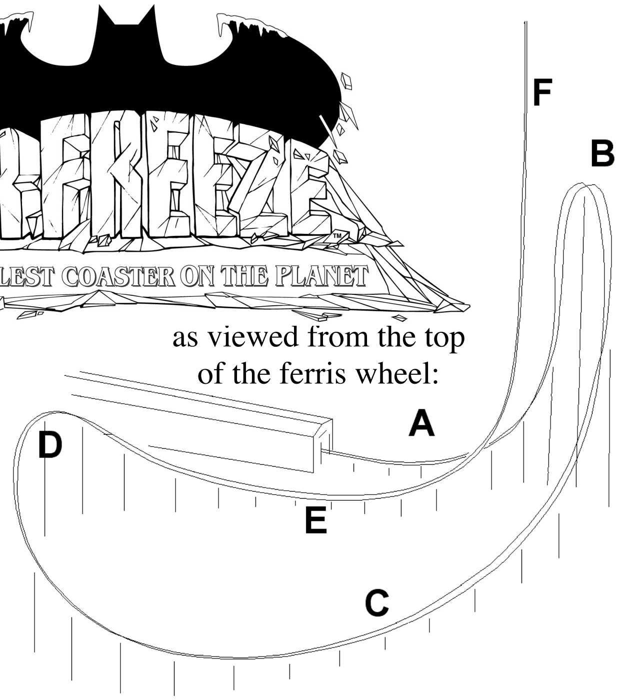
Name: Partner: Teacher:

**Mr. Freeze**

## QUALITATIVE QUESTIONS

Many of the questions that follow refer to the graphs of data collected when riding Mr. Freeze with high tech data collection vests. With your I.D., you can borrow a vest without charge just before you get on the ride. The graphs will be printed for you as you return the vest and claim your I.D. at the exit of the ride.

as viewed from the top of the ferris wheel:




1. Label your printout of the altitude vs. time graph to correspond with the lettered sections in the diagram of the ride.

2. a. Make free-body diagrams for a rider as the train starts and stops.

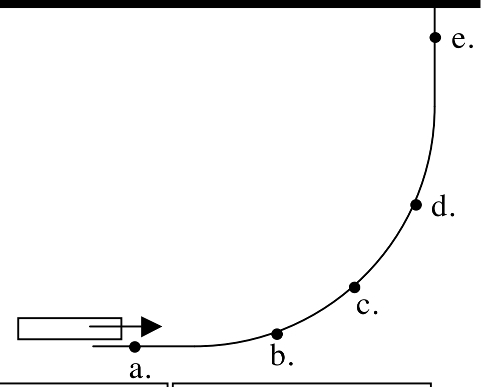
| Starting – speeding up to the right | Stopping – slowing down to the left |
|---|---|

b. The graph of Force Factor vs. time (front-to-back axis) indicates that acceleration while speeding up in the tunnel and the acceleration while stopping in the tunnel are in the same direction. Why is this so? Show your answer with a diagram of the train starting and a diagram of the train stopping that show the directions of the velocity, acceleration, and net force.

| Starting – speeding up to the right | Stopping – slowing down to the left |
|---|---|

## QUALITATIVE QUESTIONS (continued)

3. Immediately after the train comes out of the horizontal tunnel, it makes one-fourth of a circular turn until the train is moving vertically. The diagram shows five positions during the transition from horizontal to vertical motion. Draw and label a free-body diagram that includes each of the forces the rider experiences at each position.




| a. | b. | c. | d. | e. |
| --- | --- | --- | --- | --- |
| before entering the curve | entering the curve | halfway through the curve | exiting the curve | moving vertically after the curve |

4. From the force diagrams, draw the radial and tangential components of the net force at each point. Hint: Use a coordinate axis tangent to the track to analyze each point.

| a. | b. | c. | d. | e. |
| --- | --- | --- | --- | --- |
| before entering the curve | entering the curve | halfway through the curve | exiting the curve | moving vertically after the curve |

5. Explain how the <u>radial</u> net force affects the rider's motion.

6. Explain how the <u>tangential</u> net force affects the rider's motion.

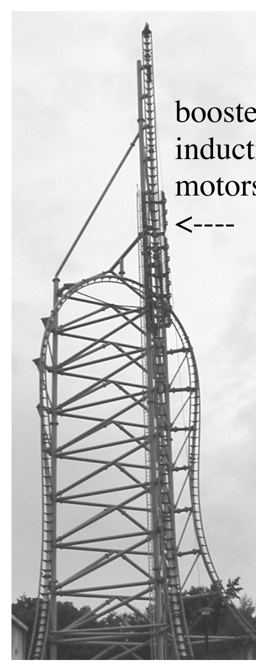
## QUALITATIVE QUESTIONS (continued)

7 a. At the peak of the loop, when you are upside down (Point B), the lap bar doesn't exert any force on you. Why do you stay in the train? Explain.

b. Under what circumstances might the lap bar be necessary at point B. Explain.

8. According to the graphs, during what lettered portion of the ride are you in free fall? What properties of the graph indicate free fall? Make sure to examine both of the Force Factor vs. time graphs.

9. The designers of this ride found it necessary to install booster motors that briefly push the train up while ascending the vertical section of the track, section F. (See the picture to the right.) Why do you think they did this?



## QUALITATIVE QUESTIONS (continued)

10. Complete the table below. Use the graph of Force Factor (front to back axis) vs. time to find the Force Factor for each section indicated. Then indicate which of the following interactions is occurring for each portion of the ride.
    I. The seat is pushing up on you.
    II. The harness is pulling down on you.
    III. The seat and harness are exerting little or no force on you.

| **Portion of Ride** | **Force Factor** (values from graph) | **Interaction** (I, II, or III) |
|---|---|---|
| a. During the boost on the way up. | | |
| b. After the boost on the way up. | | |
| c. When your velocity is zero at the top. | | |
| d. On the way down (before you get to the curved part). | | |

11. Draw free-body diagrams for a passenger at the four positions in the previous question.

| | | | |
|---|---|---|---|
| a. During the boost on the way up. | b. After the boost on the way up. | c. When your velocity is zero at the top. | d. On the way down. |

12 a. Determine the time to go from C to E forward and the time to go from E to C backward.

b. Explain why the times are different.

## QUALITATIVE QUESTIONS (continued)

13 a. What are the Force Factor values along the head to toe axis for valley E before the vertical section F (while moving forward) and after the vertical section F (while moving backward).

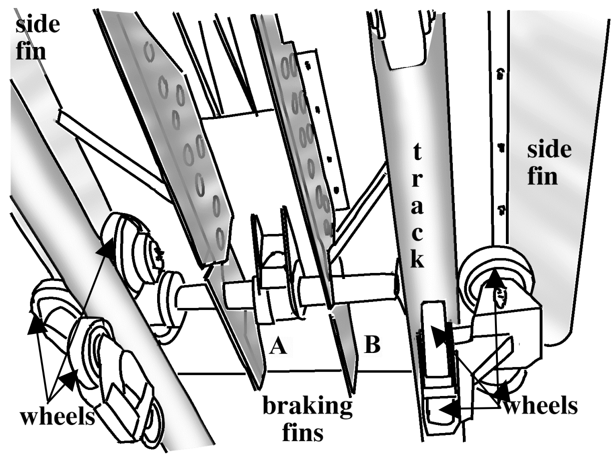
b. Draw force diagrams for the rider at valley E for each of the two times you are at that position (forward and backward). Explain why the Force Factor readings are different in these two instances.

### How Mr. Freeze Starts and Stops

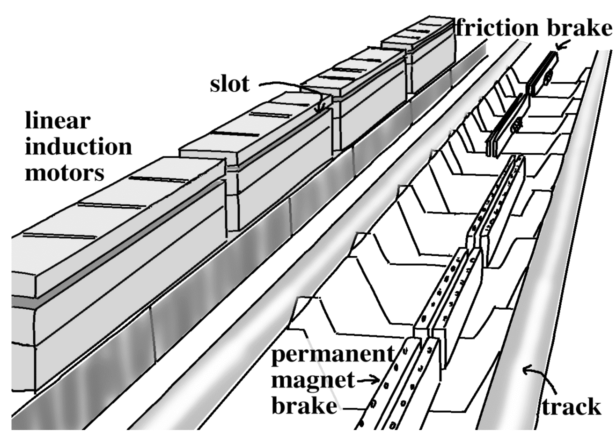
To accelerate the Mr. Freeze train, the side fins of the train car (top diagram) fit into the slot in the linear induction motors (bottom diagram) that line both sides of the track. The linear induction motors are electromagnets that induce electric currents in the aluminum side fins of the train. The currents in the side fins produce opposing magnetic fields. By precisely timing the oscillation of the north and south poles of the electromagnets, the train is propelled down the track.

There are two braking systems on Mr. Freeze. A double row of permanent magnets is located between the rails (bottom diagram). When the train reenters the tunnel, braking fin B (top diagram) passes between the permanent magnets, producing opposing magnetic fields that slow the train. The friction brake consists of pairs of plates that pinch braking fin A.

For safety, both sets of brakes are normally in their active position. When the ride is ready to start, pressurized air separates the friction plates and lowers the permanent magnets so that the car's braking fins will pass over the magnets and not between them.

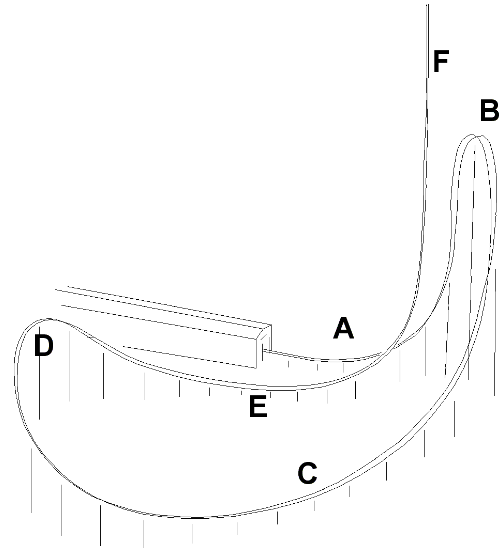



*The bottom of a Mr. Freeze train car*




*A section of the Mr. Freeze track inside the building. From this position, the loading platform is in front of you and the outside part of the ride is behind you.*

## QUALITATIVE QUESTIONS (continued)




14. The train has wheels on the top, bottom and outside of the track. For each set of wheels, what portion of the ride requires the use of that set of wheels.

    a. wheels on top of the track:

    b. wheels on the bottom of the track:

    c. wheels on the outside of the track:

15. Why do the friction brakes use air pressure to release the brakes rather than to engage the brakes?

16. The permanent magnet brakes are so strong that a steel key can't be lifted off of the magnets. It must be slid off instead. An aluminum can, however, doesn't stick at all. All of the fins on Mr. Freeze are made of aluminum. So how do they work?

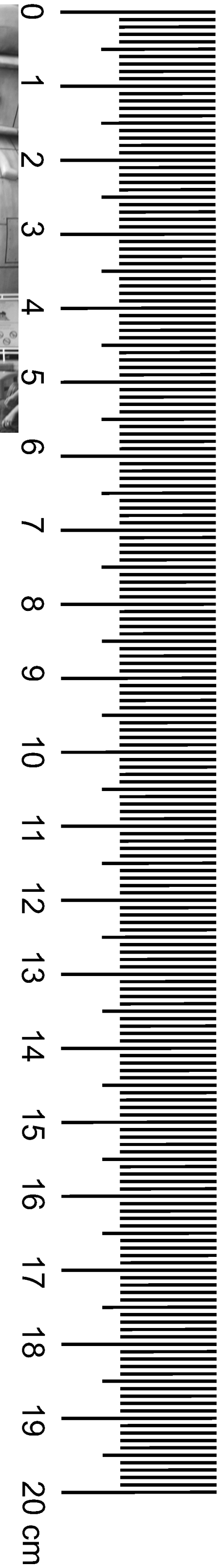
17. Could permanent magnets be used to accelerate the Mr. Freeze train instead of the electromagnetic induction motors? Explain your reasoning.

Name: Partner: Teacher:

**Mr. Freeze**

## QUANTITATIVE QUESTIONS


*The entrance to "Mr. Freeze"*




1. Carefully determine the distance the train travels before exiting the tunnel. Entering the ride, you will cross a bridge. Stand just beyond the bridge at the position marked on the diagram below. The words "ENJOY THE ONE" on the Mr. Freeze building are 11.4 meters long. Hold the ruler at arm's length to determine how many times "ENJOY THE ONE" fits across the distance from the front of the train to the end of the tunnel.

Train displacement while in the tunnel: ___________


2. The front of the train reaches the end of the tunnel 4.4 seconds after starting. Calculate the average speed of the train while in the tunnel.

## QUANTITATIVE QUESTIONS (continued)

3. Assuming that the train is accelerating uniformly while in the tunnel, determine the velocity of the train as it leaves the tunnel.

4 a. Calculate the average acceleration of the train while speeding up in the tunnel.

b. Draw a force diagram for a rider while in the tunnel.

c. Determine the average Force Factor value for the period of time the rider was in the tunnel using the Force Factor (front to back axis) vs. time graph.

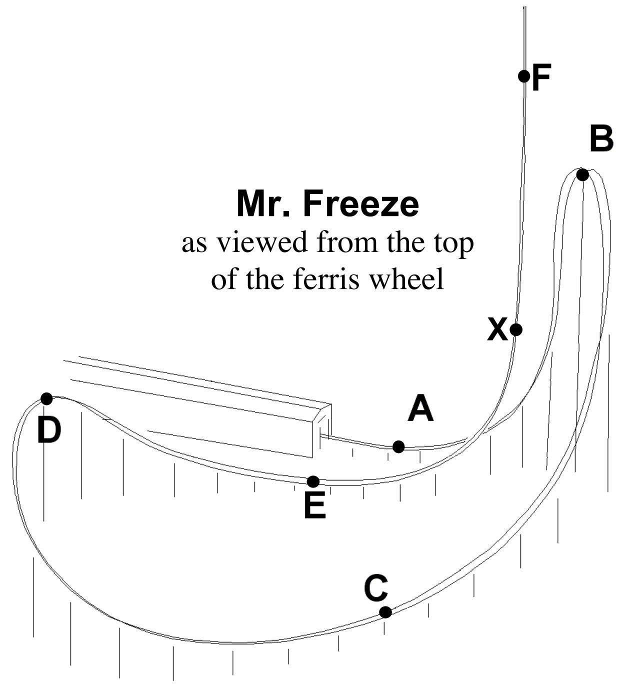
d. Calculate the acceleration of the train using the Force Factor data, your free-body diagram, and Newton's 2$^{nd}$ Law.

e. How do the two acceleration values calculated in 4a and 4d compare?

**QUANTITATIVE QUESTIONS (continued)**

**Finding the acceleration on the vertical section of the track.**

5 a. In the Mr. Freeze line, stand just beyond the bridge (shown in the diagram on the page 7.) You are horizontally 65 meters away from the vertical section of track. Use the angle-measuring device (sextant) to measure the angle to the highest position the bottom of the train reaches, then calculate this height relative to your vertical position.




b. Find the height of point X, where the curved section of the track meets the vertical section, relative to your vertical position.

c. You are horizontally 60 meters away from point A. What is the height of point A relative to your vertical position? (Observe + and – signs!)

## QUANTITATIVE QUESTIONS (continued)

6 a. Using the vertical section heights from question 5, determine the distance from the bottom of the train at its highest point to the point where the track starts to curve.

b. Measure the time for the bottom of the train to travel the distance from its highest point on the vertical section to the point where the track starts to curve.

c. Assuming uniform acceleration, calculate the acceleration of the train.

d. How close were you to free-fall?

e. What is the front-to-back Force Factor during the vertical drop?

f. Use the Force Factor value from section E on the graph and a free-body diagram to determine the acceleration of the train during the vertical drop.

g. How do the acceleration values for 6c and 6f compare? Explain.

**QUANTITATIVE QUESTIONS (continued)**

**Energy conservation from the beginning of the ride to the top of the vertical section**.

7. Use conservation of energy to determine how far the center of the train could go up the vertical section of the track if it didn't lose any energy to friction. (Use the velocity of the train from #3.)

8. The train is 13 meters long. According to your energy conservation calculation for the height of the center of the train, determine how high the *bottom* of the train would reach.

9. Using the results of your calculations from question 5, determine how much higher point F is than point A.

10. How does the height the bottom of the train reaches (as predicted by energy conservation) compare to the height you calculated in question 9? Since the ride *does* lose energy due to friction, how is the ride able to reach the height you measured?

11 a. Determine the maximum height you reached above the starting height using your altitude graph.

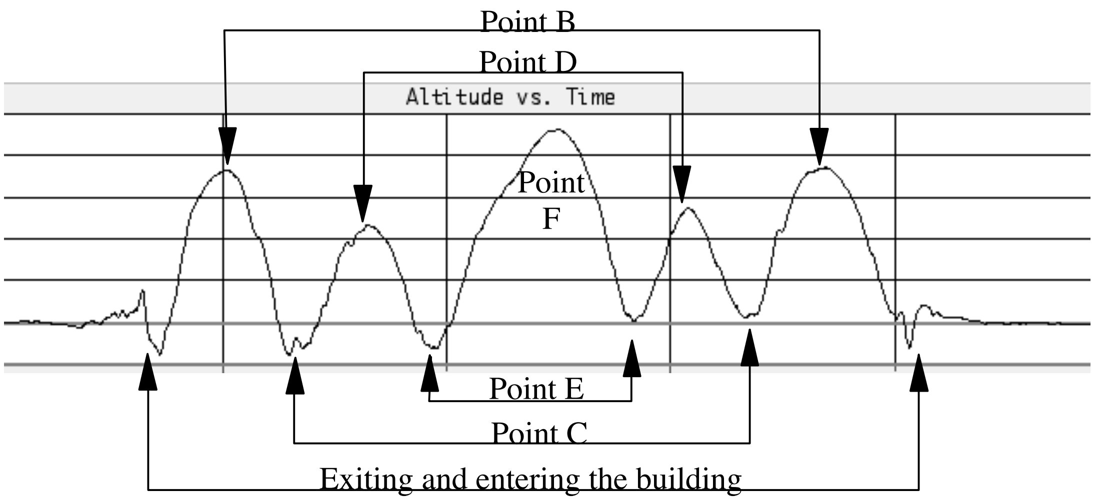
b. Find the maximum height the *bottom* of the train reached by taking into account where you sat in the 13-meter long train. (No modification needed if you were sitting in the last car. If you were sitting in the front car, you would subtract 13 meters.)

c. How does the height for the bottom of the train calculated from the altimeter data compare to the height calculated from the triangulated heights in question 9?

## QUANTITATIVE QUESTIONS (continued)

**A mystery to solve:**

Given the unique geometry of Mr. Freeze, the altitude graphs should be quite symmetrical. However, our data more typically looks like the graph below:




<u>Here's the patterns noticed after examining dozens of altitude vs. time graphs:</u>

- The graphs always start and end on zero elevation, no matter how asymmetrical the graph is.
- Point F – The altitude reading at the highest point is consistently very accurate – precise enough to allow one to deduce a rider's position in the train – no matter how asymmetrical the graph is.
- Points B and D – Even in asymmetrical graphs, the point B altitude reading is pretty consistent, though the backwards altitude reading is slightly larger than the forwards altitude reading. Point D shows a slightly more pronounced difference in altitude readings.
- Points C and D – The altitude readings are most noticeably different: the forward motion altitude readings are always lower than the backward motion altitude readings.
- Exiting and entering the building – Although the track profile smoothly ascends, the altitude reading increases then suddenly decreases when leaving the building. The pattern reverses upon entering the building.

**What's going on? Can you explain why the readings don't always match the actual altitudes?**

Here's an extreme example of the asymmetry that follows the patterns described above: