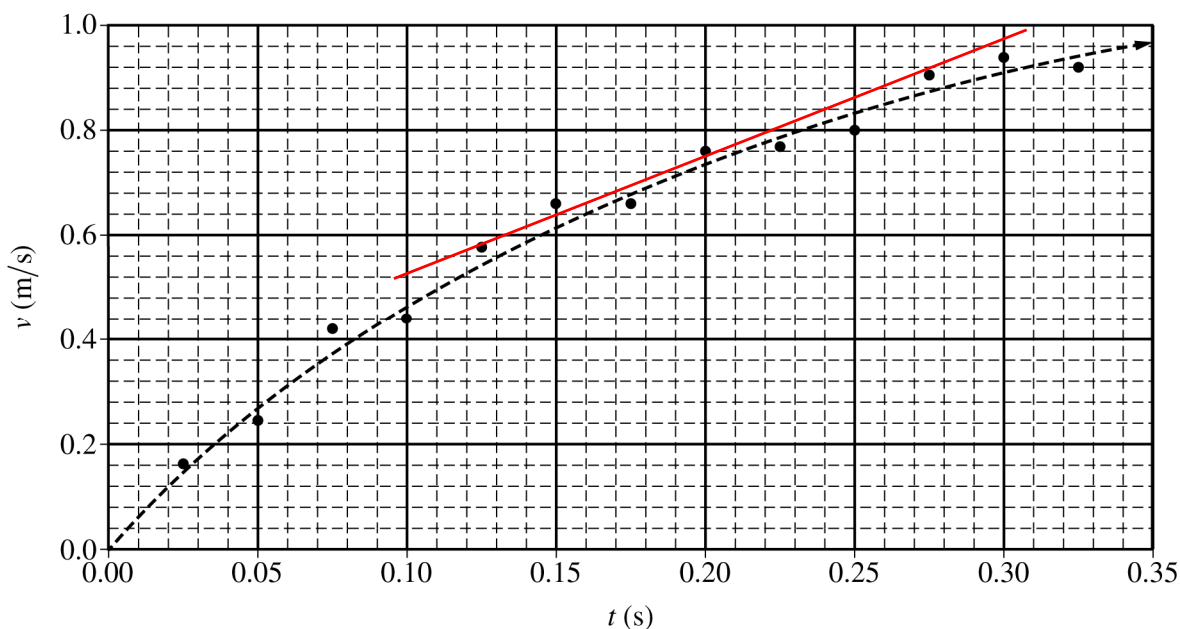
In a brief statement, describe the direction of the object’s acceleration and how the magnitude of this acceleration changed as the object fell.

For a description that includes the direction of the acceleration as being “downwards”		1 point
For a description that includes the decrease in the magnitude of the acceleration		1 point
Example: Because the object is moving downwards and speeding up, the acceleration must be downwards. Because the slope of the graph of speed as a function of time is decreasing, the magnitude of the acceleration must be decreasing.		

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Question 1 (continued)

(a) continued



- iii. LO CHA-1.C, SP 4.D, 6.C
2 points

Using the graph, calculate an approximate value for the magnitude of the acceleration of the object at $t = 0.20$ s.

For calculating the slope of a trend line at $t = 0.20$ s		1 point
$\text{slope} = a = \frac{\Delta v}{\Delta t} = \frac{(0.8 - 0.6) \text{ m/s}}{(0.226 - 0.136) \text{ s}}$		
For a correct answer using points from a tangent line		1 point
$a = 2.22 \text{ m/s}^2$		

The students use the equation $v = A(1 - e^{-Bt})$ to model the speed of the falling object and find the best-fit coefficients to be $A = 1.18 \text{ m/s}$ and $B = 5 \text{ s}^{-1}$.

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Question 1 (continued)

(b) Use the above equation to:

- i. LO CHA-1.B, SP 6.B, 6.C
3 points

Derive an expression for the magnitude of the vertical displacement $y(t)$ of the falling object as a function of time t .

For indicating that the vertical displacement is the integration of the velocity		1 point
$\Delta y = \int v dt = \int A(1 - e^{-Bt}) dt$		
For the equation for speed using appropriate limits or constant of integration		1 point
$\Delta y = \int_{t'=0}^{t'=t} A(1 - e^{-Bt'}) dt' = A \left[t' - \frac{1}{-B} e^{-Bt'} \right]_{t'=0}^{t'=t} = A \left[\left(t + \frac{1}{B} e^{-Bt} \right) - \left(0 + \frac{1}{B} e^0 \right) \right]$		
For a correct answer		1 point
$\Delta y = A \left(t + \frac{1}{B} (e^{-Bt} - 1) \right) = (1.18) \left(t + \frac{1}{5} (e^{-5t} - 1) \right)$		
<u>Note:</u> Credit given for using A and B or plugging in the given values		

- ii. LO INT-1.C.d, SP 6.B, 6.C
3 points

Derive an expression for the magnitude of the net force $F(t)$ exerted on the object as it falls through the fluid as a function of time t .

For attempting the derivative of the equation for speed		1 point
$a = \frac{dv}{dt} = \frac{d}{dt} [A(1 - e^{-Bt})]$		
For a correct equation for the acceleration		1 point
$a = AB e^{-Bt}$		
For multiplying the equation above by the mass of the object		1 point
$F = ma = m(AB e^{-Bt}) = mAB e^{-Bt}$		
$F = (.012)(1.18)(5) e^{-5t} = 0.071 e^{-5t}$		
<u>Note:</u> Credit given for using A , B , and m or plugging in the given values		

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Question 1 (continued)

(c)

The students repeat the experiment with a taller glass cylinder that is filled with the same fluid. The cylinder is tall enough so that the object reaches a constant speed.

- i. LO INT-1.I, SP 7.A, 7.C
2 points

Determine the constant speed of the object.
Justify your answer.

For stating the constant speed is $v = A$		1 point
For indicating that the constant speed can be determined by setting the time equal to infinity		1 point
Example: After a long time, the falling object will reach a terminal constant speed in the fluid. This can be determined by setting the time t in the equation for speed equal to infinity. By doing this, the constant speed is determined to be $v = A$.		
<u>Note:</u> Credit given for solving mathematically		

- ii. LO INT-1.H.b, SP 7.A, 7.C
2 points

Determine the force exerted by the fluid on the object at this time. Justify your answer.

For indicating that the net force is equal to zero when the object moves with constant speed		1 point
For indicating the resistive force is equal to the weight of the object at this time		1 point
Example: When the falling object reaches a constant speed in the fluid, the net force must be zero. Because the only vertical forces acting on the object are Earth's gravitational pull and the resistive force of the fluid, these two forces must be equal. So, the resistive force must be equal to the weight of the object or 0.12 N.		
<u>Note:</u> Credit given for solving mathematically		

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Question 1 (continued)

Learning Objectives

CHA-1.B: Determine functions of position, velocity, and acceleration that are consistent with each other, for the motion of an object with a nonuniform acceleration.

CHA-1.C: Describe the motion of an object in terms of the consistency that exists between position and time, velocity and time, and acceleration and time.

INT-1.C.d: Derive an expression for the net force on an object in translational motion.

INT-1.H.b: Describe the acceleration, velocity, or position in relation to time for an object subject to a resistive force (with different initial conditions, i.e., falling from rest or projected vertically).

INT-1.I: Calculate the terminal velocity of an object moving vertically under the influence of a resistive force of a given relationship.

Science Practices

4.D: Select relevant features of a graph to describe a physical situation or solve problems.

6.B: Apply an appropriate law, definition, or mathematical relationship to solve a problem.

6.C: Calculate an unknown quantity with units from known quantities, by selecting and following a logical computational pathway.

7.A: Make a scientific claim.

7.C: Support a claim with evidence from physical representations.

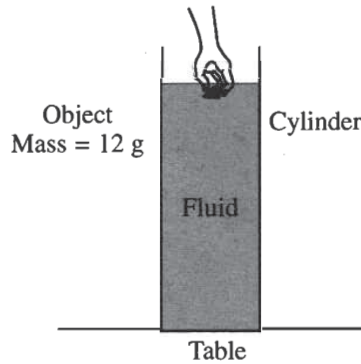
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SECTION II

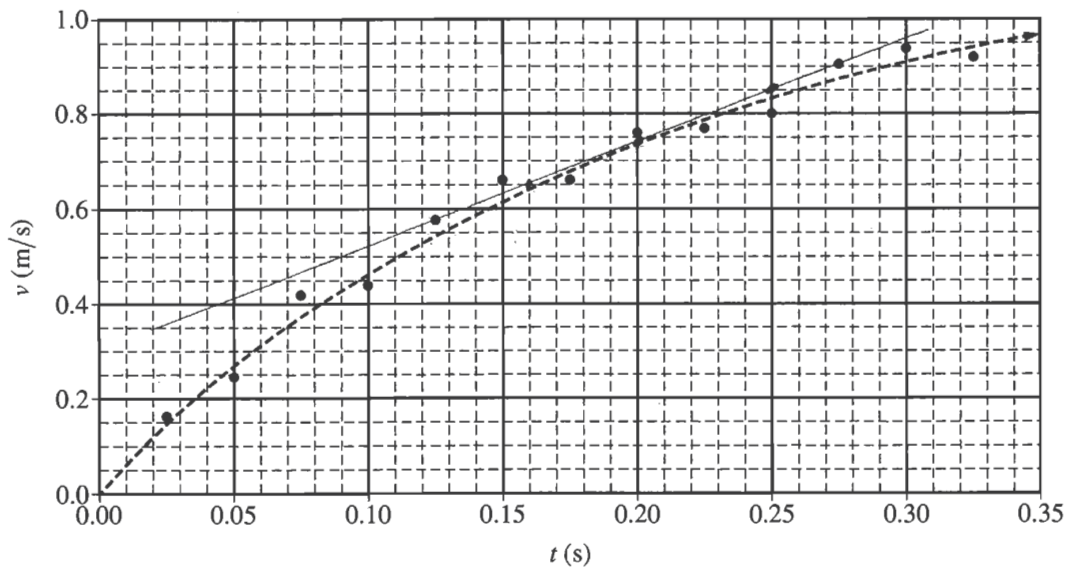
Time—45 minutes

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.



1. In an experiment, students used video analysis to track the motion of an object falling vertically through a fluid in a glass cylinder. The object of $m = 12\text{ g}$ is released from rest at the top of the column of fluid, as shown above. The data for the speed v of the falling object as a function of time t are graphed on the grid below. The dashed curve represents the best fit chosen by the students for these data.



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GO ON TO THE NEXT PAGE.

(a)

- i. Does the speed of the object increase, decrease, or remain the same?

Increase Decrease Remain the same

- ii. In a brief statement, describe the
- direction
- of the object's acceleration and how the
- magnitude
- of this acceleration changed as the object fell.

The acceleration is down. The force of gravity is acting upon the object. The magnitude of the acceleration decreases as the drag force from the fluid counteracts the force of gravity.

- iii. Using the graph, calculate an approximate value for the magnitude of the acceleration of the object at
- $t = 0.20$
- s.

slope of tangent line @ $t = 0.20$ is the magnitude of acceleration @ $t = 0.2$.

$$\text{Slope} \approx \frac{0.85 - 0.65}{0.25 - 0.16} = \frac{0.2}{0.09} = 2.222$$

approx acceleration @ $t = 0.20$ s is 2.22 m/s^2

Question 1 continues on the next page.

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GO ON TO THE NEXT PAGE.

The students use the equation $v = A(1 - e^{-Bt})$ to model the speed of the falling object and find the best fit coefficients to be $A = 1.18$ m/s and $B = 5$ s⁻¹.

(b) Use the above equation to:

- i. Derive an expression for the magnitude of the vertical displacement $y(t)$ of the falling object as a function of time t .

$$v = A(1 - e^{-Bt}) \quad \rightarrow = 1.18 \int (1 - e^{-5t}) dt$$

$$y(t) = \int A(1 - e^{-Bt}) dt = 1.18 \left(t - \frac{1}{5} e^{-5t} \right) + C$$

$$= 1.18t + \frac{1.18}{5} e^{-5t} + C$$

$$y(0) = 0 \quad y(t) = 1.18t + \frac{1.18}{5} e^{-5t}$$

- ii. Derive an expression for the magnitude of the net force $F(t)$ exerted on the object as it falls through the fluid as a function of time t .

$$F = ma \quad m = 12 \text{ g} \quad F(t) = 70.8 e^{-5t}$$

$$a = \frac{dv}{dt} = AB e^{-Bt}$$

$$F(t) = 12(1.18)(5) e^{-5t}$$

The students repeat the experiment with a taller glass cylinder that is filled with the same fluid. The cylinder is tall enough so that the object reaches a constant speed.

(c)

- i. Determine the constant speed of the object.

$$\text{constant speed} = 1.18 \text{ m/s}$$

Justify your answer.

$$\lim_{t \rightarrow \infty} 1.18(1 - e^{-5t}) = 1.18$$

- ii. Determine the force exerted by the fluid on the object at this time.

$$g = 10 \text{ m/s}^2 \quad \text{Force by fluid} = 12(10) = 120 \text{ N}$$

Justify your answer.

Since it is in equilibrium, the gravitational force equals the drag force by the fluid.

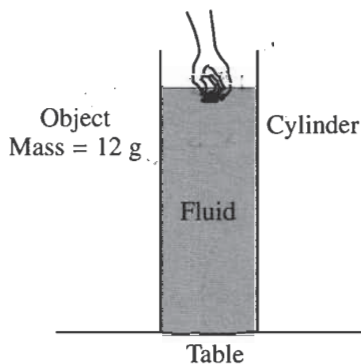
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SECTION II

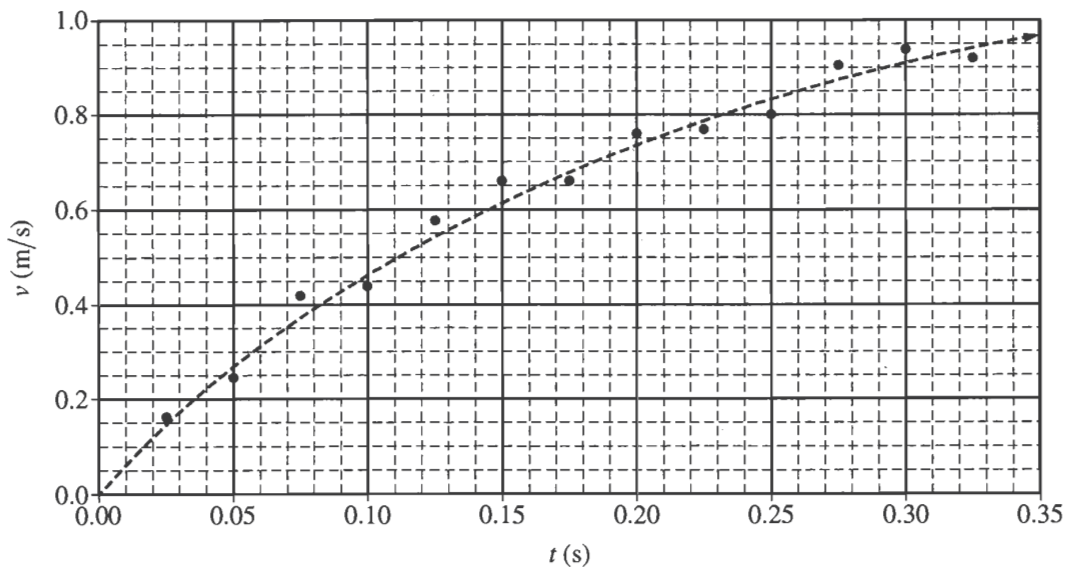
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3 Questions

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GO ON TO THE NEXT PAGE.

(a)

- i. Does the speed of the object increase, decrease, or remain the same?

Increase Decrease Remain the same

- ii. In a brief statement, describe the direction of the object's acceleration and how the magnitude of this acceleration changed as the object fell.

The object's acceleration is directed down and the magnitude of the acceleration decreased as the object fell.

- iii. Using the graph, calculate an approximate value for the magnitude of the acceleration of the object at
- $t = 0.20$
- s.

$$a \approx \text{slope} = \frac{.85 - .65}{.25 - .15} = \frac{.15}{.1} = 1.5 \text{ m/s}^2$$

Question 1 continues on the next page.

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The students use the equation $v = A(1 - e^{-Bt})$ to model the speed of the falling object and find the best fit coefficients to be $A = 1.18$ m/s and $B = 5$ s⁻¹

(b) Use the above equation to:

- i. Derive an expression for the magnitude of the vertical displacement $y(t)$ of the falling object as a function of time t .

$$\begin{aligned} y(t) &= \int v(t) dt = \int 1.18(1 - e^{-5t}) dt = 1.18 \int (1 - e^{-5t}) dt \\ &= 1.18 \left(t + \frac{1}{5} e^{-5t} \right) \\ y(t) &= 1.18t + .236 e^{-5t} \end{aligned}$$

- ii. Derive an expression for the magnitude of the net force $F(t)$ exerted on the object as it falls through the fluid as a function of time t .

$$\begin{aligned} F &= ma \\ a(t) &= \frac{dv}{dt} = \frac{d}{dt} [1.18(1 - e^{-5t})] = \frac{d}{dt} [1.18 - 1.18e^{-5t}] = 5.9e^{-5t} \\ F(t) &= ma(t) = .012(5.9e^{-5t}) = .0708e^{-5t} \end{aligned}$$

The students repeat the experiment with a taller glass cylinder that is filled with the same fluid. The cylinder is tall enough so that the object reaches a constant speed.

(c)

- i. Determine the constant speed of the object.
constant speed $\rightarrow F=0$

Justify your answer.

- ii. Determine the force exerted by the fluid on the object at this time.

Zero

Justify your answer.

$F=0$ because a constant speed means no acceleration, and since $F=ma$, $F=0$ when $a=0$.

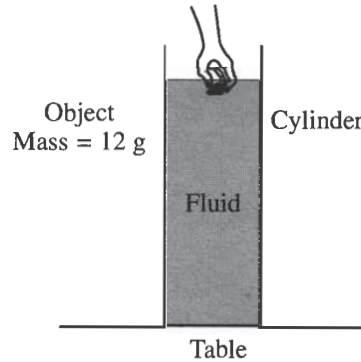
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SECTION II

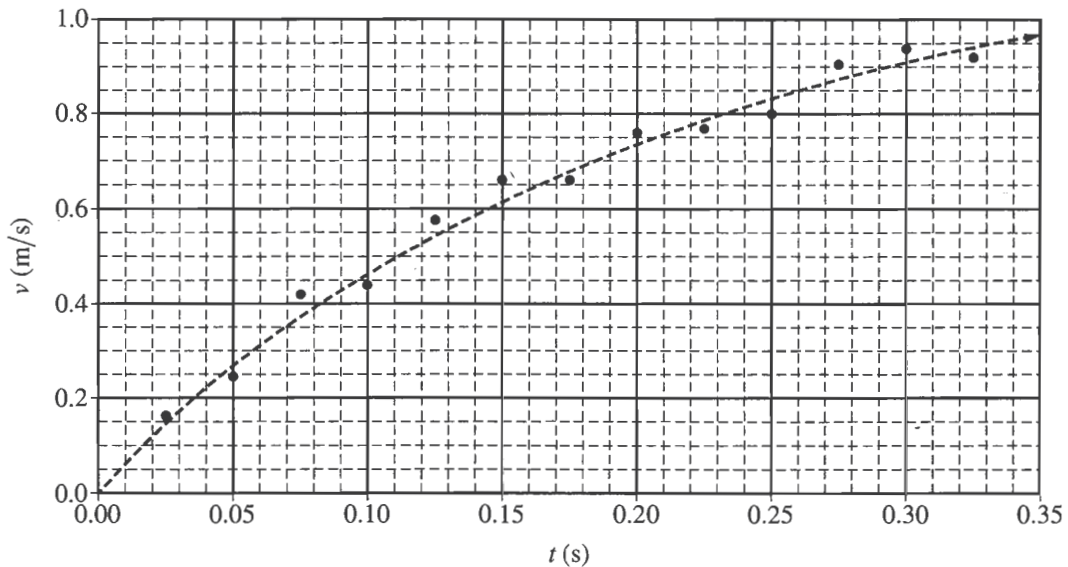
Time—45 minutes

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.



1. In an experiment, students used video analysis to track the motion of an object falling vertically through a fluid in a glass cylinder. The object of $m = 12\text{ g}$ is released from rest at the top of the column of fluid, as shown above. The data for the speed v of the falling object as a function of time t are graphed on the grid below. The dashed curve represents the best fit chosen by the students for these data.



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GO ON TO THE NEXT PAGE.

(a)

- i. Does the speed of the object increase, decrease, or remain the same?

Increase Decrease Remain the same

- ii. In a brief statement, describe the direction of the object's acceleration and how the magnitude of this acceleration changed as the object fell.

The direction of the object's acceleration is down. The magnitude of the acceleration gets smaller as the object falls.

- iii. Using the graph, calculate an approximate value for the magnitude of the acceleration of the object at $t = 0.20$ s.

$$\frac{.74}{.2} = 3.7 \text{ m/s}^2$$

Question 1 continues on the next page.

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GO ON TO THE NEXT PAGE.

The students use the equation $v = A(1 - e^{-Bt})$ to model the speed of the falling object and find the best fit coefficients to be $A = 1.18 \text{ m/s}$ and $B = 5 \text{ s}^{-1}$.

(b) Use the above equation to:

- i. Derive an expression for the magnitude of the vertical displacement $y(t)$ of the falling object as a function of time t .

$$v = A - (Ae^{-Bt})$$

$$d = \frac{1}{2} A^2 t - \frac{1}{2} A e^{-2Bt}$$

- ii. Derive an expression for the magnitude of the net force $F(t)$ exerted on the object as it falls through the fluid as a function of time t .

$$v = A - (Ae^{-Bt})$$

$$a = 1 - (-Bt)(Ae^{-Bt-1})$$

$$a = 1 + B + Ae^{-Bt-1}$$

$$\bar{F} = (0.12) (1 + B + Ae^{-Bt-1})$$

The students repeat the experiment with a taller glass cylinder that is filled with the same fluid. The cylinder is tall enough so that the object reaches a constant speed.

(c)

- i. Determine the constant speed of the object.

$$1 \text{ m/s}$$

Justify your answer.

Drag force

- ii. Determine the force exerted by the fluid on the object at this time.

$$10 \text{ N}$$

Justify your answer.

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2019 SCORING COMMENTARY

Question 1

Note: Student samples are quoted verbatim and may contain spelling and grammatical errors.

Overview

The responses to this question were expected to demonstrate the following:

- An understanding and interpretation of a nonlinear velocity vs. time graph, determining features that demonstrate the speed and acceleration at various times for an object subject to a resistive force
- Determination of displacement and acceleration functions from a given velocity function for an object subject to a resistive force
- Description of the net force on an object subject to a resistive force
- Determination of terminal velocity from a given velocity function for an object subject to a resistive force

Sample: M Q1 A

Score: 14

In part (a)(i) 1 point was earned for selecting “Increase.” In part (a)(ii) 2 points were earned for a description that includes that the direction of the acceleration is “Down” and that there is a decrease in the magnitude of the acceleration. In part (a)(iii) 2 points were earned for calculating the slope of a trend line at $t = 2.0$ s with a correct answer using points from a tangent line. In part (b)(i) the vertical displacement is indicated to be equal to the integration of the velocity equation, and a constant of integration in the integration is used, but a correct final answer is not derived, so 2 points were earned. In part (b)(ii) 3 points were earned for attempting to find acceleration by taking the derivative of the velocity equation provided, a correctly derived equation for the acceleration, and for multiplying the acceleration equation found by the mass of the object to obtain the force. In part (c)(i) 2 points were earned for stating the constant speed is “A” (1.18 m/s) from the velocity equation provided and indicating that the constant speed can be determined by setting the time equal to infinity. In part (c)(ii) 2 points were earned for indicating that the net force is equal to zero when the object moves with constant speed and that the resistive force is equal to the weight of the object at this time.

Sample: M Q1 B

Score: 9

Parts (a)(i), (a)(ii), and (b)(ii) received full credit, 1, 2, and 3 points, respectively. In part (a)(iii) the slope of a trend line at $t = 2.0$ s is calculated, but points from a tangent line are not used to calculate the slope, so 1 point was earned. In part (b)(i) the vertical displacement is indicated to be equal to the integration of the velocity equation, but the limits of integration are not correct, and a correct constant of integration is not indicated, so 1 point was earned. In part (c)(i) no points were earned because speed for the object is not included, and an incorrect justification is given. In part (c)(ii) it is indicated that the net force is equal to zero when the object moves with constant speed, but it is also stated that the resistive force is equal to 0 N, so 1 point was earned.

Sample: M Q1 C

Score: 4

Parts (a)(i) and (a)(ii) earned full credit, 1 and 2 points, respectively. In part (a)(iii) no points were earned because the slope of a trend line at $t = 2.0$ s is not calculated. In part (b)(i) the integral of the velocity equation provided is not taken, so no points were earned. In part (b)(ii) the indicated equation for acceleration is multiplied by the mass of the object to obtain the force, but there is no indication that the acceleration could be found by taking the derivative of the velocity equation provided, and the equation for the acceleration shown is not derived, so 1 point was earned. In (c)(i) a speed for the object is not included, and the justification used is incorrect, so no points

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Question 1 (continued)

were earned. In (c)(ii) an incorrect statement is given such that the resistive force is equal to 10 N with no justification, so no points were earned.