Unit 1 Progress Check: FRQ

1. This question is a long free-response question. Show your work for each part of the question.

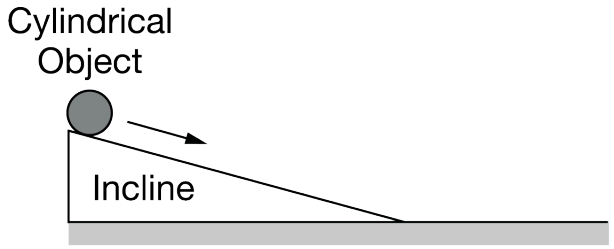

Figure 1

A cylindrical object can roll down an incline, as shown in Figure 1. The incline is slightly less than one meter in length. A group of students wants to determine the acceleration of the object while it is rolling down the incline. The students have access to the following equipment.

- A stopwatch, which can measure time intervals up to $999\ \text{s}$ with a precision of $0.01\ \text{s}$
- A clock, which can measure time intervals up to $12\ \text{hours}$ with a precision of $1\ \text{minute}\ (60\ \text{s})$
- A meterstick, which can measure lengths up to $1\ \text{m}$ with a precision of $1\ \text{mm}$
- A pair of calipers, which can measure lengths up to $10\ \text{cm}$ with a precision of $0.05\ \text{mm}$

(a) Assume the object moves with a constant acceleration as it rolls down the incline. Write an equation that includes acceleration and quantities that can be measured or obtained from measurements by using the available equipment in the list.

(b) Design an experimental procedure the students could use to measure the quantities required to determine the acceleration of the object.

In the table below, list the quantities and associated symbols that would be measured in your experiment and the equipment used to measure them. Also list the equipment that would be used to measure each quantity. You do not need to fill in every row. If you need additional rows, you may add them to the space just below the table.

Quantity to be Measured	Symbol for Quantity	Equipment for Measurement

Describe the overall procedure to be used, referring to the table. Provide enough detail so that another student could replicate the experiment, including any steps necessary to reduce experimental uncertainty. As needed, use

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the symbols defined in the table and/or include a simple diagram of the setup.

(c)

i. What quantities could be graphed to yield a straight line that could be used to determine the acceleration of the object? Only indicate quantities that either were measured in part (b) or could be determined from quantities measured in part (b).

_____ Vertical axis
_____ Horizontal axis

ii. How could the graph be used to analyze the data and determine the acceleration?

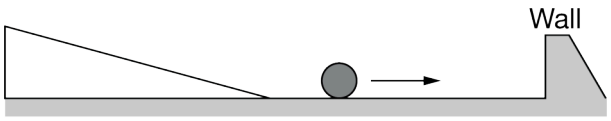

Figure 2a



Figure 2b

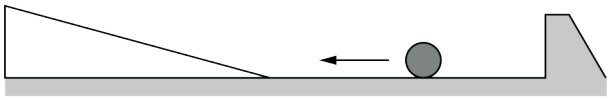

Figure 2c

(d) After rolling down the incline, the cylindrical object rolls across a horizontal surface, as shown in Figure 2a. The object then hits a vertical wall (Figure 2b) and bounces off the wall with the same speed it had before hitting the wall (Figure 2c). Note that during the bounce the object is in contact with the wall for a time interval that is very small, but not zero.

i. On the dot below, which represents the object during the time it is in contact with the wall, draw an arrow showing the direction of the object's acceleration during the bounce.



ii. During the time the object is in contact with the wall, is the magnitude of the acceleration greater than, less than, or the same as it was while it was rolling down the ramp?

Briefly explain your reasoning.

Part (a)

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

Note: The second point can be earned in part (b).

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0	1	2 ✓

Student response accurately includes both of the following criteria.

- ☐ 1 point is earned for a valid equation that includes acceleration and is conceptually relevant to the procedure described in part (b).
- ☐ 1 point is earned for stating or implying that the initial speed of the object is zero when released from rest at the top of the incline.

Example Response:

$x = \frac{1}{2}a_x t^2$

Part (b)

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2	3	4 ✓

Student response accurately includes all of the following criteria.

- ☐ 1 point is earned for listing relevant/appropriate equipment that matches the measured quantities.
- ☐ 1 point is earned for a plausible/practical way to directly or indirectly determine acceleration of the object.
- ☐ 1 point is earned for measuring the position of the object at equal time intervals.
- ☐ 1 point is earned for attempting to reduce uncertainty with multiple trials/by rolling the object multiple times.

Example Response 1:

Mark the position of the object in equal time intervals, as measured by a stopwatch, as it rolls down the incline. Measure the position of the marks using the meter stick. Repeat this procedure for three trials.

Example Response 2:
1. Mark a starting point near the top of the incline where the cylinder is to be released from rest.
2. Use the meter stick to mark off distances of $30\ \text{cm}$, $60\ \text{cm}$, and $100\ \text{cm}$ from the starting point.
3. Use the stopwatch to time how long it takes the cylinder to reach the $30\ \text{cm}$ mark after it is released from rest at the starting point.
4. Repeat step 3 for a total of 3 trials.
5. Repeat steps 3 and 4 for the $60\ \text{cm}$ and $100\ \text{cm}$ marks, with a total of 3 trials for each mark.

Part (c)i

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Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1 ✓

Student response accurately includes the following criteria.

- ☐ 1 point can be earned for choosing appropriate quantities that are related to position and time that will produce a graph that is a straight line.

Example Responses:

x and t^2

x and $\frac{1}{2}t^2$

$2x$ and t^2

$\sqrt{x}$ and t

Part (c)ii

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2 ✓

Student response accurately includes both of the following criteria.

- ☐ 1 point is earned for indicating that acceleration could be determined from the slope of the line in a graph of the quantities indicated in part (c)(i).
- ☐ 1 point is earned for correctly indicating how acceleration could be determined from the slope of the line in a graph of the quantities indicated in part (c)(i).

Example Responses:

x and t^2: Slope = $\frac{1}{2}a$, so the acceleration is twice the slope.

x and $\frac{1}{2}t^2$: Slope = a so the acceleration is equal to the slope.

$2x$ and t^2: Slope = a, so the acceleration is equal to the slope.

$\sqrt{x}$ and t: Slope = $\sqrt{\frac{a}{2}}$ so the acceleration is $2 \times (\text{slope})^2$.

Part (d)i

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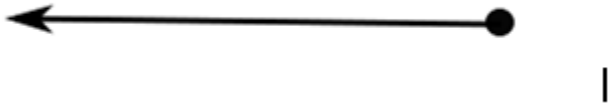
Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1 ✓

Student response accurately includes the following criteria.

- ☐ 1 point is earned for drawing an arrow to the left.

Example Response:



Part (d)ii

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

Correct answer: “Greater than”

0	1	2 ✓

Student response accurately includes both of the following criteria.

Correct answer: “Greater than”

- ☐ 1 point is earned for stating that the time of contact is less than the time it took for the object to roll down the ramp.
- ☐ 1 point is earned for a statement that relates the acceleration to the time interval.

Example Response:

Acceleration a is given by the expression $\frac{\Delta v}{\Delta t}$, where Δv is the change in velocity and Alt Text: delta t is the time interval for the change in velocity.

When the ball is released from rest at the top of the incline, Δv represents the change in the object’s speed from the top of the incline to the bottom of the incline. This change in speed takes place over a time interval Δt . When the ball collides with the wall, the object’s change in speed is twice as much as in the first scenario, and the time interval in which the change in speed occurs is much shorter than when the object is released from the top of the incline. Therefore, the acceleration is greatest for the case in which the object bounces off of the wall.

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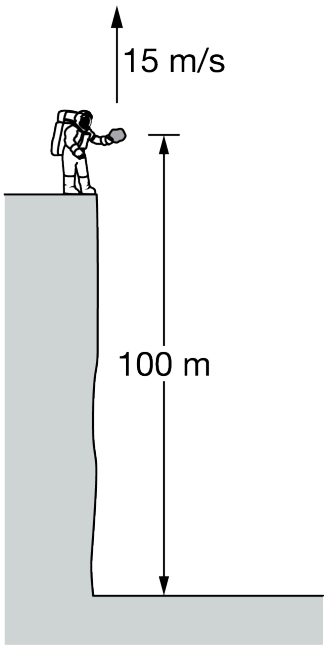
2. This question is a short free-response question. Show your work for each part of the question.



An astronaut holds a rock $100\ \text{m}$ above the surface of Planet X. The rock is then thrown upward with a speed of $15\ \text{m/s}$, as shown in the figure. The rock reaches the ground $10\ \text{s}$ after it is thrown. The atmosphere of Planet X has a negligible effect on the rock when it is in free fall.

(a)

(i) Determine the acceleration due to gravity of the rock when it is on Planet X.

ii. How does the speed of the rock when it reaches the ground v_d compare to the speed of the rock when it is thrown upward v_u?

_____$v_d > v_u$ _____$v_d = v_u$ _____$v_d < v_u$

State your reasoning.

(b) A student wants to know how the motion of the rock would be different if it was thrown upward at $15\ \text{m/s}$ from a height of $100\ \text{m}$ above Earth's surface. In a clear, coherent, paragraph-length response that may also contain figures and/or equations, explain how the motion of the rock on Earth will be different from its motion on Planet X in terms of its maximum height above the ground, the speed at which it reaches the ground, the time in which it is in free fall, and its acceleration due to gravity.

Part (a)i

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

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0	1 ✓

Student response accurately includes the following criteria.

- ☐ 1 point is earned for a correct substitution of the known quantities into an appropriate kinematic equation or pair of equations that can be used to solve for the acceleration due to gravity on Planet X.

Example Response:

$y = y_0 + v_{0y}t + \frac{1}{2}a_y t^2$

$a_y = \frac{2(y - y_0 - v_{0y}t)}{t^2}$

$a_x = \frac{2(0\,\text{m} - 100\,\text{m} - (15\,\text{m/s})(10\,\text{s}))}{(10\,\text{s})^2} = 5\,\text{m/s}^2$

Part (a)ii

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

Correct Answer: $v_d > v_u$

Note: No credit for answer without explanation.

0	1 ✓

Student response does not accurately include the following criteria.

- ☐ 1 point is earned for a correct explanation.

Example Response:

Correct Answer: $v_d > v_u$

Note: No credit for answer without explanation.

When the rock is thrown upward, it will eventually reach its maximum height above the ground. As it falls back down to the ground its speed at the same vertical height at which it was thrown will be $15\,\text{m/s}$. Since the rock continues to fall $100\,\text{m}$ below its initial vertical position, the rock's speed will increase above its initial speed of $15\,\text{m/s}$.

Part (b)

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

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0	1	2	3	4	5 ✓

Student response accurately includes all of the following criteria.

- ☐ 1 point is earned for indicating that the acceleration due to gravity for the rock is greater on Earth than on Planet X.
- ☐ 1 point is earned for indicating that the time that the rock is in free fall on Earth is less than that on Planet X.
- ☐ 1 point is earned for indicating that the maximum distance above the ground of the rock on Earth is less than that on Planet X.
- ☐ 1 point is earned for indicating that the speed at which the rock reaches the ground on Earth is greater on Earth than on Planet X.
- ☐ 1 point is earned for a response that has a sufficient paragraph structure, as described in the published requirements for the paragraph-length response.

Example Response:

The acceleration due to gravity for the rock is greater on Earth than on Planet X. Since the acceleration due to gravity is greater on Earth, the time it takes for the rock to reach its maximum height is less on Earth than on Planet X. Therefore, the maximum distance above the ground that the rock attains is less on Earth than on Planet X. This also means that the total time that the rock is in free fall is less on Earth than on Planet X. When the rock is at a position of $100\,\mathrm{m}$ above the surface of Earth and Planet X as it falls toward the ground, $v_y^2 = v_{y0}^2 + 2a_y(y - y_0)$ can be used to show that for the same height above the ground and for the same initial velocity of $15\,\mathrm{m/s}$ downward for the rock at this position, the rock will reach the ground with a greater speed on Earth than it does on Planet X, since $v_y \sim \sqrt{a_y}$.