PhyzLab: Ramp-o-Rama

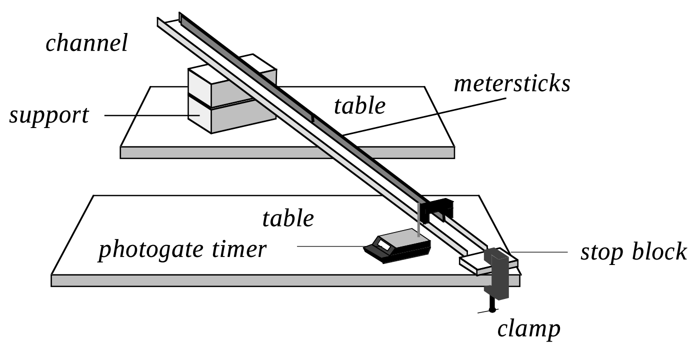
an investigation of motion on an incline

• Purpose •

In this activity, you will determine—through measurements—the nature of what Galileo called “naturally accelerated motion.” Specifically, you will investigate the possible accelerations discussed in the *Free Fall Possibilities* PhyzSpringboard. As you do so, keep in mind that you will be following in Galileo’s groundbreaking work of the Renaissance. His work shattered the 2000-year reign of Aristotle’s physics, challenged the authority Roman Catholic church-state in the midst of the Inquisition, and established the importance of experimentation and demonstration in science.

• Apparatus •

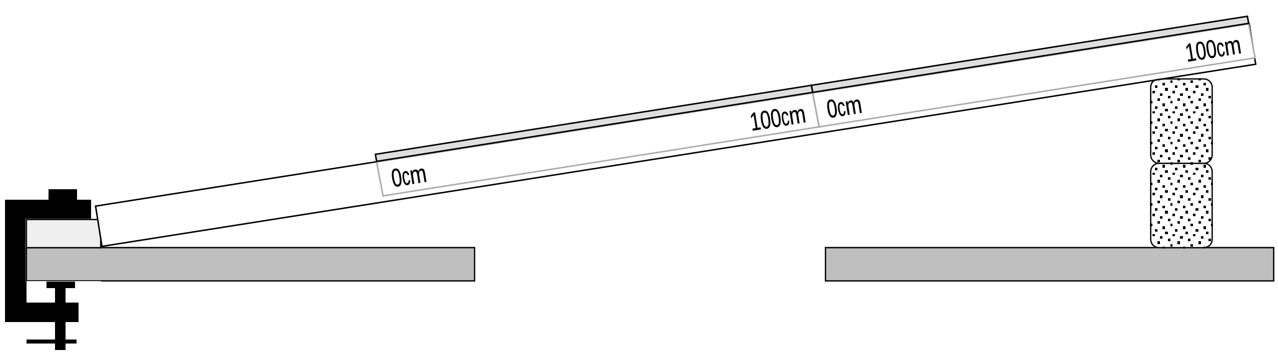
___ ramp (aluminum channel or equivalent)
___ support for incline (bricks, books, etc.)
___ steel ball
___ aluminum ball
___ stop block
___ clamp
___ two tables (or equivalent space)
___ photogate timer: **Mode = PULSE, Resolution = 0.1ms, Memory = ON**
___ auxiliary photogate
___ 2 metersticks or a 2m stick
___ access to adhesive tape



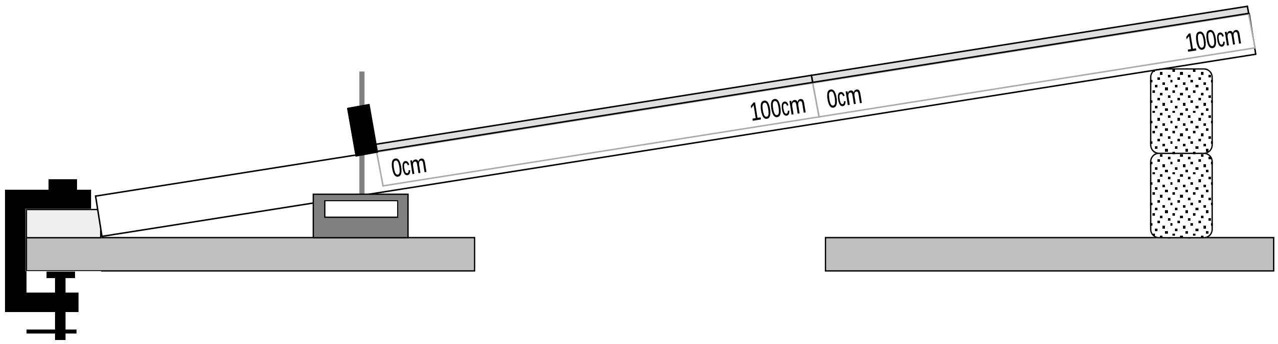
• Initial Set Up •

1. Arrange tables so that the end of one table is near an electrical outlet. This will be the location of the **low** end of the ramp (incline).

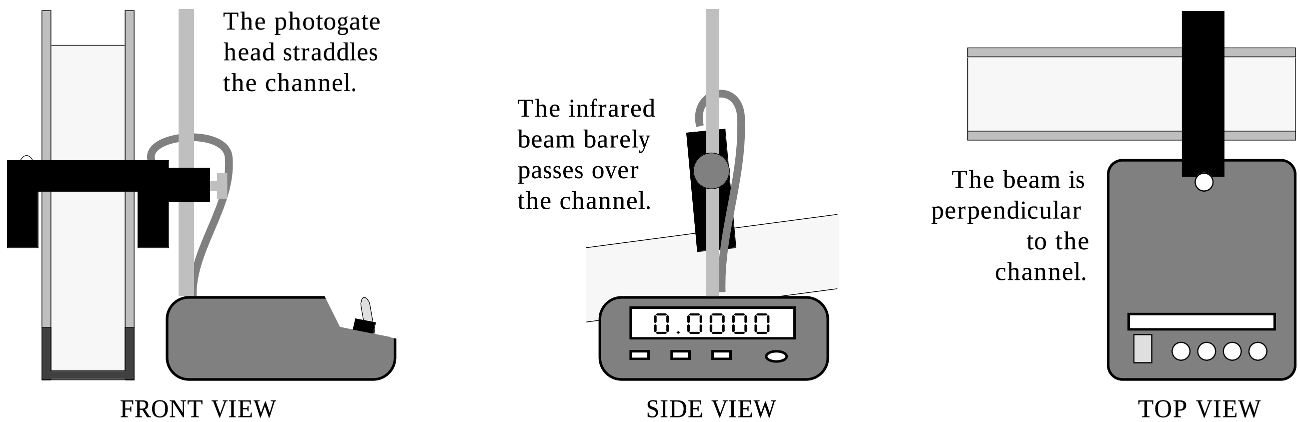
2. Secure the stop block to the table with the clamp. Set the support bricks (or books, etc.) on the other end of the other table.

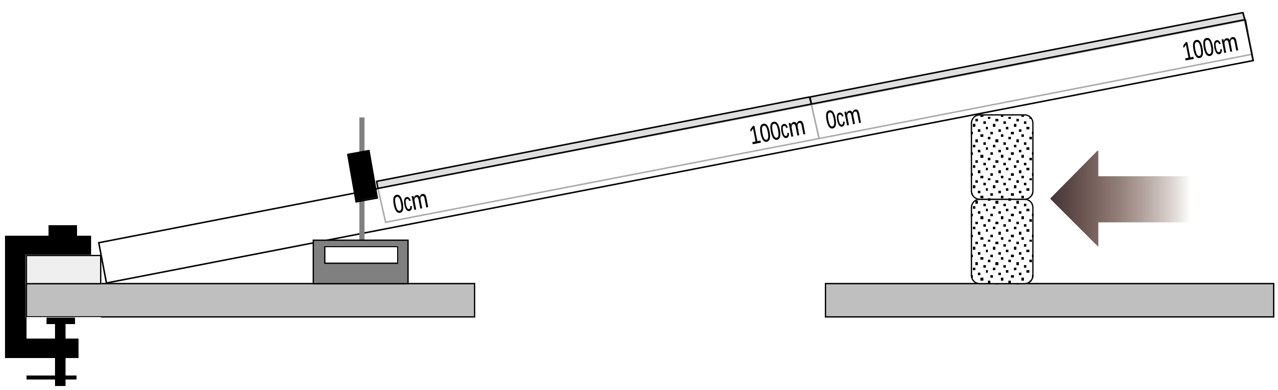


3. Arrange the ramp as shown above. Set the metersticks inside the channel so that they are end to end. The 100cm end of one is at the high end of the incline; the 100cm end of the other is adjacent to the first as shown above. You must be able to see the centimeter scale (not the inch scale). Secure the metersticks in place with adhesive tape.



4. Place the photogate timer near the low end of the incline. The head must straddle the aluminum channel so that the beam passes just in front of the 0cm mark of the lower meterstick. Adjust the position of the photogate head so that it is as low on its support pole as possible.





5. Hold the low end of the incline against the stop block. Slide the support toward the low end to raise the angle of the incline until the infrared beam of the photogate is interrupted by the aluminum channel (**not by the meterstick**). Then slide the support back just enough so that the beam is no longer interrupted. The infrared beam should pass across the channel just in front of the 0cm mark on the lower meterstick.

• Procedure •

In the *PhyzSpringboard: Free Fall Possibilities*, we considered several possibilities for free fall motion. We also considered the use of an inclined plane to make the measurements easier. We will consider the motion possiblilities in the following order.

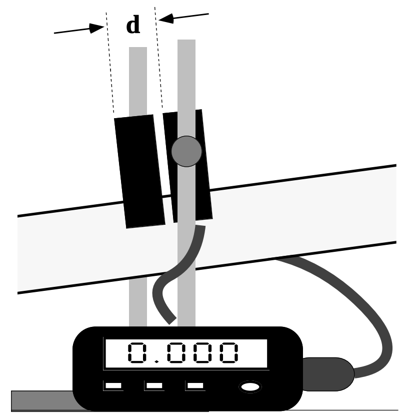
1. Constant Speed that Depends on Weight
2. Speed Increases Proportionally With Distance
3. Speed Increases Proportionally With Time

If none of these possibilities seems correct, we will analyze the data further to determine the nature of the motion.

1. CONSTANT SPEED THAT DEPENDS ON WEIGHT

Hypothesis: A body in free fall moves with constant velocity toward the ground. The speed of the body is in proportion to its weight.

a. Set Up. The measurement technique will involve the use of an auxiliary photogate (one with no timer). Do not change the photogate timer settings. Set the second photogate across the channel directly following the first one. The two photogates must be as close to each other as possible, but no closer than one ball width. Plug the second photogate into the timer (plug it all the way in) and adjust it so that the second photogate beam is nearly broken by the channel (as described in the **Set Up** section above). You will roll the ball from various distances along the incline. The timer will be triggered when the ball passes through the first gate and stopped as the ball passes through the second gate. By knowing the distance between the gates and the time taken by the ball passing from one to the other, the speed of the ball can be determined by the relation v=d/t.



The distance d should be measured as the distance between one side of a photogate and the same side of the other photogate, as shown in the diagram. (Can you figure out why?)

b. Measure photogate separation. Record the distance d between the photogates with your own small ruler. Measure this distance as precisely as possible—it limits the precision of calculated values later in the procedure.

c. Initial Observation. Use the aluminum ball (it's lighter in color and weight). Roll the ball from 50cm above the high photogate, timing its passage through the photogates. **If the ball is drilled, don't let it roll on its holes (this slows it down).** Record the time and calculate the speed. You will need to use the **distance between the photogates—d—that you measured previously**. Allow each member to release the ball for a 50cm descent. Record all photogate (pg) times and calculated speeds; determine the averages.

Aluminum Ball from 50cm

Member					Average
PG Time (s)					
Speed (cm/s)					

d. Hypothetical Predictions. Remember: predictions come **before** observations. ***Base your predictions on the hypothesis described above.***

i. What will the speed of the ball be if allowed to roll from 100cm? How will it compare to the 50cm speed?

ii. What will the speed of a ball with four times the weight be if allowed to roll from 50cm? How will it compare to the aluminum ball's 50cm speed? ***Base predictions on stated hypothesis.***

e. Observations.

i. Roll the ball from 100cm timing its passage through the photogates. Record the time and calculate the speed. Allow each member to release the ball for a 100cm descent. Record all photogate (pg) times and calculated speeds; determine the averages.

Aluminum Ball from 100cm

Member					Average
PG Time (s)					
Speed (cm/s)					

ii. Roll the steel ball (with four times the weight of the aluminum ball) from 50cm timing its passage through the photogates. Record the time and calculate the speed. Allow each member to release the steel ball for a 50cm descent. Record all photogate (pg) times and calculated speeds; determine the averages.

Steel Ball from 50cm

Member					Average
PG Time (s)					
Speed (cm/s)					

f. Percent Difference.

Hypothetical Data if speed is constant for any drop height (roll distance):

Speed v_A after rolling a distance of "1" (50cm): __________________ (record from initial observations)

Speed v_B after rolling a distance of "2" (100cm): __________________ (same value as above)

Percent Difference between **hypothetical** v_A and v_B.

$[\,|v_A - v_B| / (v_A + v_B)\,] \times 200 =$

Actual Data:

Speed v_A after rolling a distance of "1" (50cm): __________________

Speed v_B after rolling a distance of "2" (100cm): __________________

Percent Difference between **actual** v_A and v_B.

$[\,|v_A - v_B| / (v_A + v_B)\,] \times 200 =$

g. Conclusion. If the **actual** data produces the same pattern and is within 15% of the **hypothetical** difference, the hypothesis is considered valid. What is you conclusion about the hypothesis? Write a complete statement indicating the validity or invalidity of the hypothesis, not something like "It was right," or "It was wrong."

h. Percent Difference.

Hypothetical Data if speed proportional to weight:

Speed v_A of ball with a weight of "1" (aluminum): __________________

Speed v_B of ball with a weight of "4" (steel): __________________

Percent Difference between **hypothetical** v_A and v_B.

[$|v_A - v_B| / (v_A + v_B)$] x 200 =

Actual Data:
Speed v_A of ball with a weight of "1" (aluminum): ___________________

Speed v_B of ball with a weight of "4" (steel): ___________________

Percent DIfference between **actual** v_A and v_B.

[$|v_A - v_B| / (v_A + v_B)$] x 200 =

g. Conclusion. If the **actual** data produces the same pattern and is within 15% of the **hypothetical** difference, the hypothesis is considered valid. What is you conclusion about the hypothesis? Write a complete statement indicating the validity or invalidity of the hypothesis, not something like "It was right," or "It was wrong."

2. SPEED INCREASES PROPORTIONALLY WITH DISTANCE
Hypothesis: A body in free fall undergoes an equal increase in speed for each unit of distance it moves.

a. Roll the steel ball from 40cm timing its passage through the photogates. Record the time and calculate the speed. Allow each member to release the ball for a 40cm descent. Record all photogate (pg) times and calculated speeds; determine the averages.

Steel Ball from 40cm

Member					Average
PG Time (s)					
Speed (cm/s)					

b. Hypothetical Predictions. Remember: predictions come **before** observations. ***Base your predictions on the hypothesis described above.***
i. What will the speed of the ball be if allowed to roll from 80cm? How will it compare to the 40cm speed?

ii. What will the speed of the ball be if allowed to roll from 20cm? How will it compare to the 40cm speed?

c. Observations.
i. Roll the ball from 80cm timing its passage through the photogates. Record the time and calculate the speed. Allow each member to release the ball for a 80m descent. Record all photogate (pg) times and calculated speeds; determine the averages.

Steel Ball from 80cm

Member					Average
PG Time (s)					
Speed (cm/s)					

ii. Roll the ball from 20cm timing its passage through the photogates. Record the time and calculate the speed. Allow each member to release the ball for a 20cm descent. Record all photogate (pg) times and calculated speeds; determine the averages.

Steel Ball from 20cm

Member					Average
PG Time (s)					
Speed (cm/s)					

d. Percent Difference.
Hypothetical Data if speed increases proportionally with distance fallen:

Speed v_A after rolling a distance of "1" (20cm): ___________________

Speed v_B after rolling a distance of "4" (80cm): ___________________

Percent Difference between **hypothetical** v_A and v_B.

$[\,|v_A - v_B| / (v_A + v_B)\,] \times 200 =$

Actual Data:

Speed v_A after rolling a distance of "1" (20cm): ___________________

Speed v_B after rolling a distance of "4" (80cm): ___________________

Percent Difference between **actual** v_A and v_B.

$[\,|v_A - v_B| / (v_A + v_B)\,] \times 200 =$

e. Conclusion. If the **actual** data produces the same pattern and is within 15% of the **hypothetical** difference, the hypothesis is considered valid. What is you conclusion about the hypothesis? Write a complete statement indicating the validity or invalidity of the hypothesis, not something like "It was right," or "It was wrong."

3. SPEED INCREASES PROPORTIONALLY WITH TIME
Hypothesis: A body in free fall undergoes an equal increase in speed during each unit of time it moves.

To test this hypothesis, we must first determine positions along the ramp for which the roll time can be doubled. Then we can measure the speeds attained after 1 unit of time, 2 units of time, and so on.

a. Disconnect the auxiliary photogate from the photogate timer. Switch the resolution to 1ms. The technique you will use is as follows. The zero distance point is the photogate's beam. The meterstick indicates distance from that point. You will hold the ball at a given distance along the incline. Simultaneously release the ball and press the START/STOP button on the photogate timer to activate the timing circuit. When the ball rolls through the photogate, it will break the beam and stop the timer. The display will show the time of the roll.

b. Initial Observation. Roll the ball from 40cm, timing its descent. This is a **one**-person operation. Hold the ball so that its leading edge is aligned with the 40cm mark. Place a finger (from your other hand) on the START/STOP button. As you release the ball, press the START/STOP button. The timer will run until the ball breaks the photogate beam. **If the ball is drilled, don't let it roll on its holes (this slows it down).** Record the time. Allow each member to time a 40cm descent. Record all times and determine the average.

Steel Ball Roll Time from 40cm

Member:					Average
40cm Time (s)					

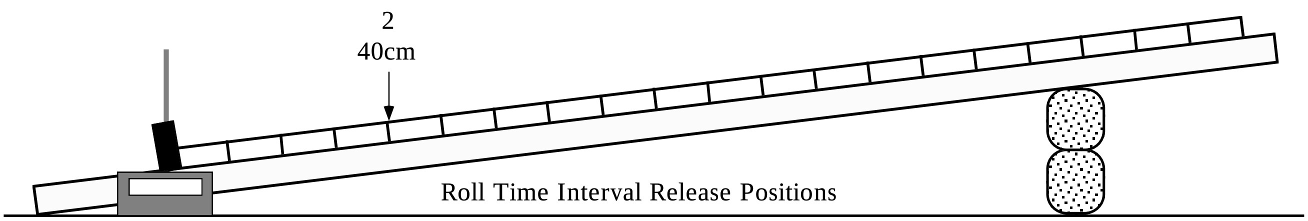
c. Determine and record the distance for which the roll time will be one half what it is from 40cm. Hint: It will be some multiple of 10cm (i.e. 10cm, 20cm, 30cm, etc.) Make sure to run several trials at the distance you believe to be correct.

t = ______________________________ d = ______________________________

d. Determine and record the distance for which the roll time will be twice what it is from 40cm. Hint: It will be some multiple of 10cm (i.e. 10cm, 20cm, 30cm, etc.) Make sure to run several trials at the distance you believe to be correct.

t = ______________________________ d = ______________________________

e. On the diagram below, label the time positions as follows: the 40cm position is "2," the position for half the 40cm roll time is "1," and the position for twice the 40cm roll time is "4."



f. Helpful hints from the ghost of Galileo.
   i. The positions labeled above will work for inclines of any angle. If you need to stop your work and continue another day, your positions will remain correct next time (even if the ramp angle isn't the same).

   ii. Show the instructor your Roll Time Interval Release Positions and convince your instructor that thes are the correct positions. In other words, obtain your instructor's "PhyzBlessing."

g. Reconnect the auxiliary photogate to the photogate timer. Switch the resolution back to 0.1ms.

h. Hypothetical Predictions. Remember: predictions come **before** observations. ***Base your predictions on the hypothesis described above.*** If the speed of the ball is "1" after rolling for a roll time of 1,
   i. what will the speed of the ball be after rolling for a roll time of 2?

   ii. what will the speed of the ball be after rolling for a roll time of 4?

j. Observations
   i. Roll the ball from the roll time 1 position timing its passage through the photogates. Record the time and calculate the speed. Allow each member to release the ball from the roll time 1 position. Record all photogate (pg) times and calculated speeds; determine the averages.

Steel Ball for a Roll Time of 1

Member					Average
PG Time (s)					
Speed (cm/s)					

   ii. Roll the ball from the roll time 2 position timing its passage through the photogates. Record the time and calculate the speed. Allow each member to release the ball from the roll time 2 position. Record all photogate (pg) times and calculated speeds; determine the averages.

Steel Ball for a Roll Time of 2

Member					Average
PG Time (s)					
Speed (cm/s)					

iii. Roll the ball from the roll time 4 position timing its passage through the photogates. Record the time and calculate the speed. Allow each member to release the ball from the roll time 4 position. Record all photogate (pg) times and calculated speeds; determine the averages.

Steel Ball for a Roll Time of 4

Member					Average
PG Time (s)					
Speed (cm/s)					

k. Percent Difference.
Hypothetical data if speed increases proportionally with roll time:

Speed v_A after rolling for a time of "1": __________________

Speed v_B after rolling for a time of "4": __________________

Percent Difference between **hypothetical** v_A and v_B.

$[\,|v_A - v_B| / (v_A + v_B)\,] \times 200 =$

Actual Data:

Speed v_A after rolling for a time of "1": __________________

Speed v_B after rolling for a time of "4": __________________

Percent Difference between **actual** v_A and v_B.

$[\,|v_A - v_B| / (v_A + v_B)\,] \times 200 =$

l. Conclusion. If the **actual** data produces the same pattern and is within 15% of the **hypothetical** difference, the hypothesis is considered valid. What is you conclusion about the hypothesis? Write a complete statement indicating the validity or invalidity of the hypothesis, not something like "It was right," or "It was wrong."

4. SOME OTHER RELATIONSHIP
If ANY of the hypotheses listed above was verified by data collected through experimentation, you have completed the task and may move on to the Post-Lab Questions. If not, consider other possibilities.

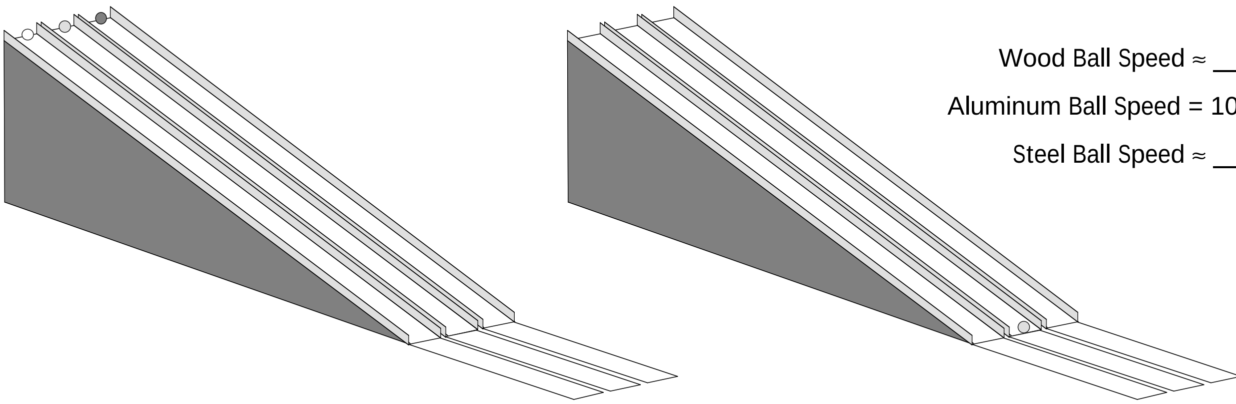
a. $v \propto \sqrt{d}$ b. $v \propto d^2$ c. $v \propto \sqrt{t}$ d. $v \propto t^2$

Which of these is verified by the numerical evidence collected? Show the data and calculations that support your selection on a separate sheet.

• Post-Lab Questions •

Answer the following questions by applying what you learned in the lab. If a hypothesis was verified, apply it; if a hypothesis was rejected, do not apply it. In this section, ignor small differences and experimental error in favor of pure, idealized results.

1. Consider a race between a wood ball, an aluminum ball, and a steel ball. The aluminum ball has four times the weight of the wood ball and one fourth the weight of the steel ball. The balls will roll down ramps inclined at equal angles as shown; they will be released simultaneously from rest. At the instant the aluminum ball reaches the bottom of the incline, its speed is 100cm/s. Based on the relationship you found between weight and speed, draw the position and indicate speeds of the other balls at that instant.

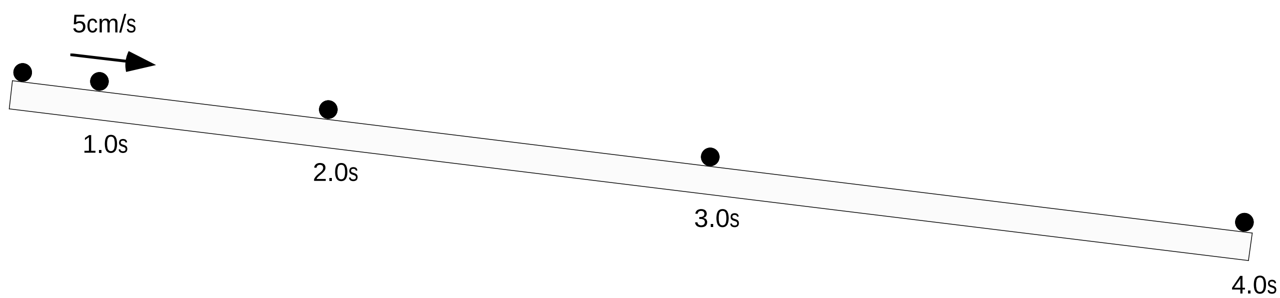


Wood Ball Speed ≈ _______

Aluminum Ball Speed = 100cm/s

Steel Ball Speed ≈ _______

2. The diagram below shows a ball rolling down an incline. Snapshots were taken every 1.0s. Label the speed of the ball at successive 1.0s intervals, assuming the speed at 0.0s is 0cm/s and the speed at 1.0s is 5cm/s.



3. The diagram below shows a ball rolling down an incline. Snapshots were taken every 1.0s. Label the distances shown above and below the incline. The distances above the incline are total distances from the starting point. The distances below the incline indicate incremental distances traveled in successive seconds. Although your data may not have revealed a simple, natural pattern in the distances rolled in successive intervals, one **does** exist. Apply that simple, natural pattern below. Don't forget units on those distance values--they're centimeters!