Chapter 9.9 - Rev.

Report: Average Speed on an Air Table

Question

What is the average speed of a puck crossing a horizontal air table?

Design

The air puck is given an initial push to send it across a horizontal air table. A graph of total distance versus total time is plotted, and analyzed to determine the average speed of the air puck.

controlled variable: slope of air table
independent variable: time elapsed
dependent variable: total distance travelled

Materials

- air table with timer
- 2 air pucks
- air pump
- legal-sized paper

Table 1 **The Travels of an Air Puck**

Dot	Total time (ms)	Total distance (mm)
1	0	0
2		
3		

Procedure

1. To avoid a shock, follow the instructions for holding the air puck and not touching the table. Students with known heart problems should stay away from the table.
2. Turn on the air pump and timer.
3. Set and record the time interval between sparks at 100 ms.
4. Secure one air puck along one edge of the table using a piece of tape. (This air puck has to remain above the carbon paper for the air table to operate properly.)
5. Place a piece of paper on the air table.
6. Set the other air puck in the centre of the table. Adjust the level of the table to stop the puck from drifting.
7. Set this air puck on the edge of the paper.
8. Press the foot pedal down and hold it to start the spark timer.
9. Give the air puck a brief initial push across the paper.
10. Release the spark pedal when the puck reaches the other side of the paper.
11. Remove the paper. If the spark trail is not satisfactory, repeat steps 5 to 10 with new paper.

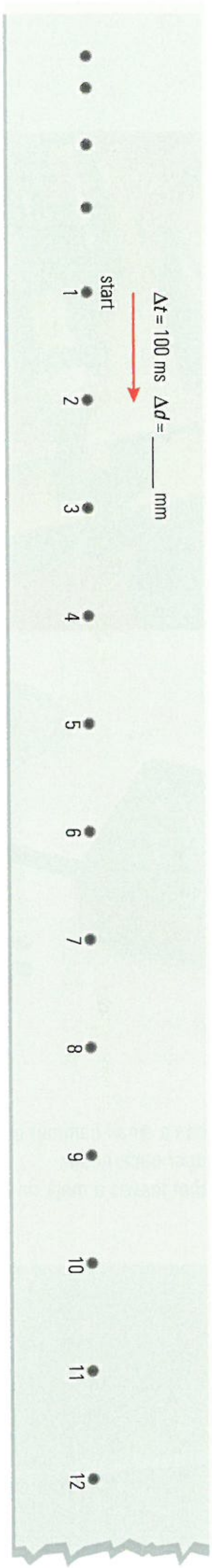

Figure 4
Analyze the results shown on this air table record. The timer is set to make a dot every 100 ms.

Figure 5
Measure from the centre of the first acceptable dot to the centre of each dot.

Analysis and Evaluation

(a) **Figure 4** shows typical results of this (M2) investigation. Starting at the dot (labelled "start") where the dots begin to be about equal distances apart, measure the total distance travelled from the start dot (1) to each subsequent dot (as shown in **Figure 5**).

(b) Why were you instructed to ignore the first few dots?

(c) Record this distance, along with the total elapsed time from the "start" dot, in your table.

(d) Repeat Step (c) for about 10 dots in **Figure 4**.

(e) Draw a total distance versus total elapsed time (V) graph of the evidence gathered.

(f) Calculate the slope of the best-fit straight line to determine the average speed of the puck in metres per second.

(g) Based on your graph, describe the motion of the air puck.

(h) How can information about the size of (O2) experimental uncertainties or errors be obtained from your graph?

(i) Evaluate the design.

Understanding Concepts

1. What are two features of the air table that make it useful in studying motion over short distances?
2. If the air table is not completely horizontal, what complication arises? How would you notice this on the spark timer tracks?

Exploring

3. Sketch what **Figure 4** might look like if the timer on the air table were set to spark more slowly.

SKILLS HANDBOOK: (M2) Quantitative Evidence (V) Graphing (O2) Evaluating the Evidence

9.10 Investigation

INQUIRY SKILLS MENU

○ Questioning	○ Planning	● Analyzing
○ Hypothesizing	● Conducting	● Evaluating
○ Predicting	● Recording	● Communicating

Determining an Average Speed

A ticker tape timer is the most commonly used technology for recording distances at regular time intervals for objects moving in a straight line (**Figure 1**). As the object attached to the end of the paper tape moves, it pulls the tape through the timer (**Figure 2**). As the tape moves through the timer, dots are recorded at constant time intervals. This method is not as accurate as the air table because the moving tape passing through the timer experiences greater friction than an air puck on the stationary paper of the air table. Another experimental uncertainty is the length of the time interval, which may vary slightly. However, the dot pattern (**Figure 4** on page 371) and the analysis of this pattern (**Figure 5** on page 371) are the same for both air table and ticker tape timer evidence.

The purpose of this investigation is to determine the average speed of an object by using a ticker tape timer, and to evaluate the experimental design, materials, and procedure.

Question

What is the average speed of the object in uniform motion?

Design

Attach a cart to the ticker tape and let it run down a smooth, slightly inclined ramp at a constant speed. Calculate the slope of a graph of distance versus time to determine the average speed of the cart.

controlled variables: cart, ramp
independent variable: time elapsed
dependent variable: total distance travelled

(a) Prepare a table, similar to **Table 1**, in which to record your evidence.

Table 1 **Motion of a Cart**

Dot	Total time (ms)	Total distance (mm)
1	0	0
2		
3		

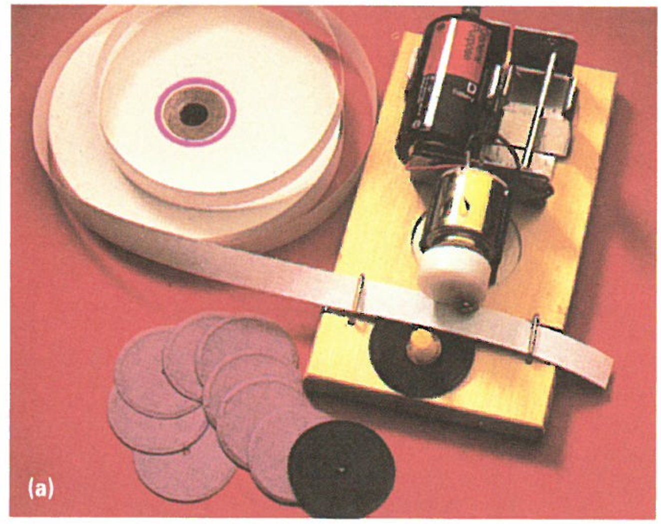

Figure 1
(a) The standard ticker tape timer has a small hammer or chain that strikes the paper tape with a carbon paper underneath.
(b) Newer timers produce a spark that leaves a mark on special paper tape.

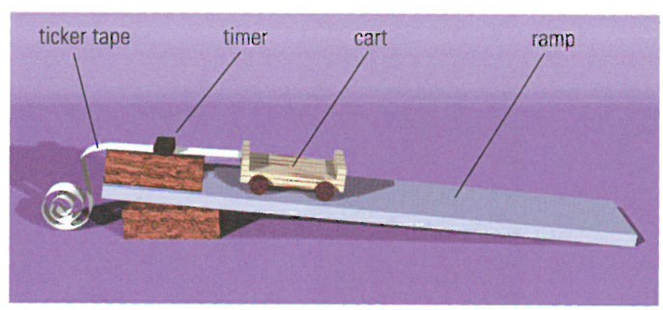

Figure 2
Studying motion with ticker tape timers is a common experiment in physics.

Materials

- ticker tape timer
- roll of tape
- cart
- about 1–2 m smooth board
- small wood blocks or books
- adhesive tape
- (optional) stand and clamps for timer and/or tape roll

Procedure

1 Place the cart at one end of the board and adjust the height of the board until the cart just starts to move.

2 Set up the ticker tape timer at the upper end of the ramp and either hold or clamp it in place.

3 Attach the end of the tape to the cart with a piece of adhesive tape.

4 Do a trial run to make sure that the tape runs smoothly through the timer when the cart is released, and that the cart's speed is about constant.

5 Return the cart to the top of the track, turn on the timer and then immediately release the cart.

6 Turn off the timer and stop the cart when it reaches the end of the ramp.

7 Cut the tape near the timer and remove the tape from the cart.

8 Record the timer setting in milliseconds.

(b) (M2) Starting at the dot where the dots begin to be about equal distances apart, measure the total distance travelled (from the beginning) for each subsequent dot. It may be that only every second or sixth dot is used, as directed by your teacher. Measure the total distance to the nearest half millimetre.

(c) Enter the values of the time and distance measurements into your table. Use about 10 distance measurements.

9 Clean up the laboratory station and dispose of, or recycle, any waste.

Analysis and Evaluation

(V) (d) Draw a total distance versus total elapsed time graph of the evidence gathered.

(e) Calculate the slope of the best-fit straight line to determine the average speed of the cart in metres per second.

(O2) (f) Evaluate the design, procedure, and materials.

(Q) (g) Write a formal lab report for this investigation.

Understanding Concepts

1. The design used in this investigation tried to compensate for the effect of friction. Briefly explain how this was done.
2. Did your cart travel at a constant speed in this investigation? How do you know?
3. Suppose your cart hit a small imperfection such as a knot or groove in the board and you did not notice this when you were doing this investigation. How might this appear on your ticker tape? Describe and explain the appearance of the dots on the tape.
4. Suggest an experimental design for this investigation that would answer the same question using different equipment.

Exploring

5. Repeat the investigation with the ramp at a different angle. Predict how your results will be affected. Carry out the investigation to test your prediction.

Challenge

1 Compare the timing device used in this investigation with those available to Galileo. In what ways can timing devices be compared?

Marilyn Reynolds

Police Constable

Marilyn Reynolds has worked as a police constable for over 14 years with Toronto Police Services. She specializes in collision reconstruction, which involves using the laws of physics to determine the cause of serious accidents.

Even at about five, Marilyn remembers thinking about a police career, but it took time to reach her career destination. After finishing some university work, she completed her police training at the Ontario police training facility in Alymer, Ontario. Then it was on to police patrol duties, which meant responding to radio calls that could be domestic disputes, drug cases, or thefts.

During high school, Marilyn particularly enjoyed mathematics and sciences. She discovered, on the job, that police accident reconstruction allowed her to apply her interests and abilities. After hours, she took specialized courses in accident reconstruction offered at Charles O. Bick College, the Toronto police college.

On a typical work day, Marilyn will visit an accident scene once it is determined that the accident is serious. Initially, she looks for evidence such as skid marks and debris. She inspects each vehicle to match up the contact points with the other involved vehicle(s) to determine how they interacted in the collision. Marilyn relies on a total station, a sophisticated type of survey equipment, to help her evaluate an accident scene.

"My reconstruction team collects all the distance measurements with our total station. The information is collected in a data recorder and then downloaded into the computer. With all the significant distance information, we make a scale diagram of the crash site."

"By analyzing skid marks, we can determine a minimum speed that vehicles were travelling at before the accident. We can also get an approximate speed from the amount of crush that the vehicles have undergone."

The information Marilyn obtains is often used in court, to settle insurance claims, and in accident inquests.

Asked what she most enjoys about her work, Marilyn says, "Figuring out exactly what happened in the accident so that we can help the victim's family cope. The investigation also helps the person who caused the collision to learn from his or her mistake. Our findings might point out the need for a caution sign, a stoplight, or even changes in legislation."

After years of accident reconstruction work, Marilyn concludes that the best way to prevent collisions is to "drive defensively and be courteous to other users of the road."

Making Connections

1. Accident reconstruction is just one area of specialization in police work. Find out about other specialty areas. Which ones apply principles of physics? How?
2. Research local, provincial, and national police career opportunities. What are the educational requirements for entry? What high school courses would help you to meet them?

Work the Web

The Toronto Police Service web site is http://www.torontopolice.on.ca. From the site information, list questions you have about a police career.

Chapter 9 Summary

Key Expectations

Throughout the chapter, you have had opportunities to do the following things:

- Evaluate the costs and benefits, including safety and environmental factors, of transportation technologies. (9.1, 9.4, 9.8)
- Describe and analyze how technology is used to measure objects, obtain scientific knowledge, and to track the motion of traffic. (9.3, 9.4, 9.8, 9.9, 9.10)
- Describe quantitatively and graphically the relationship among average speed, distance and time, and solve simple problems using this relationship. (9.4, 9.5, 9.7)
- Demonstrate the skills required to plan an inquiry into motion, controlling variables, and adapting procedures. (9.4)
- Use a broad range of tools and techniques safely, accurately, and effectively to obtain, organize and analyze distance and motion. (9.4, 9.6, 9.9, 9.10)
- Analyze everyday phenomena and technologies in terms of the motions involved. (9.4, 9.8)
- Conduct and analyze experiments to determine average speed. (9.4, 9.9, 9.10)
- Analyze and evaluate evidence to identify some experimental uncertainties or errors. (9.4, 9.9, 9.10)
- Distinguish among constant, instantaneous, and average speed. (9.5)
- Select and use appropriate vocabulary, SI units, quantity symbols, and graphs to communicate scientific and technological concepts, measurements and analyses. (all)

Key Terms

average speed
certainty
certainty rule
constant speed
defining equation
distance
instantaneous speed
precision
precision rule
quantity symbols
rounding
SI
significant digits
slope of a line
time
uniform motion

Make a Summary

Speed can be described or obtained in a variety of ways. Use the categories listed below to describe or obtain the speed of, for example, a cross-country skier.

- empirical (descriptive) definition in words
- defining equation in symbols
- common units of measure
- graphical representation
- design of an experiment

Reflect on your Learning

Revisit your answers to the Reflect on your Learning questions, page 341, in the Getting Started.

- How has your thinking changed?
- What new questions do you have?

Chapter 9 Review

Understanding Concepts

1. State the number of significant digits in each of the following values.
   (a) 10.2 km
   (b) 0.02 m
   (c) 5.0 cm

2. State, in your own words, the rule for determining the number of digits allowed in an answer calculated by multiplying two measured values.

3. If metres per second, m/s, is the unit of measure of a value,
   (a) what is the defining equation for the value?
   (b) what evidence is collected to calculate the value?
   (c) what labels are on the axes of the graph used to present the evidence?
   (d) what does the slope of this graph yield?

4. Two runners, Tiiu and Laura, compete in a marathon race. In one particular part of the race, Tiiu has twice the average speed of Laura.
   (a) Compare their distances travelled during the same time interval.
   (b) Compare their times required to run the same distance.
   (c) How would their distance-time graphs compare? Sketch the graphs to illustrate your answer.

5. On some major highways, lines were drawn across the highway at regular intervals. Police in an aircraft flew high above the road and monitored the vehicles travelling on the road. If a speeding vehicle was found, police on the ground were notified. What information did the police in the aircraft have to know and measure to determine the speed of a particular car?

6. When designing experiments to measure the speed of an object in a classroom laboratory, what are three different technologies that could be used?

Applying Inquiry Skills

7. Percy Williams is the only Canadian athlete to have ever won gold Olympic medals in both the 100-m and the 200-m sprints. He accomplished this amazing feat in the 1928 Amsterdam Olympics. Calculate the missing quantities in **Table 1**. Show your work.

Table 1 Percy Williams' Gold Medal Performances

Average speed (m/s)	Distance (m)	Time (s)
(a)	100	10.8
9.17	200	(b)

8. In the 1999 World Solar Car Challenge, the Queen's University *Radiance* car came second, completing the 2998.7-km course across Australia in a time of 41.58 h. What was the average speed of the *Radiance* (**Figure 1**)?

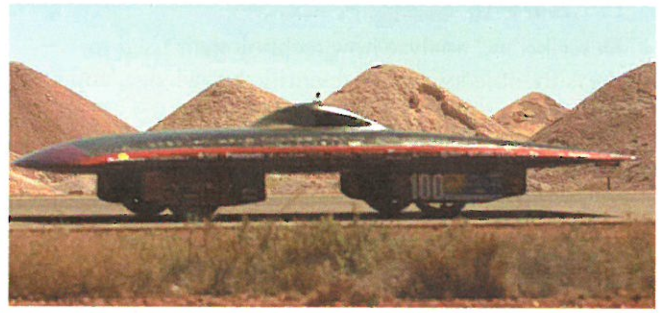

Figure 1

9. A car is moving at a constant 88 km/h when a dog suddenly appears on the road ahead. The driver immediately brakes to avoid hitting the dog.
   (a) Convert 88 km/h into metres per second.
   (b) If the reaction time of the driver is 0.2 s, how far has the car moved by the time the driver just touches the brake pedal?

10. In 1979, Bryan Allen pedalled the *Gossamer Albatross* aircraft 35 km across the English Channel in a time of 169 min (**Figure 2**).
   (a) Calculate the average speed of the aircraft.
   (b) During his famous flight, Allen had to battle a headwind that slowed him down. With no wind, he is capable of pedalling at a constant rate to keep the plane flying at 19 km/h. How long would the crossing have taken flying at 19 km/h?

Figure 2

11. Bill starts jogging down the road and 10 s later his younger brother, Mark, runs after him. The distance–time graph for both Bill (B) and Mark (M) is shown in **Figure 3**. Use the graph to answer the following questions.

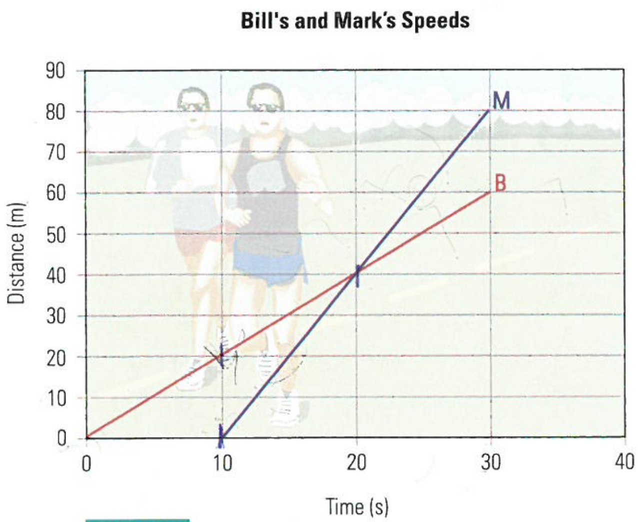

Figure 3

(a) What is Bill's average speed?
(b) What is Mark's average speed, from the time when he starts to run?
(c) At what distance does Mark catch up to Bill?
(d) How far is Mark ahead of Bill at the end of 30 s?

12. Complete the Analysis and Evaluation in the following lab report.

Question
What is Heather's average swimming speed over 50 m?

Design
Several of Heather's teammates are positioned every 10.0 m with stopwatches. All teammates start their stopwatches when Heather dives into the pool and each stops their watch when Heather reaches their assigned distance.

Evidence

Table 2 Heather's Swimming Record

Distance (m)	Time (s)
0.0	0.0
10.0	4.1
20.0	9.9
30.0	15.9
40.0	19.5
50.0	25.2

Analysis and Evaluation
(a) Plot a distance–time graph of Heather's swim.
(b) Calculate the slope of the best-fit straight line and answer the Question.
(c) Evaluate the design. What alternative design would be more efficient?

13. Suppose someone designed the following technology to sell to police forces for monitoring speeding vehicles. A cable, attached to a control box, is placed across a single lane of traffic. When the front wheels of a vehicle cross the cable (**Figure 4**), a timer starts and then stops when the rear wheels of the vehicle cross the cable. The control box calculates the average speed of the vehicle and transmits this information to a nearby police cruiser.

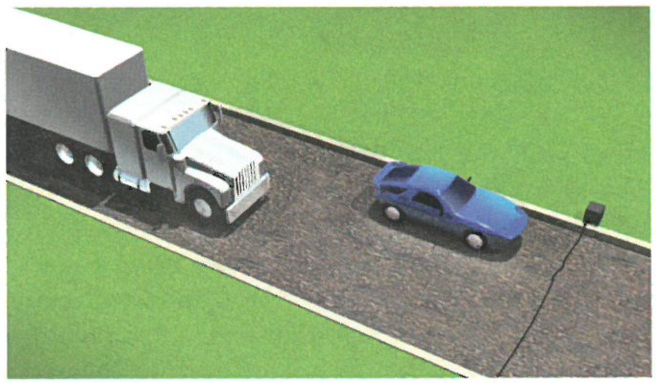

Figure 4

(a) What is the basic flaw in this design?
(b) Suggest a way to fix this design so that it will be accurate.

Making Connections

14. Cell phone technology has developed to the point that good quality units are readily available and affordable.
(a) What is a significant benefit of having a cell phone in a vehicle?
(b) What are some risks created when someone uses a cell phone while driving a vehicle?
(c) It takes about 5.0 s to dial a number on a cell phone. How far would a vehicle travel while the number is being dialed, if the vehicle is moving at a constant speed of 60 km/h?
(d) What can you do to reduce the risks when cell phones are used in vehicles?

15. Dmitri has three alternative means of getting to school: taking the bus, catching a ride in his friend's car, or riding his bike. Each mode of transportation follows a slightly different route from Dmitri's house to his school. The bus travels a distance of 7.5 km at an average speed of 18 km/h; the car travels 6.0 km at 24 km/h, and the bike travels 5.6 km at 16 km/h. Calculate the time each alternative takes. Evaluate each of the three modes of transportation from economic, environmental, health, and social perspectives.

CHAPTER

10 Distance, Speed, and Acceleration

Getting Started

HOW DO YOU KNOW IF YOU ARE MOVING?
This seems like a simple question with an obvious answer. If you are napping on a comfortable sofa or standing at a bus stop, you would say that you are not moving. Perhaps, using physics language, you might say that you are "at rest." You know you are not moving because it does not look as though your fixed surroundings are moving, and you do not feel as though you are moving. In fact, you and everything else on Earth are moving around the Sun at an amazing thirty kilometres per second (30 km/s) (**Figure 1**). Why do we not notice this? There are three main reasons: we cannot see ourselves moving past anything else; we do not feel any movement because we are moving at a fairly constant speed; and the air is moving with us.

Imagine that you are in an elevator (**Figure 2**). If the elevator is travelling at a constant speed in the middle of its trip, you have little

Figure 1
We cannot sense Earth's rapid motion through space.

Figure 2
You can feel the acceleration when an elevator starts and stops.