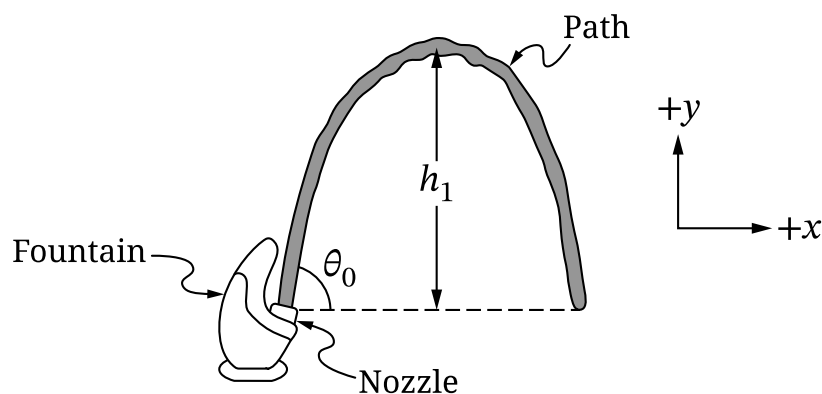


Question 1: Version J

1. Water exits the nozzle of a fountain at an angle θ_0 above the horizontal.

At time $t = 0$, a droplet of water exits the nozzle and follows the path shown in Figure 1. The droplet reaches a maximum height h_1 above the nozzle.

Figure 1



Note: Figure not drawn to scale.

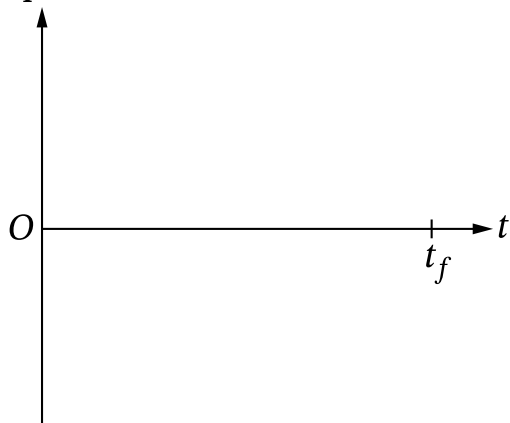
At $t = t_f$, the droplet returns to the same height at which the droplet exited the nozzle.

Part A

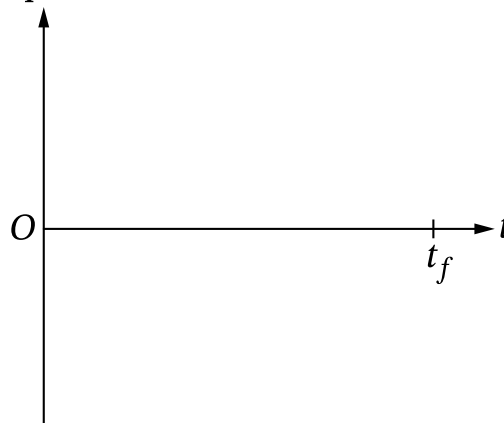
- i. On the axes shown in Figure 2, **sketch** graphs of the horizontal and vertical components of the velocity of the water droplet as functions of t from $t = 0$ to $t = t_f$.

Figure 2

Horizontal
Velocity
Component



Vertical
Velocity
Component



- ii. **Derive** an expression for the speed of the water exiting the nozzle. Express your final answer in terms of θ_0 , h_1 , and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.
- iii. The nozzle has a circular cross-section with radius r_0 . **Derive** an expression for the volume flow rate of the water exiting the nozzle. Express your final answer in terms of θ_0 , h_1 , r_0 , and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.

Part B

The fountain nozzle is replaced with a new nozzle with a radius smaller than r_0 . The water exits the new nozzle at the same angle θ_0 above the horizontal. The volume flow rate of the water exiting the new nozzle is equal to the volume flow rate of the water exiting the original nozzle. A water droplet exiting the new nozzle reaches a maximum height h_2 above the nozzle.

Indicate whether h_2 is greater than, less than, or equal to h_1 by writing one of the following.

- $h_2 > h_1$
- $h_2 < h_1$
- $h_2 = h_1$

Justify your answer. In your justification, include qualitative reasoning beyond mathematical derivations or expressions.

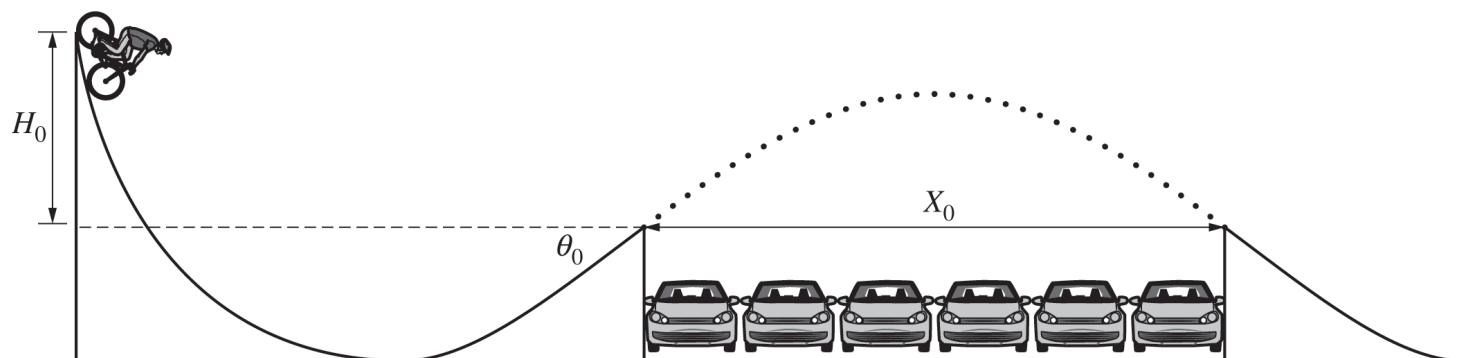
PHYSICS 1

SECTION II

Time—1 hour and 30 minutes

5 Questions

Directions: Questions 1, 4, and 5 are short free-response questions that require about 13 minutes each to answer and are worth 7 points each. Questions 2 and 3 are long free-response questions that require about 25 minutes each to answer and are worth 12 points each. Show your work for each part in the space provided after that part.



Note: Figure not drawn to scale.

1. (7 points, suggested time 13 minutes)

A stunt cyclist builds a ramp that will allow the cyclist to coast down the ramp and jump over several parked cars, as shown above. To test the ramp, the cyclist starts from rest at the top of the ramp, then leaves the ramp, jumps over six cars, and lands on a second ramp.

H_0 is the vertical distance between the top of the first ramp and the launch point.

θ_0 is the angle of the ramp at the launch point from the horizontal.

X_0 is the horizontal distance traveled while the cyclist and bicycle are in the air.

m_0 is the combined mass of the stunt cyclist and bicycle.

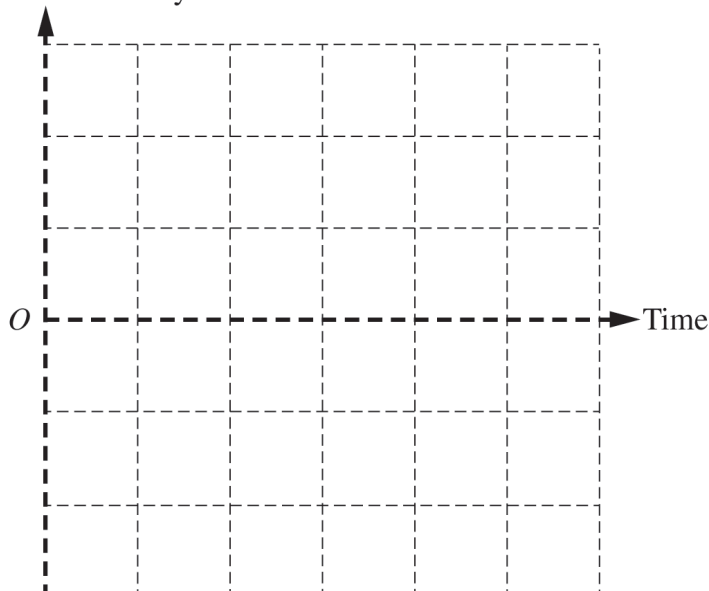
(a) Derive an expression for the distance X_0 in terms of H_0 , θ_0 , m_0 , and physical constants, as appropriate.

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Use a pencil or pen with black or dark blue ink only. Do NOT write your name. Do NOT write outside the box.

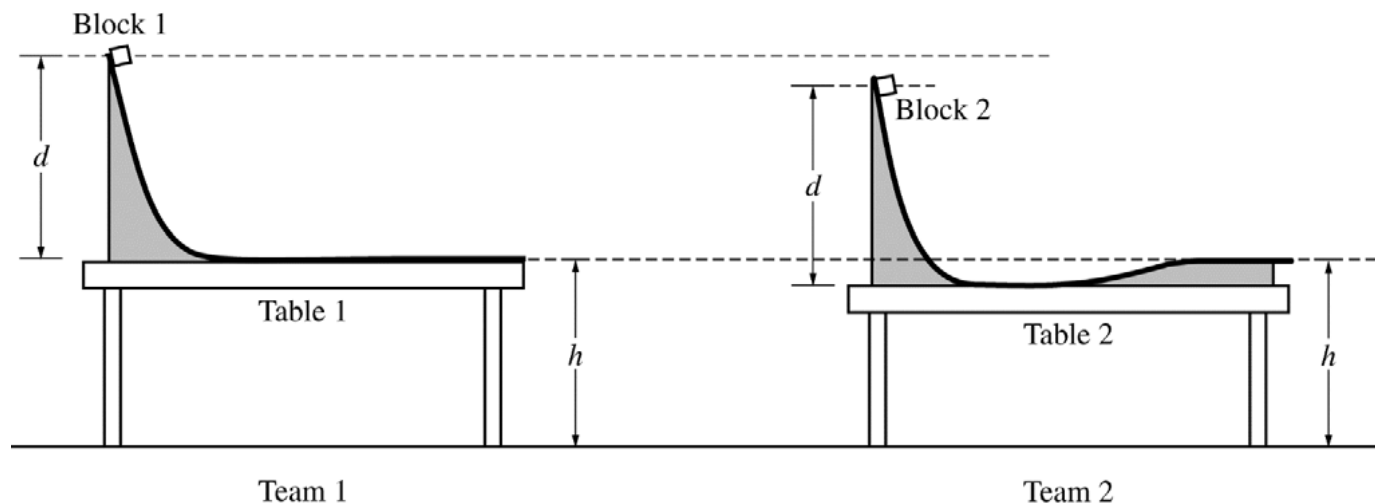
- (b) If the vertical distance between the top of the first ramp and the launch point were $2H_0$ instead of H_0 , with no other changes to the first ramp, what is the maximum number of cars that the stunt cyclist could jump over? Justify your answer, using the expression you derived in part (a).
- (c) On the axes below, sketch a graph of the vertical component of the stunt cyclist's velocity as a function of time from immediately after the cyclist leaves the ramp to immediately before the cyclist lands on the second ramp. On the vertical axis, clearly indicate the initial and final vertical velocity components in terms of H_0 , θ_0 , m_0 , and physical constants, as appropriate. Take the positive direction to be upward.

Vertical Component of
Stunt Cyclist's Velocity



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Use a pencil or pen with black or dark blue ink only. Do NOT write your name. Do NOT write outside the box.



4. (7 points, suggested time 13 minutes)

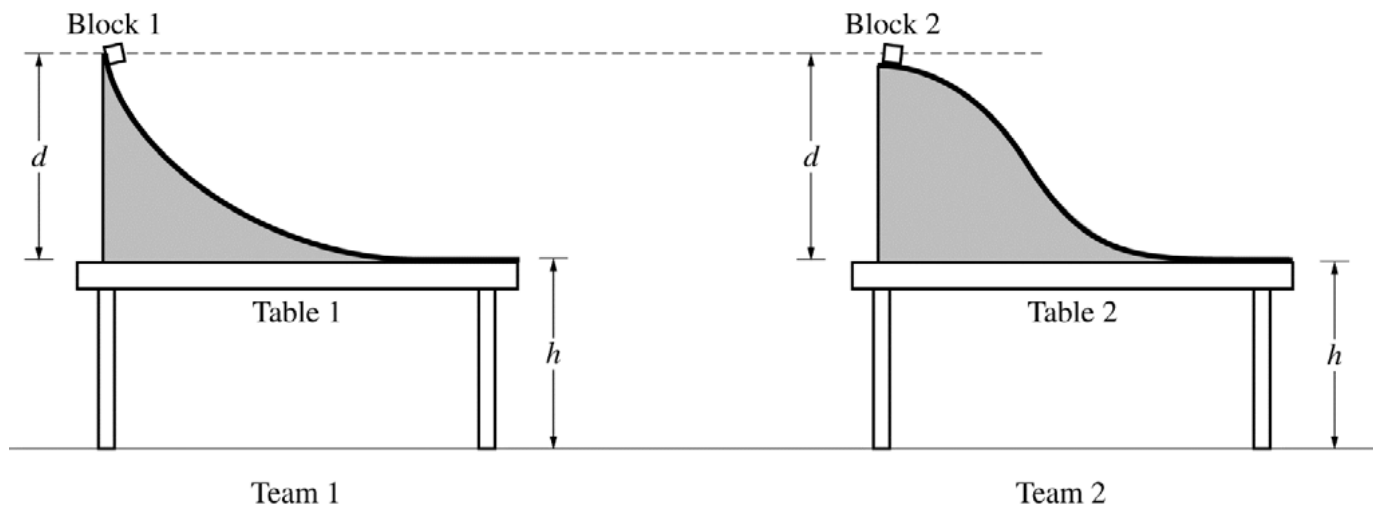
A physics class is asked to design a low-friction slide that will launch a block horizontally from the top of a lab table. Teams 1 and 2 assemble the slides shown above and use identical blocks 1 and 2, respectively. Both slides start at the same height d above the tabletop. However, team 2's table is lower than team 1's table. To compensate for the lower table, team 2 constructs the right end of the slide to rise above the tabletop so that the block leaves the slide horizontally at the same height h above the floor as does team 1's block (see figure above).

- (a) Both blocks are released from rest at the top of their respective slides. Do block 1 and block 2 land the same distance from their respective tables?

☐ Yes ☐ No

Justify your answer.

In another experiment, teams 1 and 2 use tables and low-friction slides with the same height. However, the two slides have different shapes, as shown below.



(b) Both blocks are released from rest at the top of their respective slides at the same time.

i. Which block, if either, lands farther from its respective table?

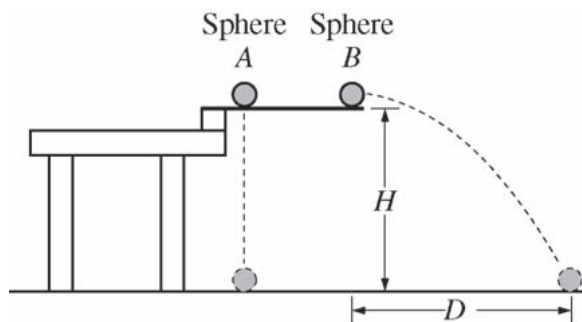
___ Block 1 ___ Block 2 ___ The two blocks land the same distance from their respective tables.

Briefly explain your reasoning without manipulating equations.

ii. Which block, if either, hits the floor first?

___ Block 1 ___ Block 2 ___ The two blocks hit the floor at the same time.

Briefly explain your reasoning without manipulating equations.



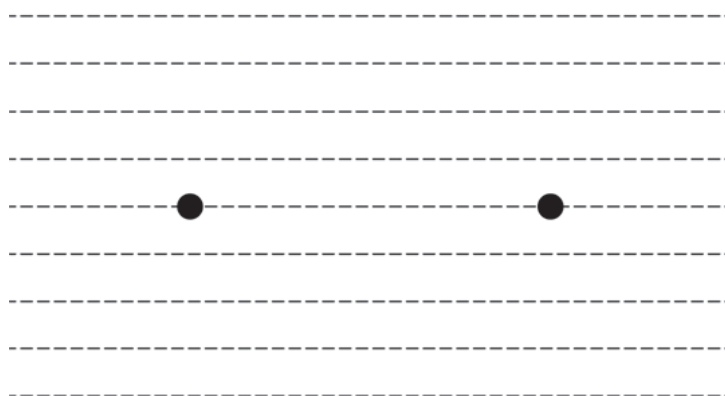
4. (7 points, suggested time 13 minutes)

Two identical spheres are released from a device at time $t = 0$ from the same height H , as shown above. Sphere A has no initial velocity and falls straight down. Sphere B is given an initial horizontal velocity of magnitude v_0 and travels a horizontal distance D before it reaches the ground. The spheres reach the ground at the same time t_f , even though sphere B has more distance to cover before landing. Air resistance is negligible.

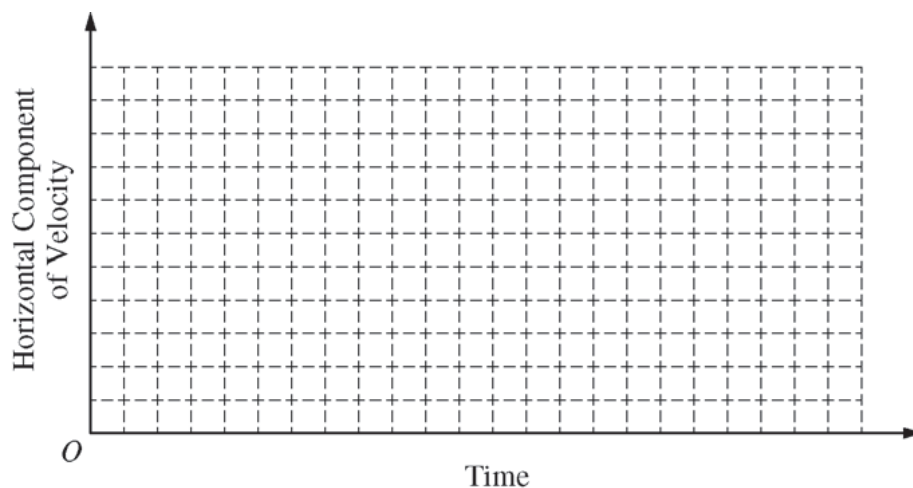
- (a) The dots below represent spheres A and B . Draw a free-body diagram showing and labeling the forces (not components) exerted on each sphere at time $\frac{t_f}{2}$.

Sphere A

Sphere B



- (b) On the axes below, sketch and label a graph of the horizontal component of the velocity of sphere *A* and of sphere *B* as a function of time.



- (c) In a clear, coherent, paragraph-length response, explain why the spheres reach the ground at the same time even though they travel different distances. Include references to your answers to parts (a) and (b).