Begin your response to **QUESTION 2** on this page.

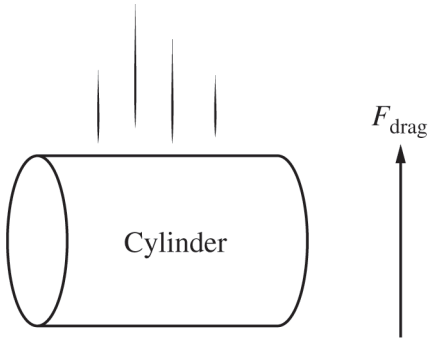

Figure 1

2. A student drops a cylinder of mass m from rest. The air exerts a drag force of magnitude F_{drag} on the cylinder, as shown in Figure 1. The student models the magnitude of the drag force as $F_{drag} = bv^2$, where v is the speed of the cylinder and b is a positive constant with appropriate units.

   (a) **Derive**, but do NOT solve, a differential equation that could be used to determine the speed v of the cylinder as a function of time t. Express your answer in terms of given quantities and physical constants, as appropriate.

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Continue your response to **QUESTION 2** on this page.

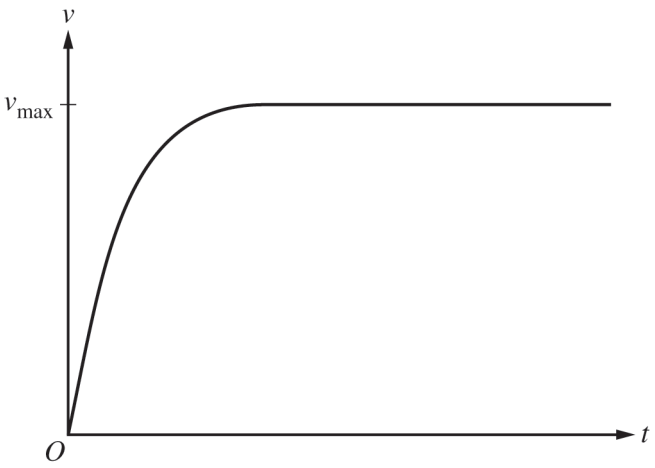

Figure 2

(b) The student correctly sketches the speed v of the cylinder as a function of time t, as shown in Figure 2.

i. **Draw** a vertical line on the sketch in Figure 2 to indicate the earliest time at which F_{drag} on the cylinder is equal to the magnitude of the weight of the cylinder. Label this time as t_1 on the time axis.

ii. **Justify** the location of t_1. Explicitly reference appropriate features of the sketch in Figure 2.

(c) Rather than dropping the cylinder from rest, the student throws the cylinder upward with a nonzero initial speed. The cylinder is in the same orientation as when the cylinder was previously dropped. The student allows the cylinder to fall toward the ground.

Indicate whether the magnitude of the cylinder's maximum downward speed after being thrown upward would be greater than, less than, or equal to the maximum speed v_{max} in Figure 2.

_____ Greater than _____ Less than _____ Equal to

Briefly **justify** your answer.

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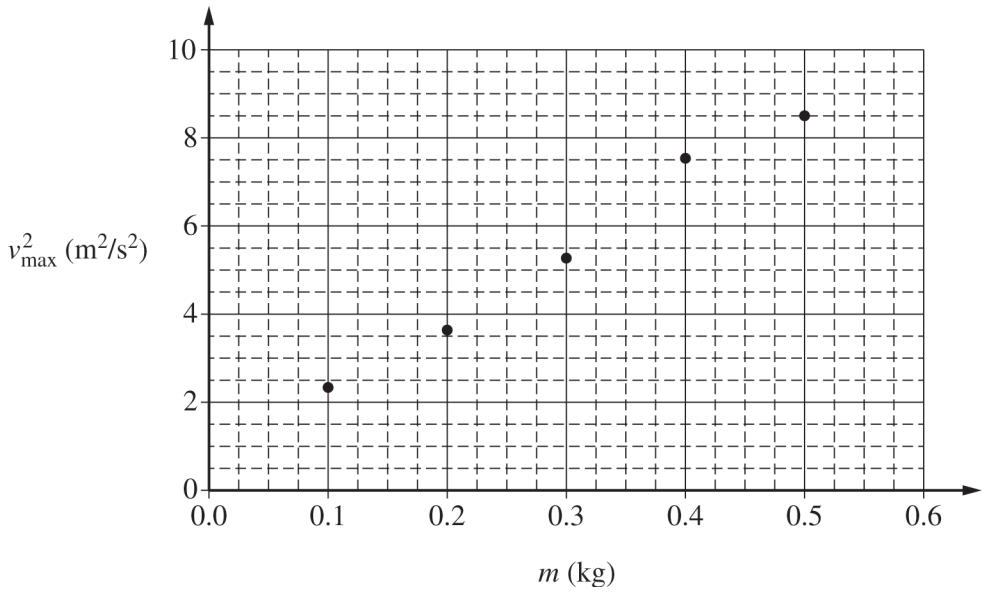
Continue your response to **QUESTION 2** on this page.

(d) The student conducts an experiment to better understand the relationship between maximum speed v_{max} and mass. The student collects data to determine the maximum speed for cylinders dropped from rest, each with the same physical size and shape but a different mass m. The student then graphs v_{max}^2 as a function of mass.



i. **Draw** the best-fit line for the data.

ii. Use the best-fit line to **calculate** an experimental value for b.

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Continue your response to **QUESTION 2** on this page.

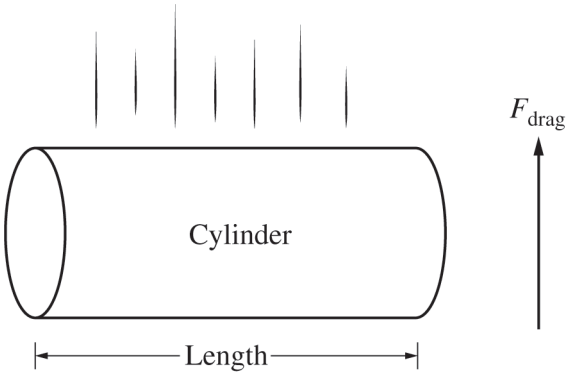

Figure 3

A student claims that the magnitude of the maximum speed of a cylinder dropped from rest depends on the length of the cylinder. The student designs an experiment to collect data that can be used to provide evidence to support the claim. The student drops cylinders with the orientation shown in Figure 3.

(e) The student has access to but does not have to use all of the following equipment.

- Cylinder Set 1: cylinders of the same known length with different known masses
- Cylinder Set 2: cylinders of the same known mass with different known lengths
- A motion detector that can measure velocity as a function of time

i. **Indicate** two quantities that when graphed could be used to determine whether the length of the cylinder affects the maximum speed.

Vertical axis: _____ Horizontal axis: _____

ii. Briefly **describe** how the quantities graphed could be used to determine the relationship between cylinder length and maximum speed.

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Question 2: Free-Response Question — 15 points

(a) For a multi-step derivation that includes Newton's second law of motion **1 point**

For indicating that the net force exerted on the cylinder includes only the gravitational force and a drag force **1 point**

Example Response

$F_{\text{net}} = F_g - F_{\text{drag}}$

For a correct differential equation that is in terms of the given variables **1 point**

Scoring Note: Variables do not have to be separated for this point to be earned.

Example Response

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

Example Solution

$\Sigma F = ma$

$F_g - F_{\text{drag}} = ma_y$

$mg - bv^2 = ma_y$

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

Total for part (a) 3 points

(b)(i) For a vertical line labeled t_1 at the approximate location at which the line becomes horizontal **1 point**

Example Response

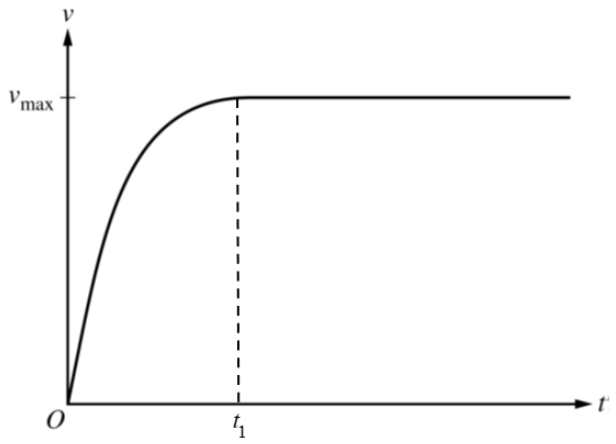

Figure 2

(e)(i)	For indicating that the length of the cylinder should be graphed	**1 point**
	For indicating that the maximum velocity of the cylinder should be graphed	**1 point**
(e)(ii)	For describing how the quantities graphed are related to the conclusions of the experiment	**1 point**

Example Response

The slope of the length vs. maximum velocity graph can be used to determine if length affects terminal velocity.

Total for part (e) 3 points

Total for question 2 15 points