Back and Forth Motion

Lots of objects go back and forth; that is, they move along a line first in one direction, then move back the other way. An oscillating pendulum or a ball tossed vertically into the air are examples of things that go back and forth. Graphs of the position *vs.* time and velocity *vs.* time for such objects share a number of features. In this experiment, you will observe a number of objects that change speed and direction as they go back and forth. Analyzing and comparing graphs of their motion will help you to apply ideas of kinematics more clearly.

In this experiment you will use a Motion Detector to observe the back and forth motion of the following five objects:

- Oscillating pendulum
- Dynamics cart rolling up and down an incline
- Student jumping into the air
- Mass oscillating at the end of a spring
- Ball tossed into the air

OBJECTIVES

- Qualitatively analyze the motion of objects that move back and forth.
- Analyze and interpret back and forth motion in kinematics graphs.
- Use kinematic graphs to catalog objects that exhibit similar motion.

MATERIALS

LabQuest	meter stick
LabQuest App	incline with dynamics cart
Motion Detector	rubber ball (15 cm diameter or more)
pendulum with large bob	protective wire basket for Motion Detector
spring with hanging mass	protractor

PRELIMINARY QUESTIONS

1. What is the shape of a velocity *vs*. time graph for any object that has a constant acceleration?

2. Do you think that any of the five objects has a constant acceleration? If so, which one(s)?

3. Consider a ball thrown straight upward. It moves up, changes direction, and falls back down. What is the acceleration of a ball on the way up? What is the acceleration when it reaches its top point? What is the acceleration on the way down?

PROCEDURE

These five activities will ask you to predict the appearance of graphs of position *vs.* time and velocity *vs.* time for various motions, and then collect the corresponding data. The Motion Detector defines the origin of a coordinate system extending perpendicularly from the front of the Motion Detector. Use this coordinate system in making your sketches.

Part I Oscillating Pendulum

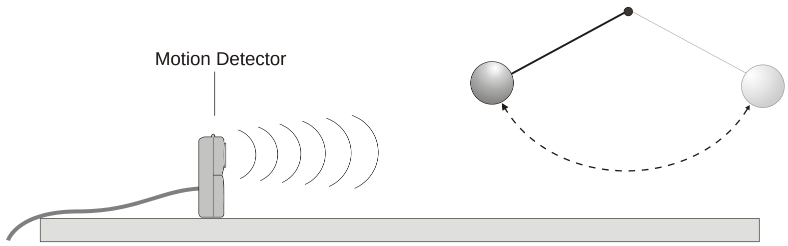
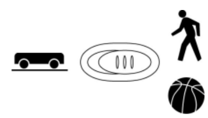


Figure 1



1. Set your Motion Detector switch to Normal. Connect the Motion Detector to DIG 1 on LabQuest and choose New from the File menu.
2. Place the Motion Detector near a pendulum with a length of 1 to 2 m. The Motion Detector should be level with the pendulum bob and about 1 m away when the pendulum hangs at rest. The bob must never be closer to the detector than 0.4 m.
3. Sketch your prediction of the position *vs.* time and velocity *vs.* time graphs of a pendulum bob swinging back and forth. Ignore the small vertical motion of the bob and measure distance along a horizontal line in the plane of the bob's motion. Based on the shape of your velocity graph, do you expect the acceleration to be constant or changing? Why? Will it change direction? Will there be a point where the acceleration is zero?
4. Pull the pendulum about 15 cm toward the Motion Detector and release it to start the pendulum swinging.
5. Start data collection.
6. When data collection is complete, a graph of position *vs.* time will be displayed. If you do not see a smooth graph, the pendulum was most likely not in the beam of the Motion Detector. Adjust the aim and try again.
   a. To take more data, start data collection after you have released the pendulum.
   b. Continue to repeat this process until you get a smooth graph.
7. Answer the Analysis questions for Part I before proceeding to Part II.

Part II Dynamics Cart on an Incline

8. Sketch your prediction of the position *vs.* time and velocity *vs.* time graphs for a cart rolling freely up an incline and then back down. The cart will be rolling up the incline and toward the Motion Detector

initially. Will the acceleration be constant? Will it change direction? Will there be a point where the acceleration is zero?

9. Hold the dynamics cart at the top of the incline. Start data collection and release the cart. Keep your hands away from the track as the cart rolls.

10. If you do not see a smooth graph, the cart was most likely not in the beam of the Motion Detector. Adjust the aim and try again.
    a. To take more data, start data collection when you are ready to release the cart.
    b. Repeat this process until you get a smooth graph.

11. Answer the Analysis questions for Part II before proceeding to Part III.

Part III Student Jumping in the Air

12. Set your Motion Detector switch to Normal. Secure the Motion Detector about 3 m above the floor, pointing down.

13. Sketch your predictions for the position *vs.* time and velocity *vs.* time graphs for a student jumping straight up and falling back down. Will the acceleration be constant? Will it change direction? Will there be a point where the acceleration is zero?

14. Stand directly under the Motion Detector. Start data collection, then bend your knees and jump. Keep your arms still while in the air.

15. If you do not see a smooth graph, you were most likely not in the beam of the Motion Detector. Adjust the aim and try again.
    a. To take more data, start data collection when you are ready to jump.
    b. Repeat this process until you get a smooth graph.

16. Answer the Analysis questions for Part III before proceeding to Part IV.

Part IV A Mass Oscillating at the End of a Spring

17. Place the Motion Detector on the floor facing upward, below a mass suspended from a spring.

18. Sketch your prediction for the position *vs.* time and velocity *vs.* time graphs of a mass hanging from a spring as the mass moves up and down. Will the acceleration be constant? Will it change direction? Will there be a point where the acceleration is zero?

19. Lift the mass about 10 cm (and no more) and let it fall so that it moves up and down the start data collection.

20. If you do not see a smooth graph, the mass was most likely not in the beam of the Motion Detector. Adjust the aim and try again.

    a. To take more data, start data collection when you are ready to release the mass.

    b. Repeat this process until you get a smooth graph.

21. Answer the Analysis questions for Part IV before proceeding to Part V.

Part V Ball Tossed into the Air

22. Sketch your predictions for the position *vs.* time and velocity *vs.* time graphs of a ball thrown straight up into the air. Will the acceleration be constant? Will it change direction? Will there be a point where the acceleration is zero?

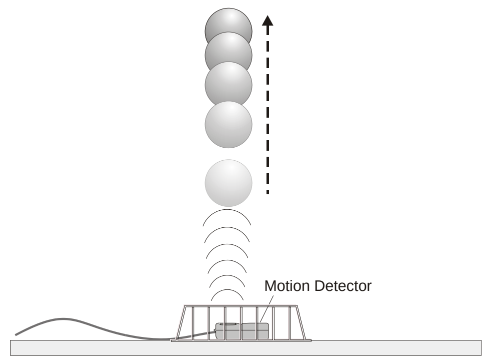


Figure 2

23. Place the Motion Detector on the floor pointing toward the ceiling as shown in Figure 2.

24. Hold the rubber ball with your hands on either side, about 0.5 m above the Motion Detector.

25. Start data collection, then gently toss the ball straight up over the Motion Detector. Move your hands quickly out of the way so that the Motion Detector tracks the ball rather than your hand. Catch the ball.

26. If you do not see a smooth graph, the ball was most likely not in the beam of the Motion Detector. Adjust the aim and try again.

    a. To take more data, start data collection when you are ready to toss the ball.

    b. Repeat this process until you get a smooth graph.

27. Answer the Analysis questions for Part V.

ANALYSIS

Part I Oscillating Pendulum

1. Print or sketch the position and velocity graphs for one oscillation of the pendulum. Compare these to your predicted graphs and comment on any differences.

2. Was the acceleration constant or changing? How can you tell?

3. Was there any point in the motion where the velocity was zero? Explain.

4. Was there any point in the motion where the acceleration was zero? Explain.

5. Where was the pendulum bob when the acceleration was greatest?

Part II Dynamics Cart on an Incline

6. Print or sketch the portions of the position and velocity graphs that represent the time that the cart was going up and down the incline. Compare these to your predicted graphs and comment on any differences.

7. Was the acceleration constant or changing? How can you tell?

8. Click on Analyze and select Tangent. Tangent lines should be displayed on the velocity graph to determine the sign of the acceleration of the cart when it was on the way up, at the top, and on the way down the incline. What did you discover?

9. Was there any point in the motion where the velocity was zero? Explain.

10. Was there any point in the motion where the acceleration was zero? Explain.

Part III Student Jumping in the Air

11. Print or sketch the portion of the position and velocity graphs that represent the time from the first bend of the knees through the landing. Compare these to your predicted graphs and comment on any differences.

12. Click on Analyze and select Tangent. Tangent lines should be displayed on the velocity graph to determine where the acceleration was greatest. Was it when the student was pushing off the floor, in the air, or during the landing?

13. When the student was airborne, was the acceleration constant or changing? How can you tell?

14. Was there any point in the motion where the velocity was zero? Explain.

15. Was there any point in the motion where the acceleration was zero? Explain.

Part IV Mass Oscillating on a Spring

16. Print or sketch the position and velocity graphs for one vibration of the mass. Compare these to your predicted graphs and comment on any differences.

17. Was the acceleration constant or changing? How can you tell?

18. Was there any point in the motion where the velocity was zero? Explain.

19. Was there any point in the motion where the acceleration was zero? Explain.

20. Where was the mass when the acceleration was greatest?

21. How does the motion of the oscillating spring compare to that of the pendulum?

Part V Ball Tossed into the Air

22. Print or sketch the portions of the position and velocity graphs that represent the time the ball was in the air. Compare these to your predicted graphs and comment on any differences.

23. Was the acceleration constant or changing? How can you tell?

24. Click on Analyze and select Tangent. Tangent lines should be displayed on the velocity graph to determine the sign of the acceleration of the ball when it was on the way up, at the top, and on the way down. What did you discover?

25. Was there any point in the motion where the velocity was zero? Explain.

26. Was there any point in the motion where the acceleration was zero? Explain.

Analysis of All Parts

27. State two features that the five position graphs had in common. State two ways that the five position graphs were different from one another.

28. State two features that the five velocity graphs had in common.

29. State two ways that the five velocity graphs were different from one another.