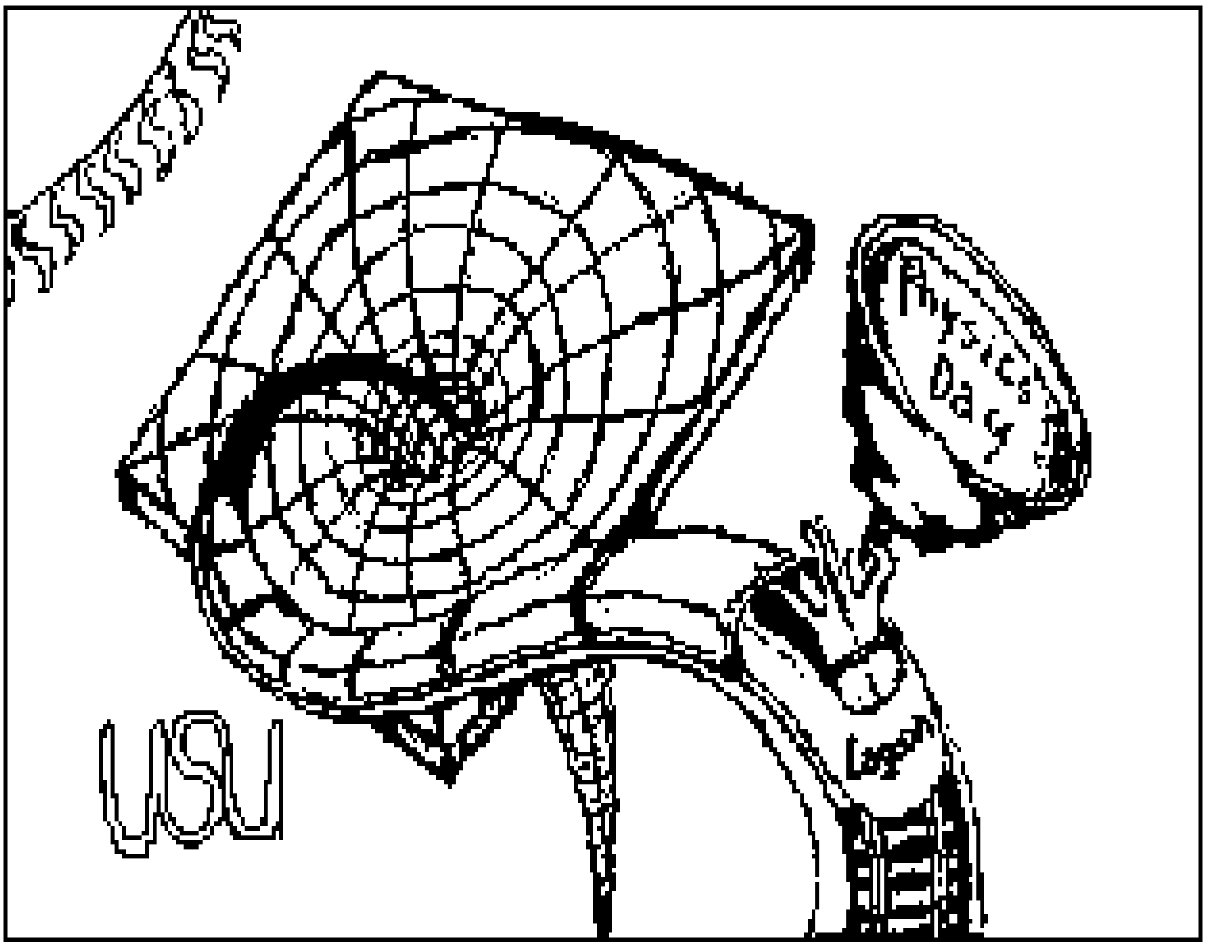
AMUSEMENT PARK PHYSICS CURRICULUM MANUAL



Utah State University

Department of Physics

1996

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ACKNOWLEDGMENTS

Many individuals and organizations have contributed to the development of Utah State University's Amusement Park Physics Curriculum Manual. The initial manual was the principal accomplishment of a two-day summer workshop held in July 1992 in Logan. The Curriculum Development Workshop was sponsored jointly by the USU Physics Department, the USU College of Science and the NASA Rocky Mountain Space Grant Consortium. Primary credit goes to the workshop organizing committee:

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J. R. Dennison	USU Physics Department	Charles Torre	USU Physics Department
Mike Harris	Northridge High School	Randy Waite	Hillcrest High School
Duane Merrell	Emery County High School		

and the workshop participants:

Chuck Humphries	Buhl High School	Paula Scott	Mount Logan Middle School
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Mel Twitchell	Provo School District	Max Weiss	Duchesne High School
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The 1996 edition of the Curriculum Manual was revised by Teresa Burns, J. R. Dennison, Jill Marshall and Jessica Tams. The work was sponsored by the Eisenhower Mathematics and Science Act of the US Department of Education through the Utah Office of Higher Education.

Jill Marshall, David Peak, Mark Riffe, Jan Sojka, Charles Torre and Jim Wheeler from the USU Physics Department have also contributed material to the manual. Marilyn Griggs has typed and edited the manual and provided invaluable assistance throughout the history of USU's Physics Day at Lagoon. Many teachers throughout the Intermountain Region have made contributions through their submissions to the Curriculum Development Contest sponsored by the USU College of Science. We also acknowledge the help of the faculty, staff and students at USU, the sponsoring organizations, and the teachers and students who participated in Physics Day at Lagoon. A special thanks goes to the administration, and particularly Dick Andrew, at Lagoon for their continuing support of Physics Day.

J R Dennison
March 1996

Cover design: Joe Westover, Davis High School, 1995 Logo Design Contest Winner

Utah State University Physics Department
Utah State University College of Science
Rocky Mountain Space Grant Consortium

PREFACE

Amusement Park Physics is an educational approach to teaching fundamental physics concepts using an amusement park as a laboratory. Many variations of such activities have been conducted across the country over the last two decades. The USU Physics Day at Lagoon is the first such activity in the Intermountain Region. Physics Day at Lagoon provides a valuable educational experience for the high school and middle school students; at the same time it is a lot of fun and provides incentive for students to develop an interest in science. Amusement parks provide nearly unlimited, illustrative and simple examples of many key physics concepts for experiments, measurements, and problem solving. The activities at Physics Day provide excellent motivation for classroom discussions, lessons, problems and experiments on topics such as rotational mechanics, centrifugal force, conservation of energy, design of measurement devices, and data collection and error analysis techniques, to name just a few. For instance, it is much easier to get students excited to think about the physics of roller coasters than about the traditional, but very dry, example of carts on an inclined plane. Physics Day provides a chance for students to apply classroom concepts to real world situations and, like most field trips and "hands-on" learning experiences, its benefits stick with students longer than traditional lessons.

This manual is designed to provide high school, middle school, and junior high school physics and physical science teachers with curriculum material related to Amusement Park Physics to complement and extend the activities at Physics Day. The goal of this project is to allow teachers to use Amusement Park Physics concepts throughout the school year to illustrate physics principles and motivate students.

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INTRODUCTION

The curriculum material developed for this manual fits into four categories: (1) material to be used during the school year to illustrate physical principles using Amusement Park Physics concepts; (2) activities to do at an amusement park or playground; (3) more in-depth follow-up activities to be completed at school after a trip to the amusement park; and (4) useful background and reference material. Included are short answer and multiple choice questions, simple problems, extended problem sets and transparency masters. We have tried to provide a good mix of qualitative "concept" questions and quantitative problems. In most cases, answers are provided.

The manual has six main sections. The General Materials section includes a collection of basic physics topics related to Amusement Park Physics, a glossary, and a general question data bank. The second section has ride specifications, questions, problems, and measurement exercises grouped by each individual ride. The third section has reference material grouped by physics concepts such as conservation of energy or kinetics. Many of these questions are particularly well suited for the classroom. The fourth section is a collection of related activities including more involved Fermi questions emphasizing estimation and problem-solving, in-class activities with marble roller coasters, and activities to do at a playground. The fifth section is related to making measurements. This includes information on making measurements and measuring devices, exercises using accelerometers and velocity measuring devices, and activities involving measurement techniques and statistics. The sixth section is a collection of additional resources to draw from. There is an extensive collection of materials developed by winners of the Curriculum Development Contest held annually at Physics Day at Lagoon. There is also a time log of a video on Amusement Park Physics available from the USU Physics Department. Finally, there is an Amusement Park Physics resource list and a detailed index.

The curriculum material in this manual covers a wide array of ideas and activities. However, there is unlimited opportunity for novel approaches and new physics to be added. We challenge you, as hopefully you will challenge your students, to examine the material critically and search for new, creative and superior ways to use it in your teaching. To this end, we would appreciate your constructive criticism and additions or corrections. Please forward correspondence to:

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HISTORY OF AMUSEMENT PARK PHYSICS

An amusement park may not seem at first the ideal place for a study of physics. There are notable disadvantages, such as the money and time involved in bringing 30 kids to the park, as well as logistic problems. Some people feel it supports a "goof-off" image of physics. However, for many, the advantages greatly outweigh any disadvantages. There are many educational benefits to be gained. A roller coaster is much more engaging than a cart on an inclined plane to teach conservation of energy; a swing ride is a lot more fun than a rotating table for teaching angular motion and periodic motion. The students get to *feel* the physics as well as make measurements and see physical laws in action. There is sufficient scientific evidence that experiences such as field trips and hands-on activities have greater educational impact on students than simple demonstrations or learning by solely reading.[1] In many cases, the trip to the park takes place in Spring, when student interest and motivation are waning. It is a way to recapture that interest, and focus their attention once again. Since the amusement park is a real life lab, many different physics concepts can be found in action. The most obvious are kinematics and dynamics. Creative curricula can also include lessons on electricity, heat and light, periodic motion, measurement techniques, statistics, and fluid flow, to name just a few. Each year, innovative teachers surprise us with the concepts and physical laws they see in action in amusement parks. In this way, the amusement park can be used as a way to summarize and reinforce concepts and principles taught the whole school year. It is also helpful to the image of physics and for the esteem of budding physicists to see thousands of students doing physics, just like them. Physics is fun, and it is not only for geeks!

The use of the amusement park as a lab is not new. The first published article concerning Amusement Park Physics (APP) appeared in 1975, in *The Physics Teacher*; however, oral evidence supports the belief that innovative teachers were bringing physics to the midway long before this.[2] In the last ten years especially, there has been increased interest and scholarly activity focused on APP. In particular, Physics Days at amusement parks have sprung up across the country. Yearly attendance at such events is estimated to be in the hundreds of thousands. In California, in 1990, over ten thousand students in one day attended Physics Day at Great America![2] Support and curriculum materials, such as those in the reference list at the end of this manual, have also blossomed, making it easier to incorporate APP in the classroom curriculum year round; this greatly improves the learning potential of such a trip. Physics Day activities can be expected to grow in the future, as evidenced by our experiences at Utah State University with Physics Day at Lagoon.

Physics Day at Lagoon had its birth at a summer demonstration workshop sponsored by Utah State University. At a summary meeting, the "university folks" asked the high school teachers what they needed to help their teaching efforts. The resounding response was "Do a Physics Day at an amusement park!" The USU Physics Department took up the challenge, despite having no experience, and now hosts the only such event in the Intermountain Region. Since the first Physics Day in 1990, attendance has increased every year to the current (1996) participation estimates of approximately 4500 students representing almost 100 schools from five states. It is our hope that this curriculum manual will see you added to the numbers if you have not participated already, or give you more ideas on how to use APP in the classroom if you already use USU Physics Day as a learning tool.

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[1] Unterman, Nathan A., *Amusement Park Physics; A Teacher's Guide* (J. Weston Welch, Portland, ME, 1990).

[2] *Amusement Park Physics Handbook*, , Carole Escobar, ed. (American Association of Physics Teachers, New York, 1991).

GRAVITY FACTS

Gravity is the force of attraction of one body to other bodies due to their masses.

Newton's Law of Universal Gravitation states that if there are two masses m_1 and m_2, separated by a distance r_{12} between their centers of mass, then the gravitational force between them is $F_{gravity} = Gm_1m_2/r_{12}^2$, where the universal gravitational constant $G = 6.670 \infty 10^{-11}$ N-m^2-kg^{-2}.

The value of g can be calculated directly from Newton's universal law of gravitation. The standard value of the acceleration of gravity on Earth at sea level at 45° latitude is **9.80665 m-sec^{-2}**.

If the Earth were a homogeneous, stationary, isolated sphere, the intensity of gravity would be the same everywhere on the surface of the Earth. However, the intensity of gravity varies as a function of both location and time. The acceleration of gravity can be expressed as[1]

$$g = 9.78049 \{1 + [5.2884 \cdot 10^{-3} \sin^2 (\phi) - 5.9 \cdot 10^{-6} \sin^2 (2\phi)] - 3 \cdot 10^{-7} h\}$$

The first term is a function of geographic latitude, ϕ, and corrects for the oblate spheroid shape of the earth. The second term compensates for the height above sea level, h. Other corrections due to the inhomogeneity of the material making up the Earth, orbital precessions, eccentricities, and external gravitational attractions (e.g., by the Moon or Sun) are not included in this expression, but are, in general, quite small. Local anomaly corrections are compiled by the US Geological Survey in the form of contour maps; a typical value for these local anomalies is of the order of $2 \cdot 10^{-3}$ m-sec^{-2}.

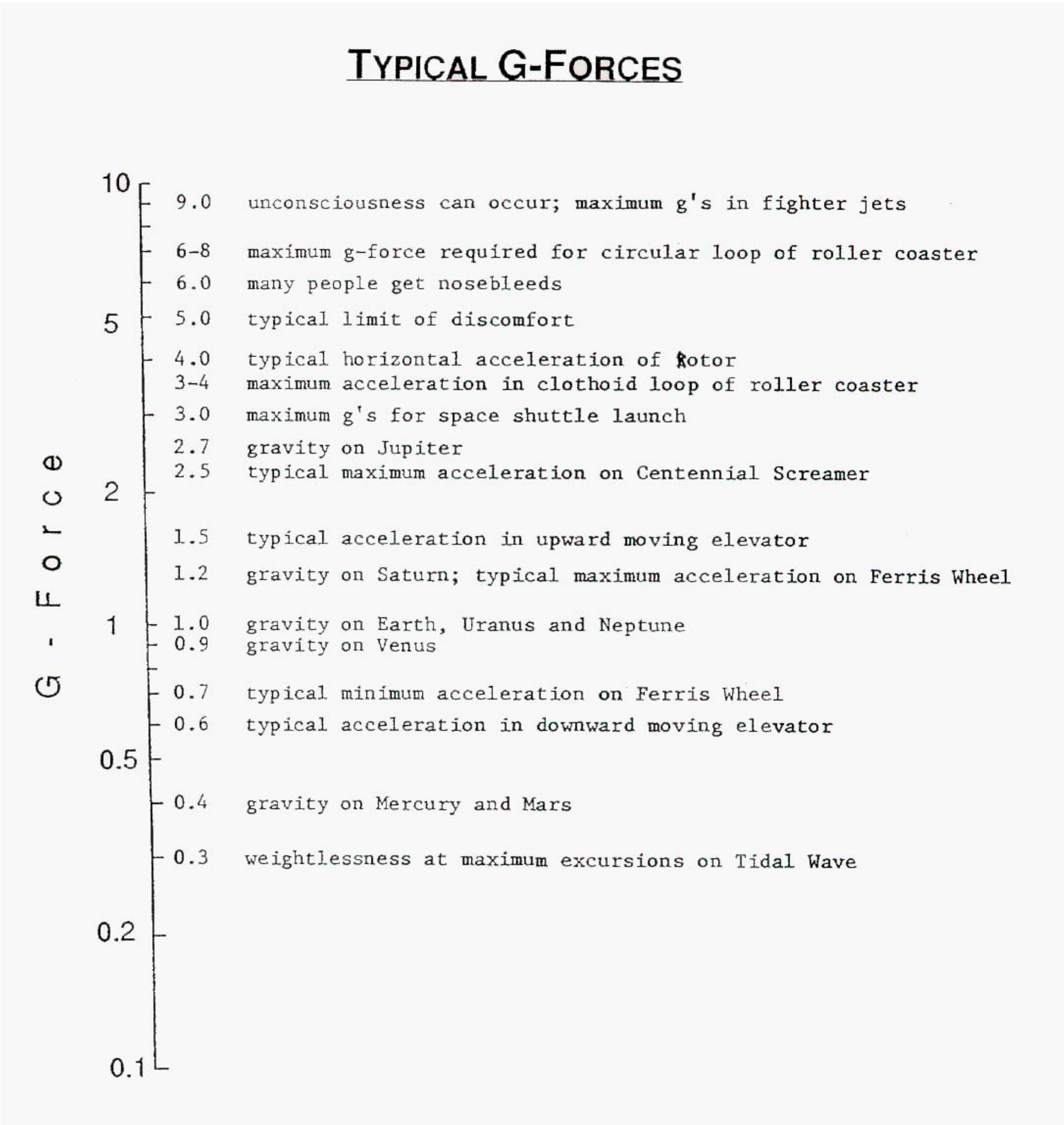
Acceleration Due to Gravity for Bodies in the Solar System

Planet	Acceleration due to gravity[2]		Planet /Body	Acceleration due to gravity[2]	
Mercury	0.37 g or	3.63 m/s^2	Uranus	1.17 g or	11.47 m/s^2
Venus	0.88 g or	8.62 m/s^2	Neptune	1.18 g or	11.56 m/s^2
Earth	1.00 g or	9.80 m/s^2	Pluto	0.25 g or	2.45 m/s^2
Mars	0.38 g or	3.72 m/s^2			
Jupiter	2.64 g or	25.87 m/s^2	Moon	0.17 g or	1.67 m/s^2
Saturn	1.15 g or	11.27 m/s^2	Sun	27.96 g or	274.0 m/s^2

1 D. Haliday and R. Resnick, *Fundamentals of Physics,* 3rd Ed. (Wiley, New York, 1988), Ch. 15.

2 Acceleration is listed in both MKS units and in terms of the acceleration of gravity on Earth in units of g.

TYPICAL G-FORCES



AMUSEMENT PARK PHYSICS GLOSSARY

ACCELERATION: Time rate of change of velocity (either speed or direction) of motion.

ACCELEROMETER: A device to measure acceleration.

AIR RESISTANCE: Force resisting motion of a body through air due to the frictional forces between the air and body.

AMPLITUDE: The largest distance from the equilibrium position during an oscillation.

ANGULAR ACCELERATION: Time rate of change of angular velocity.

ANGULAR VELOCITY: Time rate of change of angular position.

ARCHIMEDES' PRINCIPLE: There is a buoyant force upward, when a body is placed in a fluid, which is equal to the weight of the fluid displaced.

CENTER OF MASS (CENTER OF GRAVITY): The point within a body where the entire gravitational force can be thought to act.

CENTRIPETAL FORCE: A force on an object pulling or pushing the object towards the center of its curved path.

CHEMICAL ENERGY: The potential energy stored in chemical bonds, which can be released in a chemical reaction.

CONSERVATION OF ENERGY: Basic tenet of physics stating that energy can neither be created nor destroyed in any process, though it may change form.

CONSERVATION OF MOMENTUM: The total momentum of a system is constant whenever the net external force on the system is zero.

DECELERATION: Rate of decrease of velocity (see acceleration).

DENSITY: The ratio of body's mass to volume.

DOPPLER EFFECT: The change in frequency of a wave due to the relative velocity of the source to observer.

EINSTEIN'S THEORY OF SPECIAL RELATIVITY: Laws of motion most applicable to bodies moving at or near the speed of light. Fortunately these have little to do with roller coasters.

ELASTIC COLLISION: A collision in which kinetic energy is the same before and after the collision.

FLUID: A liquid or gas.

FORCE: A push or pull. The time rate of change (direction and magnitude) of momentum.

FREE FALL: Motion in which the only force causing acceleration is gravity.

FREQUENCY: The number of events or oscillations per second.

FRICTION: A retarding force that resists the motion of a body.

G-FORCE: Ratio of the magnitude of acceleration on a body to the acceleration of gravity at sea level on Earth ($g = 9.8\ m/s^2$).

GRAVITY: Attractive force between two bodies, proportional to the product of their masses.

HEAT (THERMAL) ENERGY: The energy of an object due to its temperature, resulting from random thermal motion of the particles in the system.

IMPULSE: Product of the magnitude of a force on a body times the time over which the force acts on the body.

INELASTIC COLLISION: A collision in which kinetic energy decreases as a result of the collision.

INERTIA: Tendency of a body to remain at rest or in uniform motion in a straight line.

JERK: Time rate of change of acceleration. A movie starring Steve Martin.

KINETIC ENERGY: The energy of a body associated with its motion.

LAMINAR: The smooth flow of a fluid, with each part of the fluid moving with nearly the same velocity.

LEVER: A simple machine which is made of a stiff rod with a pivot.

MASS: The amount of material a body contains. A quantitative measure of the inertia of a body.

MECHANICAL ENERGY: The energy of an object due to kinetic energy, gravitational potential energy or elastic potential energy.

MOMENTUM: The product of mass times velocity.

NEWTON'S FIRST LAW: Unless acted on by an external force, a body at rest will remain at rest and a body in motion will continue in motion with constant velocity.

NEWTON'S SECOND LAW: Force equals mass times acceleration.

NEWTON'S THIRD LAW: Actions produce equal and opposite reactions.

NEWTON'S LAWS OF MOTION: Physical laws governing the motion of bodies (at speed much less than the speed of light) expressed in terms of force, mass, and acceleration.

OSCILLATION: Motion of body which repeats itself after a fixed time.

PERIOD: The time for one oscillation.

PIVOT (FULCRUM): A fixed point about which a lever can turn.

POTENTIAL ENERGY: The energy associated with the position or state of a system.

POWER: Rate of work done per unit time.

PRESSURE: Force divided by the surface over which the force acts.

RELATIVE VELOCITY: The velocity of one moving object as seen from another.

SIMPLE HARMONIC MOTION: Motion of a body in which the distance from its equilibrium position varies sinusoidally.

SPEED: The magnitude of velocity.

TORQUE (MOMENT): Force multiplied by the perpendicular distance from the pivot.

TURBULENT: Un-smooth (non-laminar) flow of a fluid.

VELOCITY: The magnitude and direction of the time rate of change of position.

VISCOSITY: A measure of how difficult it is to force a certain shaped solid object through a fluid.

WEIGHT: A force proportional to the mass of a body and to the gravitational attraction of a body to the Earth (or other body).

WEIGHTLESSNESS: A condition under which a body feels no net force proportional to its mass.

WORK: The energy which is used or produced when a force is exerted on a body over some distance, or when one form of energy is converted to another form. Product of the magnitude of force on a body times the distance through which the force acts.

GENERAL QUESTIONS

FILL IN THE BLANKS WITH THE VOCABULARY WORDS FROM THE GLOSSARY

1. As a roller coaster drops, it __________________________.
2. At the top of a roller coaster hill you have the most ___________________ energy.
3. The force that slows down all rides is __________________________.
4. The force that makes a roller coaster roll is ________________________.
5. __________________________ causes a rider to tend to move in a straight line.
6. At the top of the Colossus loop, you experience negative ______________________.
7. The __________________________ energy is maximum at the bottom of the hills.
8. At the end of the roller coaster ride, the brakes apply ________________________.
9. _____________________ is a friction force experienced to some degree on all rides, especially the fast ones.
10. Spinning riders feel a ___________________ force.

11 As you go through the Colossus loop, you experience ____________________.

12. Bumper cars have short duration collisions, causing high _______________________.
13. Because of your speed at the bottom of a roller coaster hill, you have enough _______________________ to climb to the top of the next hill.
14. Your ___________________________ is larger when you go up a roller coaster hill than when you come down.
15. As the roller coaster is pulled up the first hill, the motors do _________________________.
16. The _________________ of a car from Flying Aces is the same on Earth and the Moon; the _______________________ is much less on the Moon.
17. A miniature golf ball hitting a hard wooden rail is an example of an _______________ collision.
18. A bumper car crash is an example of an ___________________ collision.
19. As you revolve, your _______________ is the same at the top and bottom of the Skyscraper Ferris Wheel; your ___________________ is in opposite directions at the top and bottom.

20. Two riders at opposite ends of the gondola of 1001 Nights have zero ________________, although the both appear to be moving to the ride operator.

21. Daredevils jumping from airplanes and astronauts circling the earth all experience ____________________.

22. ________________________ is done as the riders in a roller coaster are lifted to the top of the first hill.

23. As a roller coaster thunders down a hill, _______________________ is converted into kinetic energy.

24. __________________ energy is released when diesel fuel is burned to run the electrical generators at Lagoon.

25. A hot dog roaster uses ________________ energy to warm the hot dogs.

26. The electric generator powering the roller coaster converts electrical potential energy into ________________ energy of the moving cars and riders.

27. A seesaw is a good example of a ______________________.

28. The central support of a seesaw acts as the ______________________ for the lever.

29. When the passengers in the ferris wheel do not properly balance the wheel, a large ______________________ is exerted.

30. The air encountered by a speeding roller coaster rider exerts less ___________________ than the fluid encountered by someone on the water slides.

31. The water tumbling down the water slides is an example of ___________________ flow.

32. Calm stretches of water flowing in the tubing channel in Lagoon-A-Beach are examples of _________________ flow.

33. The Tidal Wave has a period of 7.8 s and undergoes approximately 11 _______________ in the 90 s duration of the ride.

34. Bottles used in carnival games have a low _________________ so that they are not easy to tip over.

35. Heavy bowling balls have a higher _______________ than cotton candy.

36. _______________________ ______________________ explains the nature of the buoyant force which allows swimmers at Lagoon-A-Beach to float in the water.

37. Helium under _____________________ exerts a force on balloon walls to keep them inflated.

38. Water, helium gas, coke and air are all examples of ___________________ encountered in physics problems at Lagoon.

39. The rotational motion of rides like the Merry-go-round and the _________________ motion of rides like the Magic Carpet can both be described by the same basic physics formulas.

40. The Centennial Screamer rotates approximately 20 times in 90 s, with a ___________ of ~4 s.

41. The Centennial Screamer rotates approximately 20 times in 90 s, with a _____________ of ~1/4 Hz.

42. As the Tidal Wave swings wider and wider, its __________________ of oscillation increases.

43. The change in pitch of the music on the Musik Express as the cars move toward you or away from you is due to the _____________________.

44. If untethered, the planes on the Air Aces would fly off with a constant tangential velocity: this is an example of Newton's __________________ in action.

45. Gravity exerts a force on the roller coaster and riders, causing them to accelerate down the hills; this is an example of Newton's _____________________ in action.

46. The collisions occurring during bumper car rides are good examples of Newton's ____________________ in action.

Useful conversion factors:

1 in = 2.54 cm	1 J = 2.78 x 10^{-7} kw hr = 9.5 x 10^{-4} BTU
1 km = 0.621 miles	1 W = 1J/s = 1.3 x 10^{-3} horsepower
1 liter = 0.264 gal	1 g = 9.8 m/s^2 = 32 ft/s^2
1 hr = 3600 sec	1 N = 0.225 lb
1 fortnight = 1.728 x 10^6 sec	1 atm = 1 x 10^5 Pa = 14.7 lb/in^2
1 m/s = 3.6 km/hr = 2.24 mi/hr	1 kg/liter H_2O = 8.35 lb/gal H_2O

Answers:

1. Accelerates
2. Potential
3. Friction or air resistance
4. Gravity
5. Inertia
6. G-force or gravity
7. Kinetic
8. Deceleration
9. Air resistance
10. Centripetal force
11. Weightlessness
12. Jerk
13. Momentum
14. Deceleration
15. Work
16. Mass, weight
17. Elastic
18. Inelastic
19. Speed, velocity
20. Relative velocity
21. Free fall
22. Work
23. Potential energy
24. Chemical
25. Thermal energy
26. Kinetic energy
27. Lever
28. Pivot (Fulcrum)
29. Torque
30. Friction, air resistance
31. Turbulent
32. Luminar
33. Periods
34. Center of mass
35. Density, mass
36. Archimedes' Principle
37. Pressure
38. Fluids
39. Simple harmonic
40. Period
41. Frequency
42. Amplitude
43. Doppler effect
44. First law
45. Second law
46. Third law

ROLLER COASTERS

COLOSSUS, FIRE DRAGON

Ride Facts:

Colossus length 631.8 meters
Maximum Height of Colossus 26.5 meters
Speed before first loop (max speed of ride) 21.93 m/s or 79 km/hr
Acceleration in top of first loop 50.74 m/s^2
Acceleration in second still 7.49 m/s^2 (75% of gravity still presses rider in seat)
Speed right before reduction brake 17 m/s
Travel times:

Start, acceleration, travel to zenith	≈	40 sec
Downhill ride to reduction brake	≈	32 sec
Downhill braking in the reduction brake	≈	04 sec
Continuing travel or transportation	≈	30 sec
Preparing train for de-training	≈	08 sec
De-training and boarding	≈	24 sec
Total time	≈	138 sec

If one train running, train completes trip every 138 sec
If two trains running, train completes trip every 69 sec
If three trains running, train completes trip every 46 sec

Loaded train ≈ 7300 kg on High School Day
Length of train: 14.9 meters
Cars in train: 7
People per car (full): 4
Approximate cost per run for Lagoon to operate $28 (1992)

Questions:

1. Determine the reading on the accelerometer at the following locations in the first and second loops of Colossus:
   a. Bottom; b. Halfway up; c. Top; d. Halfway down; e. At the bottom

2. How high is the loop on Colossus?
   How long does it take the coaster to travel through the loop? What is the average speed through the loop?

   Height: ______ m Travel time: ______ s Average speed: ______ m/s

3. Would anything catastrophic happen if the loop were taller than the first hill?
   What? Why?

4. Why don't you fall down when you are upside down at the top of the loop?

5. If the speed at the top of the loop were higher, how would you feel and why?
   What if the speed were lower?

6. How high is the first hill on Colossus?
   How long does it take the coaster to climb the first hill? Descend the first hill?

   Height: ______ m Travel time: ______ s Average speed: ______ m/s

7. Where do you feel the heaviest? The lightest?

8. How does the height of the loop compare to the maximum height of the roller coaster? Why?

9. Determine the velocity before entering the first loop and just before reaching the braking section of Colossus. Compare the two velocities and determine the amount of energy that has been lost during the ride. Where has this energy been lost?

<u>Answers</u>:

1.
2. $v = d/t$, $d = 2\pi r = \pi h$ 20 m; 3.1 s; 20 m/s Values approximate.
3. Yes. Train would fall out of loop. Not enough speed to maintain circular motion.
4. You are falling! But you are also moving sideways in such a way that you and the car move in a circle and
   stay on the track.
5. Higher: increased acceleration. Lower: decreased acceleration.
6. 26.5 m. 40 s 6.6 m/s.
7. Entering loop; top of loop.
8. Loop height lower than maximum height. Conservation of energy precludes PE of loop exceeding initial PE.
9. The two points are at approximately the same height, so their PE are equal. The energy difference is then $\Delta E = kE_1 - kE_2 = 1/2m\ (v_1^2 - v_2^2)$. The energy is lost to disparative forces such as friction and air resistance.

   $V_{loop} = 22$ m/s $E_{loss} = 1/2\ mV_{loop}^2 - 1/2\ m\ V_{brake}^2$

   $V_{brake} = 17$ m/s $m = 7200$ kg + 100 kg (passengers)

   $E_{loss} = 7.1 \infty 10^5$ N

Energy lost due to friction and air resistance.

ROLLER COASTERS

JET STAR 2

Ride Facts:

Track: length = 580 m; height = 13.7 m
Time: ascending - 60 sec; descending 45 sec
First drop: distance = about 13 m; angle = about 42°; time = about 2.2 s
Radius of shortest curve = 6.0 m
Angle of bank of shortest curve = about 45°
Each vehicle is driven by a 7.5 hp motor

Questions:

1. What and where is the source of power for each vehicle for ascending to the top?
2. Is there power on the descent phase?
3. What is the ratchet sound and what is it for?
4. How do they stop the cars for loading and unloading?
5. As you are brought to the highest point of the track your potential energy (increases, decreases).
6. The track pushes you (outward, inward) on a curve.
7. The sharper curves are tilted (more, less) than gentle curves. Why?
8. The faster you go into a curve, the (more, less) tilted the curve will be. Why?

Estimations and calculations:

1. Estimate the speed at the top of the first hill.

2. Estimate the speed at the bottom of the first hill.

3. Use energy principles to calculate the speed at the bottom of the first hill and compare with the estimates in 2.

4. Using your estimate of the angle of the first hill, calculate the acceleration down the hill. (Assume that the motion is essentially frictionless.)

5. Using your estimate of the angle of bank and the radius of curvature given above, determine the speed around the shortest curve.

6. Calculate the centripetal acceleration while in the shortest curve.

Answers:

1. Electrical contacts under each car and a power line in the center of the track to the top.

2. No. The power line ends at the top.

3. Brake.

4. A tire in the center of the track engages the bottom of the car and by a torque applied to the tire stops the car in a few feet.

5. Increases.

6. Inward. Centripetal cceleration pushes you inward.

7. More. This higher banking provides the larger centripetal force needed for a small radius of curvature.

8. Greater. This higher banking provides the larger centripetal force needed for a larger velocity.

Answers to Estimates and Calculations:

1. Estimated speed is 2 to 3 meters/sec.

2. Estimated speed is 15 to 18 meters/sec.

3. The drop from the top of the track to the first hill is about 0.5 meters. Assuming no friction, an energy calculation gives a velocity of 3.1 meters/sec at the top of the hill. The hill is about 13.0 meters high. Again assuming no friction, an energy calculation gives 16.3 meters/sec.

4. Assuming no friction, $a = g \sin(42°) = 0.67$ g.

5. Assuming that the curve is banked like a highway to avoid any right or left accelerations, then $\mathrm{Tan}(\text{Ø}) = V^2/rg$ or $V = \sqrt{rg \tan(\text{Ø})} = \sqrt{6(9.8)\tan(45°)} = 7.67$ meters/sec.

6. $a = V^2/r = (7.67\ \text{m/sec})^2 / 6.0\text{m} = 9.9\ \text{m/sec}^2$.

ROLLER COASTERS

LOG FLUME: LAGOON-A-BEACH

There is a nice segment on this ride in the *PM Magazine* video (see Reference List).

Questions:

1. What turns the water wheel?

2. Where would you distribute the weight in the log flume to stay dry? Why?

Answers:

1. Motor.

2. Towards the rear. This keeps the front end up. Refer to the "Evening Magazine" video listsed in the USU Amusement Park Physics Video Time Log for further details.

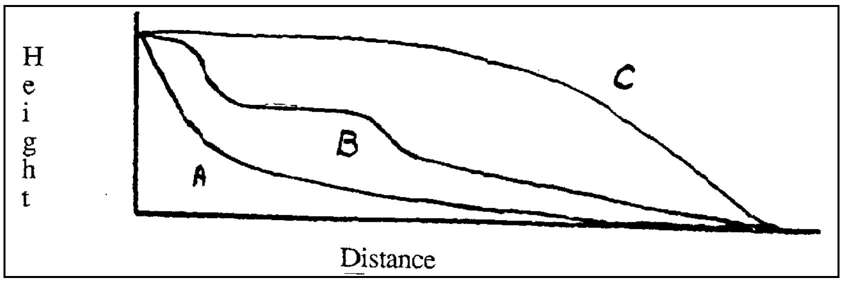
ROLLER COASTERS

WATER SLIDE: LAGOON-A-BEACH

Questions:

1. Is the final speed the same for objects falling from the same height?
2. Two water slides begin at the same height, but one slide has more turns. How does having more turns affect the final speed of an object?
3. What would happen to a person sliding down a dry slide?
4. Why do people travel faster than the water on the slide? (the fastest slides)
5. Why do people cross their legs when traveling down the fastest slides?
6. How fast (relative) would a steel ball travel down the slide?
7. Two water slides begin at the same height, but they have different configurations. How will this factor affect the speed of the participants?
8. What type of flow would be desired for the pipes feeding the top of the slides?
9. What type of flow occurs down the fastest water slides?
10. What type of flow occurs down the gentler (slower) sloped slides?
11. Where does the potential energy finally end up from the participants?
12. Why don't people travel on the slides head first or stomach down?
13. Would a steel ball roll faster down a dry slide or a wet slide? Why?
14. How does the mass of the participants affect their velocities?

15. Calculate the discharge in the canal.
16. If the pool and water slide were a closed system (that is, if no energy was added to or lost from the system), how many participants would be needed to raise the temperature of the water 10° C? Assume 20 m^3 of water and assume 2,500 Kcal/day per participant.
17. Which slide in the figure below will take the least amount of time (A, B, C)? Why?
18. What is the volume of water coming down the water slides (at the northwest corner of Lagoon-A-Beach)?
19. What is the power required to pump the water back to the top ($1m^3$ H_2O weighs 10^3 kg)?
20. How much area would be required to cover in solar panels (10% eff) (solar constant 1340 W/m^2) to run the pumps (80% eff)?



Answers:

1. Neglecting friction, yes. From conservation of energy, PE = mgh = 1/2 mv^2 = KE.
2. More turns and a longer track increases friction and decreases the final speed.
3. Excess friction will cause skin burns.
4. Water flow is turbulent which slows the speed of the water. People are sliding over the top of that water.
5. Minimize water impact.
6. Faster.
7. Final velocity will be the same to the extent you can neglect friction.
8. Laminar.
9. Turbulent.
10. Laminar.
11. Heat into the system.
12. Lose your suit.
13. Dry slide.
14. Velocities are essentially the same — inertia, however, will carry the more massive farther in the slow down pool.
15. Q = A Discharge = Area x velocity

    (Depth times width) x (meters per second or feet per second)

16.The 20 m^3 of water has a mass of $2 \infty 10^7$ gm (density of water is 10^3 kg/m^3). This requires $2 \infty 10^8$ cal or $2 \infty 10^5$ kcal of energy to raise the temperature 10°C (specific heat of water is 1 cal/gm-°C). Thus, only 80 participants, each contributing 2,500 kcal/day, are required.

17. A. Conservation of energy tells us that riders on all three slides will reach the same final speed (assuming no loss of energy to friction), as discussed in Question 1 above. However, the rider on slide A reaches a higher velocity sooner due to the steeper incline, hence the travel time to the finish is least.

18. Q = 3 slides · area · velocity = 3 · [(0.8 m) (0.7 m)] 0.5 m/s = 0.084 m^3/s = 302 m^3/hr = 22.2 gal/sec

19. $P = \rho Q g h = \frac{10^3 kg}{m^3} \left(0.084 \frac{m^3}{s}\right) (9.8\ m/s^2)\ 10\ m = 8.2\ kW$

20. $\text{Area} = \frac{P}{(.10)(.80)\ s} = 76\ m^2$

ROLLER COASTERS

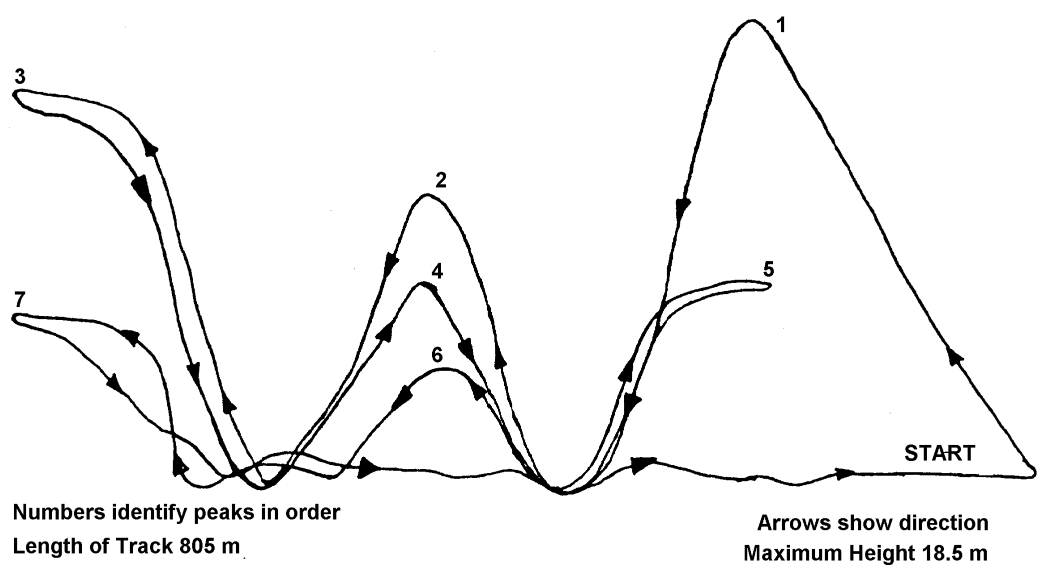
WOODEN ROLLER COASTER

Ride Facts:

Wooden Roller Coaster length 805 meters, 1/2 mile long
Built 1921, opened August 19, 1922
1 minute 55 seconds per run
Maximum height 18.5 m
Length of track 805 m

Questions:

1. How long does it take the coaster to climb the first hill? Descend the first hill?
2. Describe the sensations of weight at the following points, and compare them with the readings on your accelerometer.
   a. climbing the first hill
   b. at top of first hill
   c. going down the first hill
   d. at the bottom of the hill
3. Determine the height of the first and second hills.
4. Determine the maximum velocity of the ride.
5. Determine the angles of ascent and descent of the first hill.
6. Identify at least three (3) sources of friction in this ride.
7. Complete the diagram by putting in the proper labels. Label the following: minimum potential energy, G; maximum potential energy, X; maximum kinetic energy, K; minimum kinetic energy, M; weightless sensation, W; heavy sensation, H.



8. Determine the average speed of the roller coaster ride.

Answers:

1. 31 sec. 5.8 sec.

2. (a) Normal weight; no increased acceleration since upward velocity is constant.
   (b) Normal weight; no acceleration.
   (c) Decreased weight; acceleration in direction of g.
   (d) Increased weight; acceleration opposing g.

3. 18.5 m

4. 13 m/s

5. 28°. 40°.

6. Friction between wheels and track, air resistance, friction in axles and bearings.

7. G, at start and all equally low points in path; X at point 1; K at bottom of first hill; M at point 1; W on rise to points 1, 2, 3, 4, 5, 6 and 7; H on downward slope beyond points 1, 2, 3, 4, 5, 6 and 7.

8. Total time for ride t = 115 s. Length of ride L = 805 m. Average velocity $\overline{V}$ = 7 m/s.

SPINNING RIDES

CENTENNIAL SCREAMER

Ride Facts:

Number of carriers: 20
Number of people per seat: 2
Length of ride: 1.30 minutes
Length of time between rides: 2.00 minutes
Radius: 6 to 8 m
Minimum rotational period: 4s
Maximum angle of tilt: 85°

Questions:

1. Calculate the minimum speed necessary to stay in your seat at the top of the ride.
2. Calculate the frequency of the ride at full speed.
3. Compare kinetic energy and potential energy at four different points.
   a) at 12:00 b) at 3:00 c) at 6:00 d) at 10:00
   based on a clock face with 12:00 being the top and 6:00 being the bottom.
4. Measure the angle each car makes with the vertical as the wheel approaches full speed while still rotating horizontally. Is each car uniformly the same angle, regardless of its position around the wheel?
5. Calculate the circumference of the ride.
6. Determine the tangential speed of the ride.
7. Calculate the centripetal acceleration of the ride, when it is horizontal, using velocity.
8. Calculate the gravitational, centripetal, and tensional forces acting on you while you are on this ride. Do this for the following four cases:
   a) at rest;
   b) moving, but not tilted;
   c) moving, tilted, and at the top of the orbit;
   d) moving, tilted, and at the bottom of the orbit.

9. Draw a force diagram showing all of the forces acting on your body in each of the following situations:
   a) at rest;
   b) at full speed, but while still horizontally oriented;
   c) at full speed, but at maximum vertical orientation:
      i. at the top;
      ii. halfway down;
      iii. at the bottom;
      iv. halfway up.
10. Where did you feel lightest during the ride? (top, bottom, equal throughout)
11. Where in the ride do you feel normal weight (1 g)?
12. How did you feel your weight compared to your normal weight at:
    a) the lowest point when the ride was vertical? (greater than normal, same as normal, less than normal);
    b) the highest point when the ride was vertical? (greater than normal, same as normal, less than normal);
    c) any point when the ride was horizontal and at maximum speed? (greater than normal, same as normal, less than normal)?
13. Write a brief explanation of your answers to Question 12.

<u>Answers</u>:

1. $V_{min} = \sqrt{rg} \approx 8$ m/s (for r = 7m)
2. $f = \frac{1}{T} = 1/4$ Hz
3. Rotational KE the same for all points since the velocity is the same. PE is the same at 3:00 and 9:00, larger by mgr at 12:00 and smaller by mgr at 6:00.
4. ~ 5°.
5. $2\pi r \approx 44$ m (for r = 7m)
6. $v = 2\pi r/T = 11$ m/s
7. $a_c = v^2/r \approx 17$ m/s^2 downward.
8. Gravity is constant at 9.8 m/s^2. Centripetal acceleration is radial outward with magnitude 17 m/s^2. Tension is radially inward and balances the combined radial component of the first two forces.
9.
10. Top
11. one-half way down and one-half way up.
12. a) greater than normal; b) less than normal; c) same as normal.
13. At 6:00 centripetal acceleration is in opposition to gravity. At 3:00 and 9:00 centripetal acceleration is at right angles to gravity. At 12:00 centripetal acceleration and gravity point in the same direction.

DATA COLLECTION:

Questions:

1. Estimate the radius of the ride. ___________ meters
2. Measure the time for one full revolution when the ride is at full speed. _________ sec
3. How far from vertical is the ride at its highest? __________________ degrees

Answers:

1. 6-8 m
2. 4 s
3. 5°

SPINNING RIDES

FLYING ACES

Ride Facts:

10 planes each capable of carrying 2 people

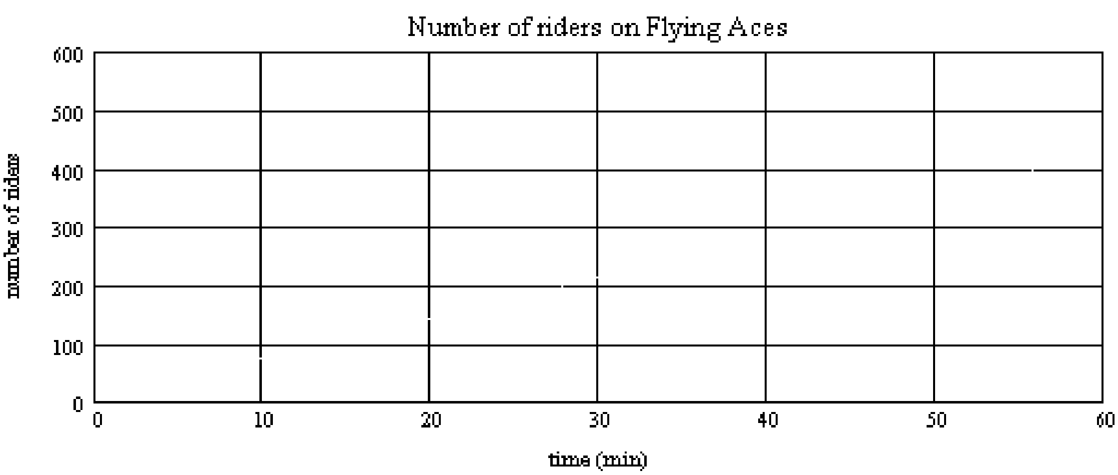
5.8 meters from center post to where the plane hangs vertical

5.0 meters distance that plane hangs from support arms

3.2 meters distance plane moves away from vertical when at a 40° angle

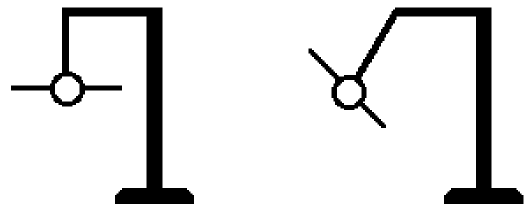
Questions:

1. What causes the plane to move away from the center when it rotates?
2. Although the center hub rotates at a constant rate, it does not feel that way when you are on the ride. Why?
3. Graph the number of people that can ride Flying Aces in an hour.



4. Planes move (toward, away from) the center as they turn faster.
5. What causes this to happen?

6. Diagram vector forces acting on the planes shown below.

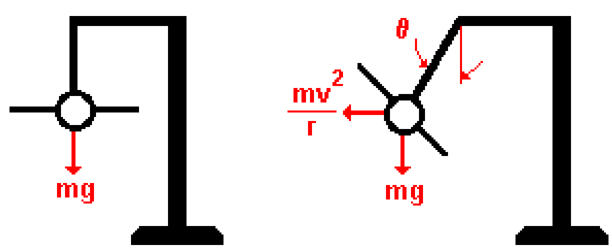


Plane at Rest | **Plane in motion at maximum angle from vertical**

7. Calculate the speed of the planes in the two figures above.
   ____________ m/s ____________ m/s

Answers:

1. Inertia.
2. You are unable to maintain the same angle of attack and therefore the plane moves in and out from the center. The changes in direction cause changes of acceleration.
3. Graph rises evenly from 0 to 300 by the end of 60 minutes.
4. Away from the center
5. Centripedal force.
6.



7. 0 m/s 10 m/s using
   $\tan\theta = mg/(mv^2/r) = gr/v^2 \Rightarrow v = \sqrt{gr/\tan\theta} = \sqrt{(9.8\ m/s^2)(9m)/(\tan 40°)}$

MEASUREMENTS:

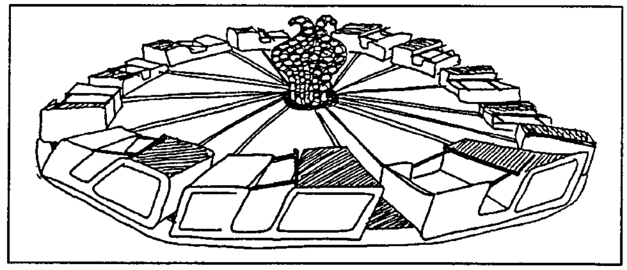
1. What is the time for a single revolution at top speed? ______________________ s/rev
2. What are the maximum and minimum radii of the planes and their angles with respect to vertical? Maximum: ______ m ______ ° Minimum: ______ m ______ °

Answers:

1. 5 sec per revolution using $v = 2\pi r/t$
2. Maximum: 9.0 m and 40° Minimum: 5.8 m and 0°

SPINNING RIDES

MUSIK EXPRESS



Ride Facts:

Number of carriers: 20
Number of people per carrier: 3
Length of ride: 1.30 minutes
Length of time between rides: 1.00 minute

Questions:

1. Calculate the change in your gravitational potential energy from the high to the low point.
2. Calculate the kinetic energy when moving at the maximum speed.
3. Calculate the total distance traveled during the ride. (Calculate for both the inside and outside rider.)
4. Compare the centripetal acceleration of the inside person to the outside person.
5. Calculate the frequency and period of the ride.
6. What minimum centripetal force is required to keep the 500 kg car loaded with riders of 100 kg, 80 kg and 50 kg moving in the circle at maximum speed?
7. Measure the time for one full revolution when the ride is at full speed. ____________ sec
8. How far from vertical is the ride at its highest? ________________ degrees
9. The more massive rider requires (a larger, a smaller, the same) force to stay on the inside.
10. The centripetal acceleration on a large rider is (more than, less than, the same) as on a small rider.
11. Explain how the ride would be different without the hills and valleys.

Answers:

1. PE = mgh
2. KE = 1/2 mv^2 (equals PE = mgh assuming no friction)
3. Distance = constant * # rev.
4. inside < outside
5. $f = \frac{\#rev}{sec}$ $T = \frac{\#sec}{rev} = 1/f$
6. $F_c = \frac{mv^2}{r} = \frac{m4\pi^2 r}{T^2}$
7. 4 s
8. 5°
9. Larger. $F_c = mv^2/r$. Therefore, larger m means increased centripetal force.
10. More than. See Question 4.
11. Acceleration would be uniform.

DATA COLLECTION:

Collect the following data and then do the calculations:

Questions:

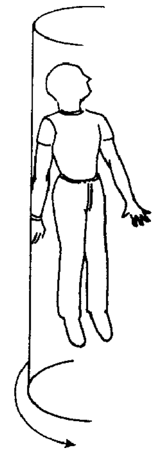
1. Estimate the radius for the inside rider: ________________ m
2. What is the time for one ride? ______________ s
3. How many revolutions does a rider make in one ride? _____________
4. Calculate the average angular speed. ______________ rev/s
5. Calculate the average linear speed of an inside rider. ______________ m/s
6. Would the answer to Question 5 be different for an outside rider? Why or why not?

Answers:

1. ~6 m
2. 78 sec
3. ~15 revolutions
4. 0.2 rev/sec
5. Circumference is $2\pi r$ or 37 m. Average linear speed is 7 m/sec.
6. Yes. Distance traveled per revolution is circumference $2\pi r$. This increases with increasing r.

SPINNING RIDES

ROTOR

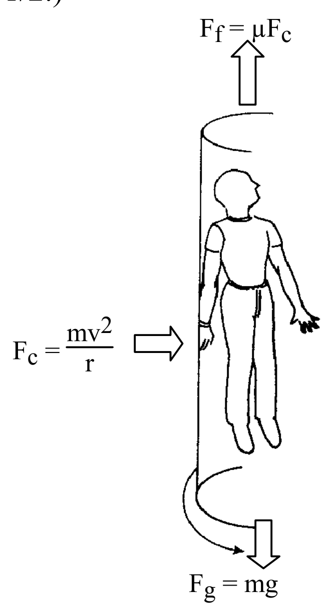


Ride Facts:

Typical diameter: D = 4 m
Typical period of rotation: T = 1-1/2 s
Typical total time of ride: t = 100 s

Questions:

1. One type of ride often found at amusement parks spins the riders, pinning them to the wall. The
   floor then drops out from under them! Estimate the diameter of the ride and the minimum period of rotation. What is the force exerted on a 65 kg student by the wall?
2. If the ride spins on a horizontal axis, how fast must it spin to keep Jane Student from falling on her nose? (Assume a coefficient of static friction of $\mu = 1/2$.)
3. Draw a free body diagram of the situation in Problem 1.



Free Body Diagram

Answers:

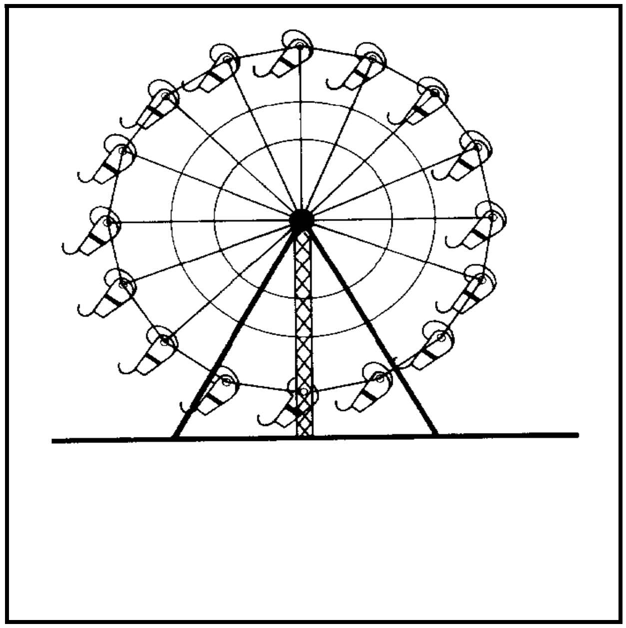
1. Using the typical value from above, the tangential velocity is $v = 2\pi r/T = 8.4$ m/s and the centripetal acceleration is
   $a_c = v^2/r = 35$ m/s^2. The centripetal force is
   $F_c = ma_c = 2300$ N.
2. To keep Jane from falling, the frictional force must at least balance the gravitational force. Thus, $F_f = \mu m(4\pi^2 r/T^2) = mg = F_g$

   and

   $$T = \sqrt{\mu 4\pi^2 r/g} = 2 \text{ s}$$

SPINNING RIDES

SKYSCRAPER FERRIS WHEEL



Ride Facts:

Height: 44 m
Mass: 181,000 kg
Radius at top: 21.8 m
Radius at bottom: 20.0 m
Radius of main wheel: 21.8 m
Height of car: 2.4 m
Period: 40 s
Ride cycle: 15-20 min.
Number of riders per car: 5-6
Number of cars: 36
Number of light bulbs: 180,000
Power consumption (including lights): 280 kW
Drive system - rim driven by four 25 W motors

Questions:

1. Where does a passenger experience the greatest g-force? The least g-force?

2. Why is the force that drives the Ferris Wheel applied to the outer rim rather than at the center?

3. The force that drives the Flying Carpet is not applied the same way as the Ferris Wheel. Why are they different?

4. Does a passenger experience near free fall?

5. Why are the light bulbs in parallel rather than series? (Give at least two reasons.)

6. How much power would be saved if 40 watt bulbs were used as opposed to 60 watt bulbs?

7. If there were only enough passengers to fill one-half the seats, how should the passengers be placed on the wheel?

8. If suddenly an electrical storm came up and lightning struck the Ferris Wheel, would the people riding be in great danger or would they experience very little danger? Why?

9. Describe the kinetic energy and potential energy of the entire wheel during one rotation.

10. Calculate the difference, if any, in the rider's velocity at the top and bottom of the Skyscraper.

Answers:

1. Halfway up on the rising side. Halfway down on the descending side.

2. A certain torque needs to be applied to turn the Ferris Wheel. This can be achieved with a small motor applied to the outer rim (with a large lever arm) or a large motor applied near the axis (with a small lever arm).

3. The Ferris Wheel has a constant velocity (except during starting and stopping) and is well balanced. These combine to require a constant applied force to run the ride. This is not the case for the Flying Carpet.

4. No. The change in vertical acceleration is not large anywhere on the ride.

5. Large voltages would be required to run series lights. When lights are in series, all lights go out when one bulb burns out.

6. 30%.

7. They should be distributed uniformly to maintain the wheel's balance.

8. The high altitude conductors forming the Skyscraper act as good lighting attractors. In principle, the structure is well grounded which minimizes the danger (but I would not want to test this design aspect).

9. The rotational KE is constant, since the magnitude of the velocity is constant. If the wheel is balanced the PE is also constant. Small imbalances cause small changes in PE.

10. The magnitude of the velocity is constant. The direction is tangential and therefore changes with rotation.

SPINNING RIDES

SPACE SCRAMBLER

Ride Facts:

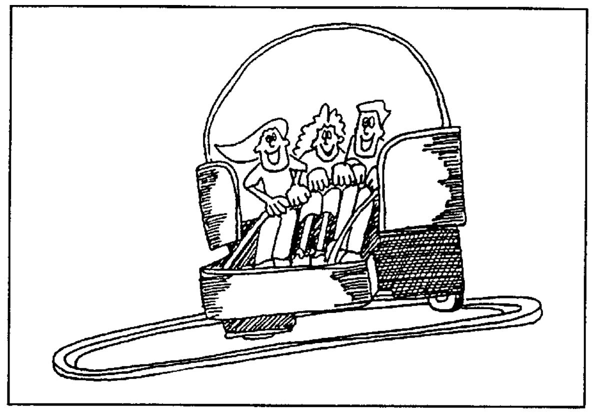
Number of seats: 12
Seat capacity: 3 persons
Length of ride: 1.30 minutes
Length of time between rides: 1.00 minute
Radius of primary axis: 5.5 m
Radius of secondary axis: 3.7 m

Questions:

1.

SPINNING RIDES

TILT-A-WHIRL



Ride Facts:

Number of carriers: 7
Number of seats per carrier: 4
Length of ride: 1.30 minutes
Length of time between rides: 1.00 minute

There is an excellent article by Kautz and Huggard (see reference list) on the chaotic dynamics of the Tilt-a-Whirl.

Questions:

1. Which direction does the ride rotate about the main axis?
2. Which direction does the ride rotate about the secondary axis?
3. How long (time in seconds) was the ride?
4. How many rotations about the main axis did the ride make?
5. What can you do, as a rider, to maximize the spin on the Tilt-a-Whirl?

Answers:

1. Counterclockwise
2. Depends on riders (direction will alternate)
3. 90 s
4. 8 revolutions
5. At the highest position of the carrier (relative to the ground), mass must be moved toward the direction the carrier is moving.

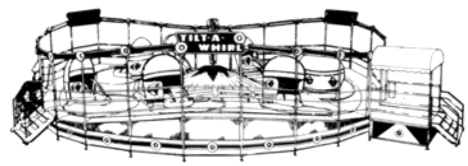
Activity:

Graph the acceleration vs. time for the Scrambler.

SPINNING RIDES

TILT-A-WHIRL

When you hang a stone from a string, pull it aside, and let go, the stone swings back and forth in an almost exactly repeating way. These repetitions are so regular that you can keep pretty good time with such a simple toy. In fact, if you look inside a grandfather's clock you'll see that the thing that "ticks" is a lot like a stone hanging from a string.



The repetitive swinging of a stone hanging from a string is very predictable. After you watch it for awhile it gets kind of boring. There are many things in nature that repeat like a swinging stone. For example, the sun comes up every day, the moon is full every month, the temperature gets hot every summer, your heart beats about once every second (at least, if you are sitting still and not watching a horror movie). Those things, just like the swinging stone, are predictable.

On the other hand, there are lots of other things which don't repeat in such a nice fashion and are very unpredictable. Some examples are the gurgling ripples in a rushing stream, the stretching and puffing of clouds blown by the wind, the flickering of a candle's flame, and the faces of a pair of dice that come up when you roll them.

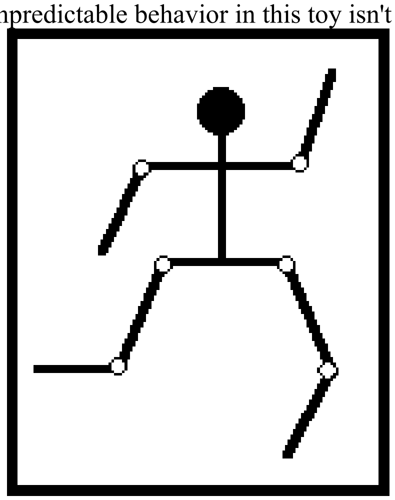
Why do you suppose that some things are so regular and others so unruly? Maybe some parts of nature are governed by rules and are tame while other parts are run by luck and chance and are wild. Maybe.

But, hold on a second. If you make a gurgling stream slow down enough the gurgles go away. And if you make the flame burn in just the right way it becomes as smooth and regular as can be. Hmm.

But, the situation's more complicated still. The summer is hot every year, all right, but never quite the same -- sometimes boiling, sometimes okay. And if you time your heartbeat very carefully you'll find it isn't regular either -- sometimes it's a little fast, sometimes a little slow.

There are good reasons to believe that tame and wild behavior are both governed by rules -- they are opposite sides of the same coin. People are beginning to realize that some things that appear to be run by chance and to be unpredictable (streams and flames and hearts are all examples) actually march to the same kind of rules as the swinging stone. We call such unruliness "chaos."

You may have seen a toy like the one pictured in the box. Its arms are free to flail about, as are its legs. The whole body rotates around a pivot in its chest. When you give the toy a good spin around its pivot, the arms and legs go every which way without any seeming rhyme or reason. If you give it a gentle spin, the arms and legs swing back and forth in a regular, repetitive manner. In both cases, the arms and legs go where rigid rules tell them to go. The wild, unpredictable behavior in this toy isn't due to chance. It's chaos.



The Tilt-a-Whirl ride at Lagoon is similar to this toy. Notice how unpredictable the ride feels. Pick a spot on the ground. Every time you pass that spot jot down (if you can) which way you're facing. Later, after you can think straight again, look at your record. Does it seem repetitive or irregular? The irregularity of the Tilt-a-Whirl is not due to some genie playing chance with you. This ride obeys rigid rules. The unexpected whips and turns you just experienced are chaos.

(So here's an interesting question for you to ponder when you have nothing better to do: When you have an accident or you have a little good luck or it rains when it isn't supposed to or you decide to eat a hot dog instead of a piece of pizza, is that because of chance, or are you doing a chaotic dance just like the toy?

SPINNING RIDES

TURN OF THE CENTURY

Ride Facts:

Length of ride: 140 s
Period of rotation: 7 s
Number of chairs: 48
Mass of chair: 30 kg
Length of support chains: 4.5 m
Distance of chairs from
 axis of rotation when at rest: 5.0 m
Separation of chairs when at rest: 1.9 m 22.5°
Distance of chairs from axis of
 rotation when moving: 8.2 m
Separation of chairs when moving: 3.2 m 22.5°
Deflection angle when moving: 45°

Questions:

Physics:

1. As the ride speeds up, you and your chair begin to move outwards: why?
2. Draw a sketch of the forces at work on the rider.

Observations and Estimations:

3. Estimate the length of the chair's support chain.
4. Estimate the distance of the chair from the axis of rotation when stationary.
5. Estimate the maximum distance of the chair from the axis of rotation when moving.
6. Estimate the mass of the average rider plus chair.
7. Measure the rotation period when moving at ride speed.
8. Estimate angle between ride chair and the vertical direction.

Theory:

9. Compute the angular velocity when the ride is moving at maximum speed.
10. Compute the force of gravity.
11. Compute the centripetal force when the chair and passenger are moving at maximum angular speed.
12. Compute from a force balance diagram the angle of the chair with respect to the vertical direction.

DATA COLLECTION (WHILE ON THE RIDE)

1. How long did the ride last? ________ s
2. How many times did you go around? ________ s
3. When stationary, how far were you from the axis of the rotation?
4. When moving, how far from the axis of rotation were you now?
5. Does the distance from you to the chair in front increase or decrease as the ride speeds up? At maximum speed, what is that distance? ______ m

(WHILE OFF THE RIDE)

6. How many chairs are on the ride? ________
7. When stationary, how far apart are they? ________ m

Questions:

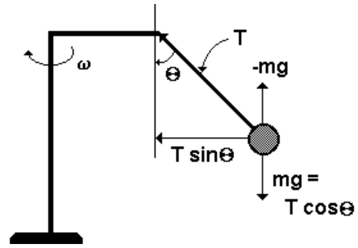
8. What is the circumference at the radius from which the chairs are hanging?
9. Hence, what is the radius, using the fact that $C = 2\pi R$? R = ________ m
10. Is this radius the same as you estimated in Q3?
11. Using information in Q1 and Q2 to get the time for a single turn and Q4, calculate the maximum speed you move.

$$\text{speed} = \frac{\text{circumference}}{\text{period of rotation}} = \frac{2\pi\text{Radius}}{\text{period}} = \text{\_\_\_\_\_\_\_\_ m/s}$$

12. How many miles/hour does this speed correspond to?________ mph (1 mile = 1609 m, and 1 hour = 3600 seconds)
13. Is this faster than your school bus coming to Lagoon?
14. As the ride speeds up, what happens to the passenger, her chair, and the chain supporting both?
15. What is the physics that leads to this effect called? Or how do you explain what you observe?

Answers - Physics:

1. The natural motion of the chair and rider is in a straight line.
2. As the ride speeds up there is a tangential acceleration (force) moving rider that way.



Answers - Observations and Estimations:

3. ~4.5 m
4. 5.0 m
5. ~8.2 m
6. ~100 kg
7. ~7 s
8. ~ 45 °

Answers - Theory:

9. 0.9 radians/sec.
10. mg= (100 kg)(10 m/s^2) = 1000 N
11. $f_e = mr\theta$ = 738 N
12. θ = factor (f_c/mg)

Answers - Data Collection:

1. 140 s
2. 21
3. ~5.0 m
4. ~8.2 m
5. Increases. 8.2 m
6. Three rows of 16.
7. 1.9 m
8. 11.9 m
9. 1.9.
10. Yes.
11. 2.9 m/s
12. 6.4 mph
13. No.
14. They all swing out at an angle.
15. Inertia. Moving objects will maintain a constant velocity unless an external force acts on them.

PENDULUM RIDES

MAGIC CARPET (1001 NIGHTS)

Ride Facts:

Gondola mass: 7200 kg
Capacity: 8 seats with 4 riders each
Distance from pivot to center of gondola: 8 m
Distance from pivot to center of counterweight: 3 m

Synopsis:

This ride illustrates elementary circular motion. It is also an example of a lever.

Questions:

1. Draw the free body diagram showing all relevant forces.
2. Given the radius and the time to fall from rest, what is the average angular and linear acceleration? How close did you come to being weightless (9.8 m/s^2)?
3. Where should you sit to maximize your centripetal acceleration, i.e., your g-forces?
4. What is the role of the counterbalance? Is it necessary?
5. Can the fulcrum be relocated? How would it change the ride?
6. Why is this ride driven from the axis while just the opposite is true of the Tidal Wave?
7. As you ride, does the wind velocity change with the location of the "carpet"? Why?
8. Estimate the circumference.
9. Where do you think the g-forces will be greatest/least? After the ride: were you right?
10. What kind of simple machine is this? Lever Inclined Plane Pulley Screw

PENDULUM RIDES

MAGIC CARPET (1001 NIGHTS)

Gondola mass: 7200 kg

8 seats with 4 riders each

Counterweight is designed to balance half-filled gondola

Assume rider mass is 70 kg ea.

A B C D E F

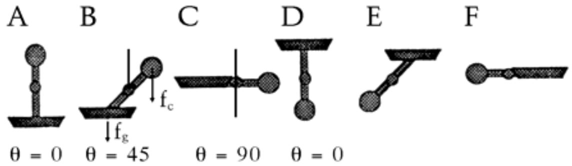
QUESTIONS

1. Estimate the distance from the axis of rotation to the center of the counterweight: __________ m.
2. At which position(s) is there maximum torque? Why?
3. Estimate the torque when the gondola is full of riders when in position A: ______ N-m; Position C: ______N-m; Position D: ______ N-m; Position E: ______ N-m.
4. How much energy is required to lift a full gondola from position A to position D? ____________ J.
5. Assuming free rotation (no friction) and zero velocity at position D, what is the rotational kinetic energy after the gondola falls to position A? ________ J. What is the angular velocity? ______________radians/s. What is the maximum linear velocity? ________ m/s

Estimate the dista

Answers

1.



2. r = 8m, t = 4.0 s. The circumference is $2\pi r$ = 50 m. The average acceleration is
$a = 2 \cdot [\frac{1}{2}\ 50\ m]/(4.0\ s)^2 = 3.1\ m/s^2$. This is 30% of the constant acceleration in free fall of 9.8 m/s^2. The angular acceleration $\alpha = a/r = 0.4\ s^{-2}$.

3. Since acceleration increases with radius, acceleration and force will be largest for riders at the ends of the gondola.

4. The counter balance reduces the torque on the pivot support and reduces the energy required to run the ride. (Refer to the next set of questions.)

5. Changing it would upset the positive effects of the counter balance.

6. Because this ride uses a counter balance (unlike the Tidal Wave), there is a much reduced torque. Thus a large motor is not needed, even when driving the ride from the axis. It is mechanically much easier to drive the ride from the axis.

7. The magnitude of the wind velocity changes since you move faster at the bottom of the ride than the top. The direction of the wind velocity also changes as it is tangential to the ride axis.

8. $C = 2\pi r$. C = 50 m.

9. Greatest g-forces occur when going upward with the gondola parallel to ground. Least g-forces occur at the bottom of ride.

10. Lever.

Answers

1. $r_c = 3$ m, $r_g = 8$ m

2. C or F. $\tau = mgr\sin\theta$. m, g and r are constant and $\sin\theta = 1$ is a maximum for positions C or F.

3. Net torque due to 16 riders (estimated mass m_r = 75 kg each) in gondola at radius r_g. A: 0 N-m.
B: $\tau = (16m_r)\ gr_g\sin 45° = 6.7 \infty 10^4$ N-m. E: $6.7 \infty 10^4$ N-m. F: $9.4 \infty 10^4$ N-m.

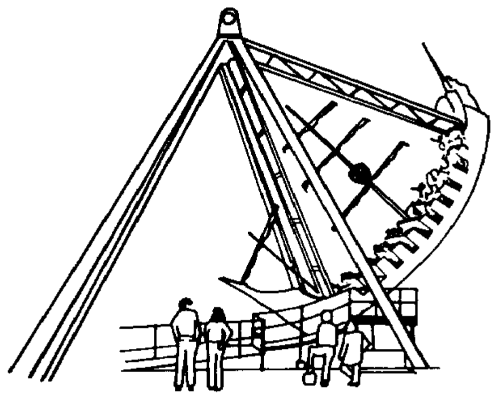
4. Energy required to raise full gondola
$E_g = (m_g + 32\ m_r)\ g\ (2r_g = (7200\ kg + 32 \infty 75\ kg)\ 9.8 \frac{m}{s^2} (2 \cdot 8\ m) = 1.51$ MJ
Energy gained by lowering counterweight
$E_c = m_c\ g(2r_c) = (22400\ kg)\ 9.8 \frac{m}{s^2} (2 \cdot 3\ m) = 1.32$ MJ
Net energy required $E_g - E_c = 0.19$ MJ or 12% of energy without counterweight
NOTE: Determine m_c from counterbalance condition
$$m_c g r_c = (m_g + 16\ m_r)\ g r_g$$

5. From conservation of energy KE = $1/2\ mv^2 = 1/2\ (mr^2)\ \theta^2 = E_g - E_c - 0.19$ MJ
$v = \sqrt{2(E_g - E_c)/(m_g + 32\ m_r + m_c)} = 0.3$ m/s
$\theta = v/r = (0.3\ m/s)/8m = 0.04$ rad/s

PENDULUM RIDES

TIDAL WAVE

Ride Facts:



Number of rows: 8
Number of seats per row: 5
Number of passengers: 40
Length of ride: 1.30 minutes
Length of time between rides: 30 s
Length of boat: 13.0 m
Strut support length (effective length of
the pendulum): 12.9 m
Period: 7.8 s
Maximum angular displacement: 37.5 °

Synopsis:

The tidal wave is an example of a pendulum. It behaves as if all of its mass were concentrated at the center of mass. For small displacements, ignoring friction or other forces (besides gravity), its period is related to the distance to the center of mass (L) and the acceleration of gravity (g)

$$T = 2\pi\sqrt{\frac{L}{g}}$$

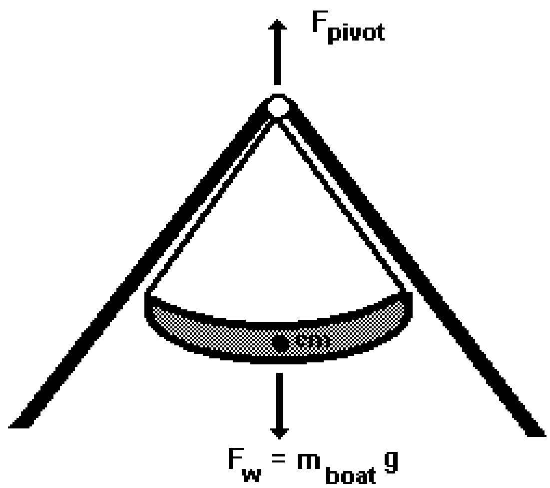
Questions:

1. What types of forces are at work on you as you ride this ride?
2. At what point does your body feel the greatest amount of force pushing it downward?
3. At what point does your body feel the least amount of force pushing it downward? Explain this sensation of weightlessness.
4. Ride the ride with your eyes closed. In what way does it feel different than when you ride with your eyes open?
5. How many supports are there? ________ When does the supporting structure experience the most force: (at the top) or (at the bottom) of the swing?
6. Maximum angular displacement? ________________
7. What is the period? __________
8. What is the origin of the force needed to get the boat moving?
9. Draw the free body diagram showing all relevant forces.
10. Why isn't the boat driven from its point of suspension?
11. What would be the trajectory of a particle launched from the moving frame of the boat? (Think about various points along the swing.)

12. Estimate the value for L.
13. What is the length of the distance traveled by the boat in one period?
14. What is the average speed of the ride during a full swing of the boat?
15. During a swing of the pendulum when is the kinetic energy greatest? Lowest?
16. During a swing of the pendulum when is the potential energy greatest? Lowest?

<u>Answers</u>:

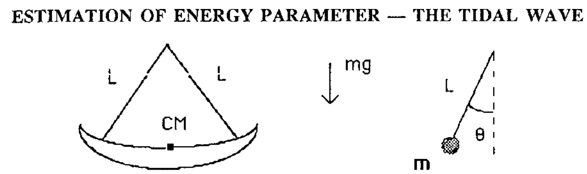
1. Gravitational force (downward) and centripetal force (radially outward).
2. At the bottom of the arc. Here the gravitational force <u>and</u> the centripetal force are both downward.
3. At the moment the pendulum begins to move downward from its maximum angular displacement. Here the order is essentially in free fall and hence experiences weightlessness (almost).
4. Without a visual reference, it is difficult to determine which direction is down.
5. Maximum force on the supports occurs when the torque is largest, when the pendulum is at maximum angular displacement.
6. 38°
7. 7.8 s
8. A motor.
9.



10. Driving the boat from a point far from the point of suspension uses the mechanical advantage of a lever requiring a smaller force.
11. The particle would have the trajectory of a projectile with an initial velocity tangential to the motion of the boat at the instant it is thrown.
12. 12.9 m
13. Circumference of full revolution is $2\pi L = 81.1$ m. Distance traveled in one period is $2\,(2\pi L)\,(38°/360°) = 17.1$ m.
14. 2.2 m/s
15. KE is highest at the bottom of swing, and lowest at the top of swing.
16. PE is highest at the top of swing. PE is lowest at the bottom of swing.

PENDULUM RIDES

ESTIMATION OF ENERGY PARAMETER – TIDAL WAVE



The Tidal Wave ride is a pendulum. The gravitational force on a pendulum is shown in the figure, the magnitude of the force is F = mg sinθ, where g is the acceleration due to gravity. The energy of the pendulum is

$$E = \frac{1}{2}\ m v^2 + m\ g\ L(1 - \cos\theta)$$

where v is the linear velocity of the center of mass. Assuming that other forces are negligible and that the angle of displacement (θ) is small (so that $\sin\theta \approx \theta$), we have a *simple pendulum*. The *simple* pendulum oscillates in a simple harmonic fashion with period

$$T = 2\pi\sqrt{\frac{L}{g}}$$

Notice that the period is independent of the mass or amplitude.

1. Estimate the distance to the center of mass: L =______ ± _____ meters
2. Measure the period of the oscillation at maximum amplitude. T = _____ ± _____ seconds
3. What is the maximum angular displacement of the center of mass? θ_{max} = ____ ± ____ radian
4. What is the average *speed* of the ride during one swing (from θ_{max} to θ_{max})? $\langle v \rangle$ = ______ ± _____ m/s
5. Neglecting friction, what is the energy per unit mass supplied to the ride to get it oscillating at maximum amplitude? $\frac{E}{m}$ = ____ ± ____ Joules/kg
6. Is the tidal wave approximately a *simple* pendulum? Yes__ No__ Why? Why not?
7. Assume that the ride is driven by a 220 V motor and that the motor works for 1 minute to bring the ride to maximum amplitude and then does no more work. If the loaded ride weighs 20 tons and electricity costs 5 cents per kilowatt-hour, how many times do you have to ride the Tidal Wave to use up your $12.00 admission fee?

Answers:

1. 12.9 ± 0.2 m
2. 7.8 ± 0.2 s
3. 38°
4. 5.0 ± 0.5 m/s
5. Energy per unit mass is $E/m = gL\ (1 - \cos\theta_{max})$ or 26.8 joules/kg
6. No. The measured period (7.8 s) does not match the period predicted by the theory for simple harmonic motion (7.2 s). Possible sources of error include the facts that the oscillation angles are not small, the oscillations are driven, and the oscillations are damped by friction.
7. From Question 5 the total energy (neglecting friction) required is (26.8 joules/kg) (20 tons · 907 kg/ton) = $4.9 \infty 10^5$ joules = 0.14 kilowatt-hours. The electricity to do this amount of work costs money. Therefore, it would take 1700 times on the ride to use up your $12.00 admission fee. In practice, friction accounts for most of the energy needs and hence drastically increases the cost per ride.

OTHER RIDES AND ACTIVITIES

BUMPER CARS

Ride Facts:

100 kg bumper car
300-400 DC amps
50-60 V DC
Parallel circuit

Questions:

1. Why is the floor smooth and the top a wire grid?
2. What type of circuit is illustrated by the bumper cars - parallel or series? Why must it be this type of circuit?
3. What happens in a collision to each car when?
   a. one bumper car is not moving?
   b. a rear-end collision takes place?
   c. a head-on collision takes place?
   d. bumper car hits a stationary object, i.e. the wall?
   e. cars sideswipe each other?
4. When will a driver:
   a. feel the strongest jolt?
   b. be thrown forward?
   c. be thrown backward?
   d. be accelerated?

5. Why is the car bumper made of rubber? What would be the effect of steel bumpers?
6. What four things do forces do? Do bumper cars illustrate these four?
7. How is the power to the cars controlled?
8. Is the voltage the same throughout the grid? Why?
9. Calculate the momentum of the bumper car at full speed if its mass is 100 kg? ($p = mv$)

10. Calculate the kinetic energy of a car. ($KE = 1/2mv^2$)
11. How much give is there in a bumper car's bumper?
12. How much energy is lost to sparking?
13. Is there an ozone rich atmosphere? Why?
14. What is the impulse of an average collision?
15. What is the time of interaction of a collision?
16. If your car is hit head on by another car, what direction is your car accelerated? How do you know?
17. If your car is hit head on by another car, what determines whether your car continues to move forward or backward after the collision? (Hint: $F = ma$)
18. What is the role of friction between the cars and the floor? In what direction do you think the friction is greater?
19. Why would you not design a bumper car with very soft bumpers? Why would you not design a bumper car with no bumpers at all?
20. What would happen if the circuit was series?
21. For 30 cars, what is the current per car?
22. Assuming constant voltage, what happens when there are half the cars?
23. What type of electricity is used on the bumper cars? AC or DC? Why?
24. Which of Newton's laws are illustrated?
25. What is the difference between two pieces of clay that collide and two marbles that collide? Do bumper cars behave more like clay or marbles?

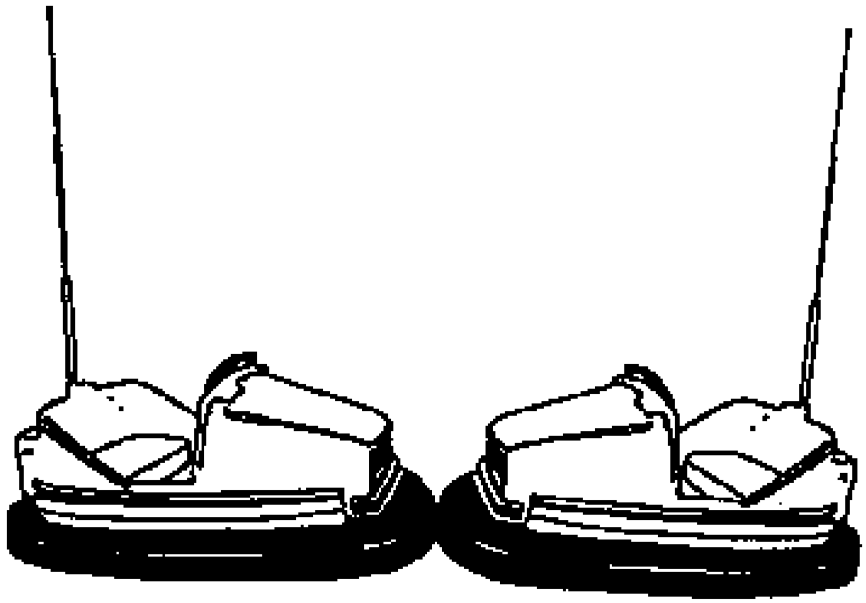
Answers:

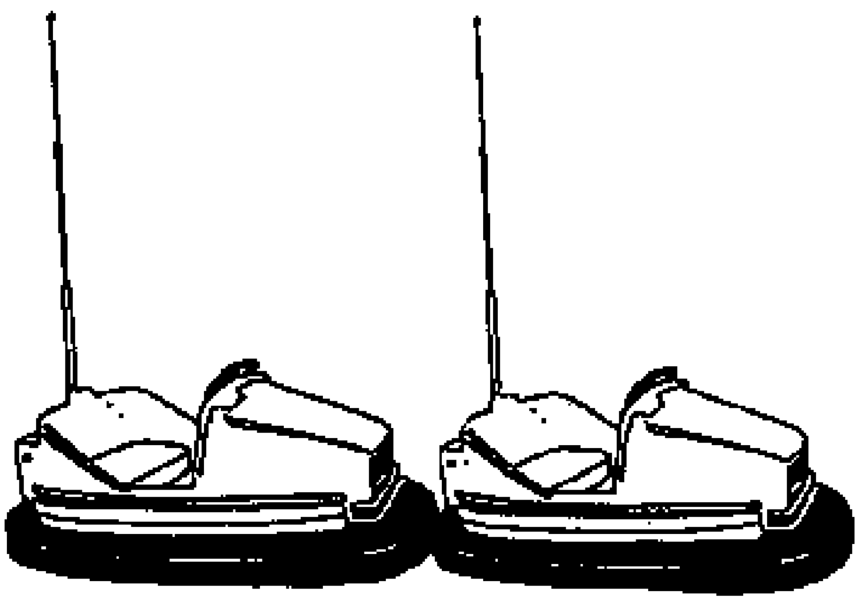
1. The floor is smooth to reduce friction. The top can be a wire grid or a sheet of metal; any conductor will do the job.
2. Parallel. Serial operation would require a much larger (and more dangerous) voltage.
3. a. Stationary car and rider move in direction of moving car.
   b. Rider and car thrown forward.
   c. Cars tend to step, or move slowly in direction of car with larger momentum.
   d. Car and rider recoil backwards.
   e. Cars and riders thrown sideways away from collision.
4. a. Head-on collision.
   b. Head-on or rear-end collision.
   c. Collision with stationary object.
   d. During any collision.
5. Rubber bumpers cause nearly elastic collisions, no damage — steel bumpers would cause very inelastic collisions with destruction.
6. (1) change direction; (2) change shape; (3) start things moving - speed up; (4) stop things - slow down

   (yes)
7. By operator's foot pedal.
8. Yes. Same potential in parallel circuit.

9. [100 kg + ________________] ∞ velocity = momentum. Assuming a student mass of 45
   student's mass)
   kg and a velocity of 2 m/s, the momentum is 290 kg-m/s.
10. KE = 1/2 mv^2 = 290 J
11. A lot.
12. 30% +
13. Yes. Amounts of sparking produces ozone.
14. I = time of contact (sec) ∞ force
15. Less than 1 sec.
16. Reverse. Newton's 2nd Law
17. Large masses move forward equal or smaller masses move backward.
18. Friction slows down cars. Also contact. Reverse action has more friction.
19. No jolt. Too much cushioning on collision. Destruction.
20. Operation is possible, as long as the voltage can always flow through all the cars in the correct order. However, series operations would require a much higher (and more dangerous) voltage.
21. ~10A
22. Less total current flow.
23. DC
24. All.
25. Clay has INELASTIC collision. Marbles collide nearly ELASTICALLY. Bumper car collisions are rather
    inelastic.

BUMPER CARS
NEWTON'S LAWS OF MOTION

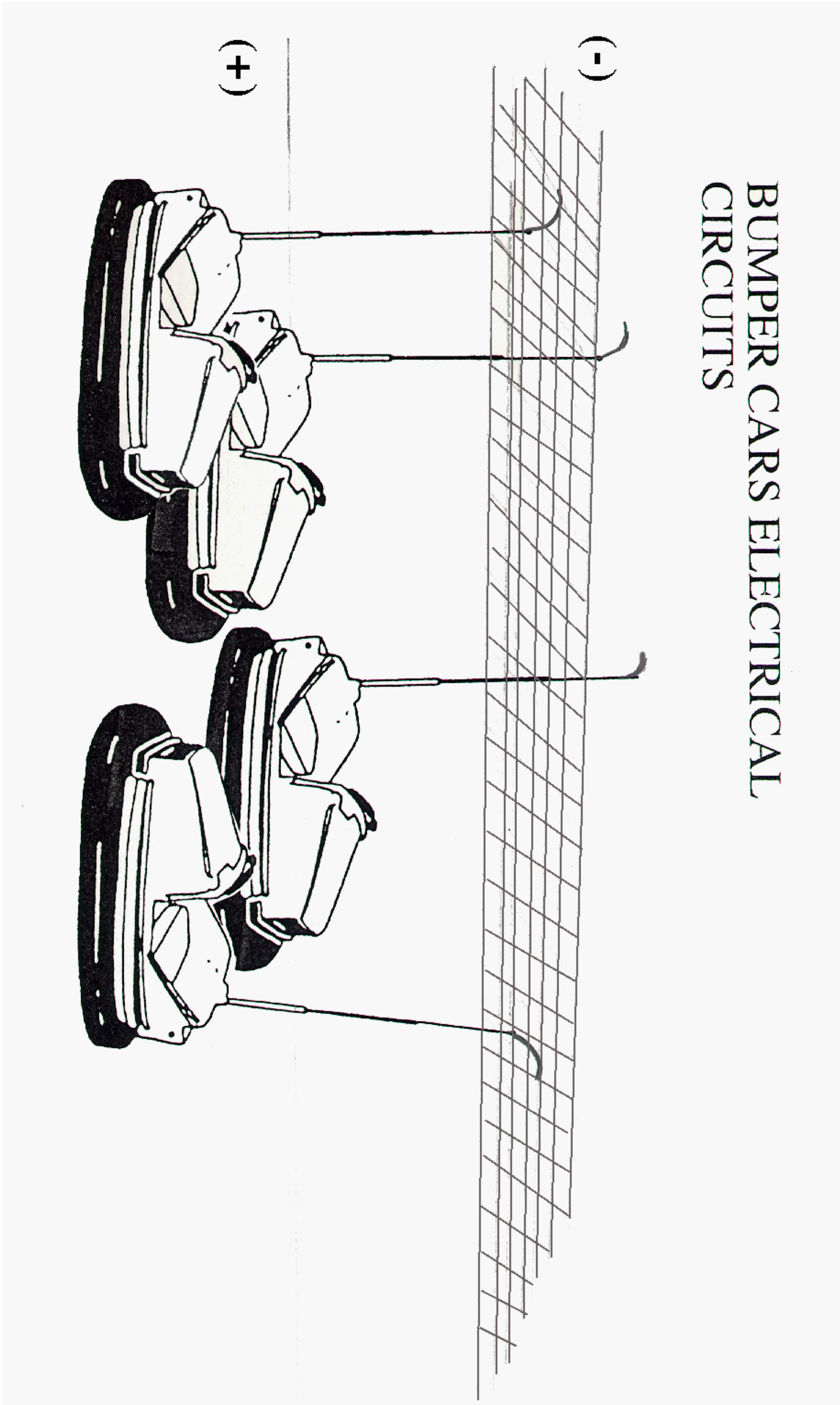




LAW OF INERTIA

F = MA

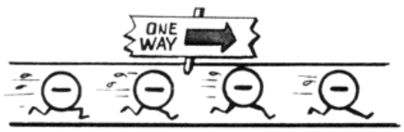
EQUAL BUT OPPOSITE REACTION


BUMPER CARS ELECTRICAL CIRCUITS
(+)
(-)

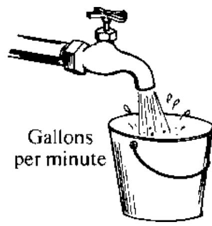
OTHER RIDES AND ACTIVITIES

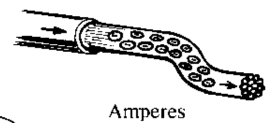
FLOW RATES

An important concept that shows up in many branches of physics is flow rate (sometimes called flux). Flow rates measure the amount or number of something going past a certain point in a certain amount of time. The questions below provide several examples of flow rate found at Lagoon.



DC Current always flows one way at the same strength.





QUESTIONS

1. Check out the biggest water slide in the Water Park. Estimate the water flow rate in cubic feet/min. (HINT: Estimate the cross-section - the height time width - of the water in the trough. Then multiply by the velocity of the water in feet per minute. Also see Page 7.)

2. The lights on the Skyscraper Ferris Wheel are 40 W 120 VAC bulbs. Estimate the electron flow rate through each bulb in number of electrons per sec. (HINT: First calculate the current through each bulb in Amps, where current is power (in W) divided by voltage. Then convert current to electrons per second. Recall 1 Amp = 1 Coulomb per sec and that there are 6.2 x 10^{-18} electrons per Coulomb).

<u>Answers</u>

1. Slide cross-sectional area $A = Hw = (0.3\text{ ft})\,(3\text{ ft}) = 0.9\text{ ft}^2$ Maximum possible velocity can be found by equating the PE at the top of the slide to the kE at the bottom.
   $PE = mgH = (1/2)mv^2 = KE \Rightarrow v = \sqrt{2gH}$ $v = \sqrt{2(9.8\text{ m/s}^2)\ 20\text{ m}} = 20\text{ m/s}$.
   Friction and turbulent flow will reduce this to ~ 18 m/s. Finally, the flow rate
   $Q = Av \approx 16\text{ ft}^3/\text{s} = 970\text{ ft}^3/\text{m}$.

2. For one bulb $I = P/V = 40W/120V = 0.33$ A.
   This corresponds to 5.3 ∞ 10^{19} electrons per second. There are bulbs on the ferris wheel. Thus the total current is A and the total electron flux is ∞ 10 .

OTHER RIDES AND ACTIVITIES

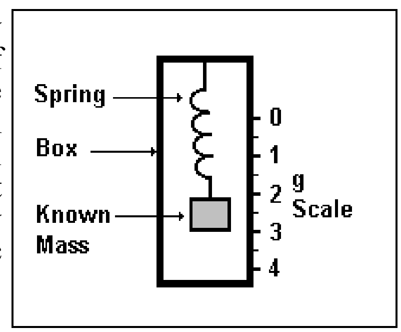
WAVES AND PERIODIC MOTION

A key aspect of physics is the ability to develop descriptions (physical laws) which are applicable to a wide array of natural phenomena. Often it is the language used in our descriptions, the language of mathematics, which makes it easy to recognize that problems that appear completely different on the surface are, in fact, very similar. An excellent example of this aspect is the similarities of circular motion, simple harmonic motion, pendulum motion, and sinusoidal motion. All of these types of **periodic motion** can be described by the simple trigonometric equation for motion in some coordinate X as a function of time, t:

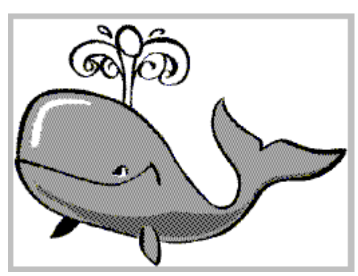
$$X(t) = X_{max} \sin[(2\pi/T)t + \delta]$$

where X_{max} is the maximum motion in X (called the amplitude), T is the time it takes for the motion to begin to repeat (T) is called the period), and $X_{max} \sin(\delta)$ is the position at time equals zero (δ is called the phase factor). Refer to the figure at right. There is no better place to see how this works than at the amusement park.

In simple harmonic motion, we have a single coordinate, say height H, which repeats periodically. For example, the height of someone bouncing up and down after jumping off a bungee tower or the height of a mass in a spring accelerometer is given by $H(t) = H_{max} \sin[(2\pi/T)t]$. [Note: here and below we will assume we start our timer when the motion is at its midpoint, that is when the coordinate is zero. Then $\delta=0$.] Can you identify other rides in the park which exhibit this kind of simple harmonic motion; can you write down their equations of motion?

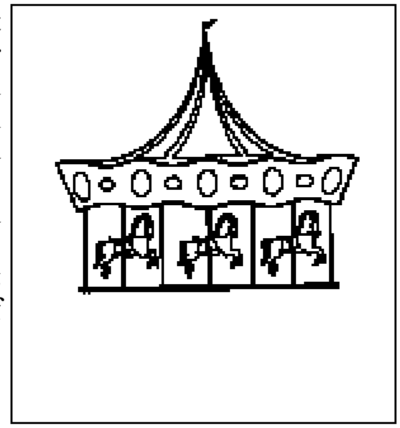


To see how this up and down motion relates to the sine function, go visit Bulgy the Whale, adjacent to Lagoon-A-Beach. The up and down motion of the whales, Z(t), is guided by a sinusoidal shaped track; the motion can be described by the equation $Z(t) = Z_{max} \sin[(2\pi/T)t]$. Also note that horizontal circular motion of Bulgy the Whale can be described with equations of the same form. The motion in the East-West and North-South directions can be described, respectively, as:



$$X(t) = X_{max} \sin[(2\pi/T)t] \quad \text{and} \quad Y(t) = Y_{max} \sin[(2\pi/T)t]$$

The horses on the Merry-Go-Round are another excellent example of the same combination of motions, horizontal circular motion and vertical simple harmonic motion. Actually, if you look closely at the drive mechanism for the up and down motion of the horses, you will see how the vertical motion is created using a cam moving in a circular motion. If you look at this, it is easy to see why the physics of simple harmonic motion and circular motion are so similar! Can you write down the appropriate equations of motion for the horses in the x, y and z directions? How about the equations for the circular motion of the Sky Scraper Ferris Wheel? Can you identify other examples of circular motion and write down their equations of motion?



Circular motion is easily related to pendulum motion. Watch the motion of Magic Carpet. During mid-ride, the gondola moves in a complete circle. This motion (at least approximately) can be described by the equations Y(t) = R sin[(2π/T) t] and Z(t) = R sin[(2π/T)t], where R is the radius from the pivot to the gondola. At the beginning and the end of the ride, the gondola acts like a pendulum rather than an object in circular motion. But this is the same physics; we simply replace R in the equations above with the amplitude Y_{max} (the maximum horizontal displacement of the gondola from the bottom position) and R with the amplitude Z_{max}:

$$Y(t) = Y_{max} \sin[(2\pi/T)t] \quad \text{and} \quad Z(t) = | Z_{max} \sin[(2\pi/T)t]|$$

Note for the vertical motion we added absolute value notation, since Z is only above the bottom position. Other pendulum rides include Tidal Wave and Sky Coaster. Can you write down the equations of motion for these or other pendulum rides?

Finally, note that wave motion can be described with the same equations. For example, the height of the water waves at Lagoon-A-Beach, the density of air in sound waves from the myriad sounds around the park, the oscillating electric fields in AC electrical lines used to power the rides, and even the electromagnetic fields associated with the light from all the bright lights can ***ALL*** be described with equations of the same form used above.

Physics can be much simpler (and very elegant), if you learn the language!

OTHER RIDES AND ACTIVITIES

TO CATCH A WAVE

Waves are all around us. There are many kinds of waves at Lagoon, with wavelengths from a few meters long to 10^{-20} m long. Some you can see, some you can hear, and some you can feel. A common theme in the physics of these problems is how to describe the waves. Briefly,

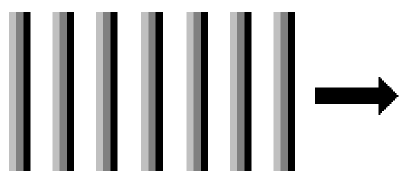
$$v = \lambda\nu$$

λ (lambda) is the wave length, that is the distance between peaks in meters.

ν (nu) is the frequency, that is the time between peaks in 1/s or Hz.
v is the speed of the wave in m/s.

v_S = 331 m/s is the speed of sound in air.
$c = 3 \infty 10^8$ m/s is the speed of light in vacuum.

Transverse Wave



Longitudinal Wave

Questions:

1. Can you find two examples each of waves with 10 m < λ < 10 cm? With 10 cm < λ < 1 mm? With λ < 1 mm?

2. What is oscillating or vibrating in each wave you listed above?

3. How fast is each wave moving?

4. Using the equation in the box above, calculate the frequency of each wave.

5. Are each of the waves transverse or longitudinal?

Answers:

Type of wave	λ	ν (m/s)	ν (Hz)	mode
Water	0.6 m	~2.4	4	longitudinal
Radio	1 m	$3 \infty 10^8$	$3 \infty 10^8$	transverse
Bass Sound	3.4 m	331	100	longitudinal
Vibrations of a Motor	5.5 m	331	60	longitudinal
Infrared Radiation	0.1 cm	$3 \infty 10^8$	$3 \infty 10^{11}$	transverse
Treble Sound	3.3 cm	331	$1 \infty 10^4$	longitudinal
Red Light	600 nm	$3 \infty 10^8$	$5 \infty 10^{14}$	transverse
Blue Light	300 nm	$3 \infty 10^5$	$1 \infty 10^{15}$	transverse
Gravitational Wave	10 m	$3 \infty 10^8$	$3 \infty 10^7$	transverse
"The Wave" in a Stadium	20	40	2	transverse

OTHER RIDES AND ACTIVITIES

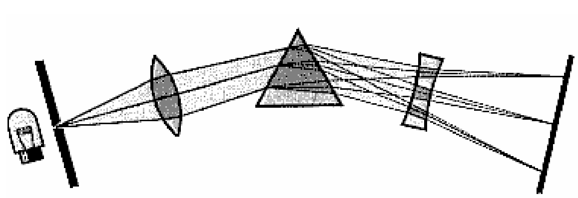
BUILDING A SPECTROSCOPE

A spectroscope is a simple device that will break incoming light down into its component wavelengths (colors). If the incident light is white (all colors), then the result will be a "rainbow" spectrum. Light that is emitted when some gases (for example, neon) are stimulated by an electrical current will consist of only a few colors, and the spectroscope will produce a spectrum consisting of only a few lines when light from these gases enters it.

The basic components of the spectroscope are a diffraction grating and a tube. An expensive diffraction grating might be a metal plate with many extremely fine parallel lines etched in it. Cheaper diffraction gratings may be cut from sheets of plastic with fine lines scratched in them (available from Edmund Scientific: Fax: 1-609-573-6295, Item #E40,267). A 3 cm x 3 cm piece of diffraction grating may be mounted on the end of the tube directly or made by mounting it in a slide frame first for ease of handling. The diffraction grating may be used by itself without the tube, especially in situations where the light in the room is coming from one source only. In situations with more stray light, the spectrum will be more clearly visible looking through the tube.

Before mounting the slide on the tube, determine the orientation of the grating material. (It will be impossible to see the scribed lines directly.) Look through the grating towards a narrow line source (such as a neon lamp) in an otherwise dark room. You will actually want to look slightly to one side of the source. Several very thin, bright lines of different colors should appear. If they do not, rotate the grating by 45°. Once the lines appear, the grating will be properly oriented. With the lights back on, quickly mark the "up" direction on the properly oriented grating. Now tape the grating to one end of the tube. Toilet paper and paper towel tubes work well. Make sure that the grating completely covers the end of the tube; if it does not, cover the remainder with aluminum foil or black tape.

Now cover the other end of the tube with aluminum foil and make a narrow slit down the foil from the "up" direction as marked on the grating to the down direction. A straight pin or a tack may be used to make the slit. Now test the spectroscope by looking through the diffraction grating end. Aim the slit directly at the light source, but look through the grating at an angle so that you are looking at the inside of the tube. The same set of thin bright lines should appear. If not, move the spectroscope around slightly. If the lines still do not appear, make the slit wider.



Amusement Park Physics

Inservice Workshop

Black and White: Which is Hotter?

Background

Different materials, and the same materials with different colors or surface textures, absorb different amounts of radiant heat energy from light. This means that if a white object and a black object made of the same material are in the sun, or under a heat lamp, or even just sitting in a room with the lights

demonstrate this, we set two soda cans full of water in front of a heat lamp for several hours, and recorded the temperature versus time for both cans. In this Mathcad sheet, we will enter this data, and plot the temperature versus time for both cans.

Data Entry

We begin by entering the data for the elapsed time and temperatures (in °C) of the two cans.

Number of Data Points: $Num := 7$ $n := 1 .. Num$

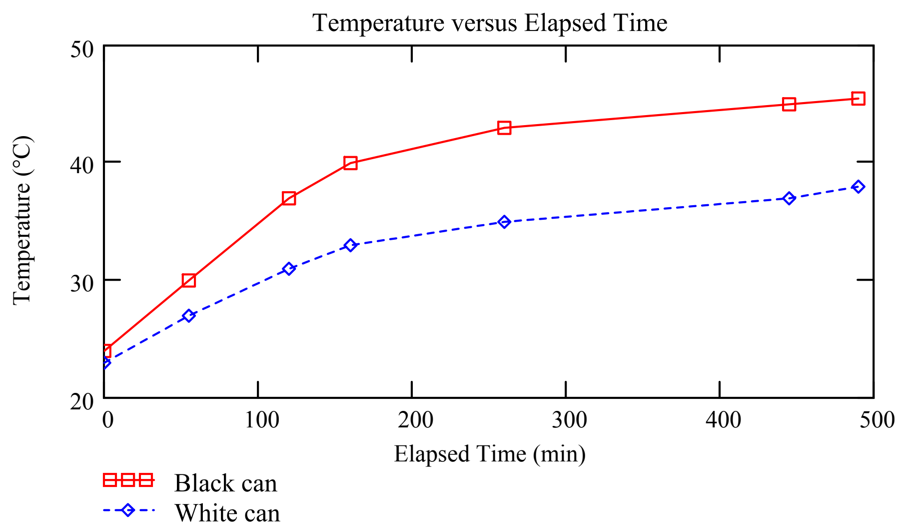
Data:

$T_{elapsed_n} :=$	$black\_temp_n :=$	$white\_temp_n :=$
0	24	23
55	30	27
120	37	31
160	40	33
260	43	35
445	45	37
490	45.5	38

$$T_{elapsed} := T_{elapsed} \cdot min$$

Results

Let's now plot the data and see how the temperature changes as a function of time:



white. Another observation we can make regards the shape of the curves.

begins to level off. This happens as the two bodies come into equilibrium with their surroundings. The temperature levels off as the amount of heat energy given off by the bodies equals the amount absorbed.

Extensions

Here are some extension questions:

Can you identify different ways that heat energy is given off?

How would you expect the plot of a blue object or red object to compare to those above?

How would the material affect the amount of heat energy adsorbed?

Would you expect a silver item to be hotter or colder than the white object?

CURRICULUM MATERIAL CROSS-INDICES

Section B of this manual lists a large number of Amusement Park Physics Activities organized by the type of rides and the individual rides on which the activities take place. This is particularly useful if you are walking around Lagoon in search of things to learn. However, since a primary objective of this Curriculum Manual is to promote the use of Amusement Park Physics concepts and activities outside the amusement park and in the classroom, it is useful to view the activities as organized in relation to more traditional curriculum.

This section of the Manual presents four cross-indices to provide different prospectives to the teacher. The first table lists physics topics, organized as you might find them in a typical physics text. The second index cross-references related activities to material in the Curriculum Manual. The third and fourth indices cross-reference the material found in this manual to concepts listed in the 1995 Utah Science Core Curriculum and the pre-1995 Core Curriculum, respectively. A topical index is found at the end of the Curriculum Manual.

Table C-1: Physics Concepts Reference Cross-Index

Physics Concepts	References
Kinematics and Mechanics	
Velocity	B-2, D-5, D-7, D-12, E-13, F-18
Acceleration	B-1, B-23, E-6-7, E-12
Force	B-11-12
Newton's First Law	B-35, F-10, F-13, F-46
Newton's Second Law	B-35, F-13
Newton's Third Law	B-35, E-6, F-13
Friction	B-6, B-18, D-13, D-21, D-24, F-6-8, F-53
Air resistance	B-9, D-6-10
Momentum	B-34-37, F-18
Collisions	B-34-37
Conservation of momentum	B-34-37
Work, Energy and Power	
Work	B-1-11, B-28-34, D-2, F-15
Forms of energy	B-1-20, B-28-34, B-44-45, D-5-15, F-14-19
Energy conversion	B-1-11, B-28-34, D-5-15
Energy conservation	B-1-11, D-5-15, F-17
Power	B-3, B-7, B-19, B-39, D-1, F-6
Simple Machines	B-28, F-10-12
Periodic Motion	
Rotational mechanics	B-11-27, B-28-34, B-40, D-21-23, F-22
Centripetal force	B-4, B-11, B-14, B-16, B-18, B-28, D-25, F-38
Angular momentum	B-26, B-28-29
Simple harmonic motion	B-28-33, B-40
Period and frequency	B-13, B-16, B-40-43, F-21-22
Other Topics	
Heat and thermodynamics	B-44-45, D-2, F-6, F-31-37
Fluids	B-6-8, B-39, F-5-9, F-14-19
Sound	B-40
Waves	B-40-43
Light	B-41-43, F-31-37
Electricity	B-19, B-34, D-1, F-6
Modern physics	A-4, F-32
Chaotic motion	B-24

Table C-2: Related Topics and Activities Reference Cross-Index

Related Topics and Activities	References*
Amusement Park Activities	
General Manuals	(CM), (Unterman, 1990; best general reference), (AAP Handbook, 1991), (Escobar, 1991), (Weise, 1994; introductory level), (Lagoon, 1989)
Roller Coasters	(CM; B-1-10, F-14-16), (Unterman, 1990; best general reference), (AAP Handbook, 1991), (Wolff, 1989), (Escobar, 1991) (Weise, 1994, Ch. 2; introductory level), (McGehee, 1988), (Walker, 1989)
Spinning Rides	(CM; B-11-27), (Unterman, 1990; best general reference), (AAP Handbook, 1991), (Escobar, 1990; good summary reference), (Escobar, 1991) (Weise, 1994, Ch. 2; introductory level), (Roeder, 1975; the first published APP article)
Pendulum Rides	(CM; B-28-33), (Unterman, 1990; best general reference)
Other Rides	(CM; B-34, B-40, F-5-9, F-53), (Unterman, 1990; best general reference), (Weise, 1994, Chs. 2 & 3; introductory level), (Palffy-Muhoray, 1993; bungee-jumping)
Classroom Activities	
General (High School)	(CM; F-57, F-62), Unterman, 1990; best general reference)
General (Middle School)	(CM; F-57, F-62), (Weise, 1994; excellent introductory level), (Lagoon, 1989)
Elevators	(Unterman, 1990; best general reference), (AAP Handbook, 1991), PASCO, includes student handouts)
Playgrounds	(CM; D-21-26), (Unterman, 1990; best general reference), (Weise, 1994; simple activities), (Taylor, 1995; Simple exercises with the CBL), (PASCO; includes student handouts)
Model Roller Coasters	(CM; D-5-20, F-17-20, F-58), (Blaszczak, 1991)
Detailed Physics Analysis	
Chaos	(CM; B-24), (Kautz, 1994; lots of sophisticated details)
Roller Coasters	(CM; B-1-10), (Speers, 1991; detailed analysis), (Clark, 1988, 1989), (Nelson, 1980), (Unterman, 1990; best general reference), (AAP Handbook, 1991)
Spinning Rides	(CM; B-11-27), (AAP Handbook, 1991)
Measurements and Apparatus	
Accelerometers and Other	(CM; E-6-13), (Unterman, 1990; best general reference), (AAP Handbook, 1991),
Measurement Apparatus	(CM; B-43, F-3, F-27-30, F-46-52), (Escobar, 1991), (Weise, 1994, Ch. 1; introductory level)
Computer Based Laboratory (CBL) Techniques	(CM; D-16-23, F-63), (Taylor, 1995; Simple exercises with the CBL), (Taylor, 1995), (Brueningsen, 1995), (Stowe, 1995), (Stump, 1995)
Measurement and Analysis Methods	(CM; B-44, D-7, E-1-6, F-5), (AAP Handbook, 1991)
Video Techniques	(CM; D-7, F-64), (Graney, 1995), (Molnar, 1995)

* CM refers to this manual. Other references are listed in Section F 62-65.

Table C-3: Standards and Objectives in the 1995 Science Core Curriculum Cross-indexed to Amusement Park Physics Curriculum

Grade Level/Topic		References
	8th Grade Integrated Science	
3240-0301	Demonstrate the results of forces	A-2, B-1-34, D-21-26
3240-0302	Identify the role of energy in motion	B-1-4, B-9-10, B-31-33, D-5-15
3240-0303	Analyze energy movement and transformations	B-1-11, B-28-34, D-5-15
3240-0401	Construct simple levers and calculate the force-distance ratio	B-28, F-10-12
	9th Grade Earth Systems	
3600-0702	Analyze the transfer of energy within Earth systems	B-1-11, B-28-34, D-5-15
	Physics	
3640-0201		B-1-34, F-38-42
3640-0202	Analyze motion of, and within, a system	B-35, E-6, F-10, F-13, F-46
3640-0203	Analyze motion using Newton's three laws	B-1-27, D-6-10, D-13, D-21,
	Relate various forces to their effect on motion	D-24, F-6-8, F-53
3640-0204		B-34-37
3640-0301	Apply principles of momentum to motion	B-12-27, B-40, F-21-22
3640-0302	Compare and contrast periodic motion and waves	
	Differentiate wave phenomena in events and	B-40-43, F-21-23
3640-0401	systems	B-1-25, B-44-45, D-1-15,
	Characterize various forms of energy	F-14-19
3640-0402		B-1-11, D-5-15
3640-0501	Compare and contrast potential and kinetic energy	B-1-25, D-1-15, F-14-19
	Determine the characteristics of energy conservation and change	

CM refers to the USU Amusement Park Physics Curriculum Manual

ADDITIONAL RESOURCES

Table C-4: Key Physics Concepts in the Pre-1995 State Science Core Curriculum Cross-indexed to Amusement Park Physics Curriculum

Concept/Topic	Utah State Science Core Curriculum Standards and Objectives Objectives Covered by Proposed Project				Curriculum Manual References
	Physics (9-12)	Principles of Technology (9-12)	Physical-Earth Science (9-12) & Physical Science (7-8)	Science Level 6 & Science Level 5	
1a. Data Collection & Use of Apparatus	3640-0101	3660-0101		3060-0507	D-1-4, D-7, D-23, E-1-13, F-3-9, F-27-30, F-46
1b. Experimental Design, Data Analysis & Statistics	0102-05	0102-04	3420-0101-05		D-1-4, E-2-5, F-50, F-53-56
2a. Kinematics	0201-05	0401	3420-05-07	3060-0602-03	B-1-15, B-34-38, D-5-23, F-2-9, F-38-45
2b. Rotational Mechanics	0206	0206			B-1-27, B-40, D-21-23, F-22
2c. Periodic Motion				3050-0701	B-11-33, B-40-43, D-21-23, F-21-26, F-43-45
3. Newton's Laws & Momentum	0301-09	0201, 0501, 0801	3600-0802 3420-0501-05,08		B-1-38, F-53-56
4. Work, Energy, & Power; Conservation of Energy	0401-07	0301-02, -0601, -0701	3600-0202-03 3600-0301-02 3420-0201,08 3420-0506,08	3050-0301-05	B-1-33, D-5-20, F-15-19
5a. Heat and Thermodynamics	0502, 04, 05	-0204, -0404, -0504, -0604		3060-0401-07	B-44, D-2, F-6, F-31-37
5b. Fluids		-0202, -0402, -0502, -0602 -0702, -0803	3420-0202,04,05		B-6-8, B-39, F-5-9, F-14-19
6. Waves & Sound	0601-05		3600-0402 3420-0601-03		B-40-43
7. Light & Optics	0702, -07-10		3420-0701,04		B-41-43, F-31-37
8. Electricity & Magnetism	0804-08	-0203, -0303, -0503, -0603, -0703			B-34-38, F-6-8

AMUSEMENT PARK PHYSICS ACTIVITIES

FERMI QUESTIONS

Enrico Fermi was one of this country's greatest physicists. Among his accomplishments were the 1938 Nobel Prize for nuclear and particle physics and the title "Father of the Atomic Age" for his role in building the first nuclear reactor. He had a rare talent as both a gifted theorist and experimentalist. One of his legacies is the *Fermi Question*, an insightful question requiring both an understanding of physics principles and estimation skills.

The Fermi Questions given below require information gathered from the amusement park, estimation and some clever thinking: The additional questions provide hints for *one possible way* to figure out the answer.

ENRICO FERMI

Questions

1. How many times do you have to ride Colossus to pay for your Lagoon entrance ticket? Assume an electric motor is 30% efficient, lifts a fully loaded Colossus roller coaster (7200 kg) up the first hill on Colossus.

   a. Calculate the power necessary to raise the train.
   b. If Utah Power and Light charges 10 cents per kilowatt hour, determine the cost of the electricity used to power this ride for one hour. Assume the ride to be operating at maximum capacity of a new train every two minutes.
   c. So, how many times do you have to ride Colossus?

2. Go check out the Skyscraper Ferris Wheel. This is one big, bright ride! Is it bigger or brighter?

   a. How much mechanical power is required to turn the ferris wheel? Estimate the radius, mass and angular velocity to calculate the power needed to form the ferris wheel. Assume the wheel turns 50% of the time and that the electric motor is 30% efficient.
   b. How much power is required to run the lights? They are 40 W bulbs.
   c. Does it take more power to turn the ferris wheel or light it?

3. **Lun-A-Beach**
   In the year 2001, imagine an amusement park built on the Moon. On the Moon there are two important differences: (1) the acceleration due to gravity is only 16% of that on Earth; and (2) there is no air resistance (or air!). How would they affect a swimmer going down a water slide just like the one here at Lagoon-A-Beach? Specifically, how much faster or slower will the swimmer be going at the bottom of the slide and how much bigger or smaller will the splash be?

4. How many gallons of soft drinks will be drunk during Physics Day today at Lagoon?

   a. How much does the "average" person at Lagoon drink during the day? Estimate the number of soft drinks an average person drinks and their average size.
   b. Here is the tough part: how many people are here today? There are many ways to do this. For instance, you could check out the parking lot. Or you could estimate the number of rides, games and drink stands and the number waiting at each of these. (Can you come up with a better way?)

5. Estimate the rate of heat produced (in BTU/hr) by the collisions taking place in the Bumper Car pavillion. Compare this with the heat given off by the excited bodies riding in the cars (each person radiates about 100 W of thermal energy). Refer to page B-34 for additional notes on Bumper Cars and page A-9 with help on units.

   a. Determine the average number of cars and riders. Then estimate the number of collisions per hour.

   b. Estimate the difference in the kinetic energy of a car before and after a typical collision. Each car weighs approximately 350 kg without a rider. You will have to estimate the velocities involved.

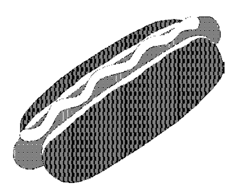
   c. The "lost" kinetic energy has to go somewhere. Where does it ultimately go?

6. How much water is evaporated from the tubing channel on a hot day at Lagoon-A-Beach? [Useful physical constants: density of water is 10^3 kg/m^3; specific heat of water (heat to raise 1 kg of water 1 °C) is 4.18 kJ/kg-°C; latent heat of vaporization of water (heat to boil 1 kg of water) is 2.3 MJ/kg; solar constant (average energy per m^2 falling on the Earth from the Sun) is 1.4 kW/m^2.]

   a. Estimate the surface area of the water in the tubing channel.
   b. How much energy is required to evaporate (boil) l kg of water in the channel?
   c. How much energy is added to the tubing channel by the Sun on a hot day?
   c. How much total water is evaporated on a hot day?

7. How many times will the energy from your lunch get you to the top of the water slide?

   Assume you eat one hot dog (250 Calories) and a 16-oz coke (140 Calories). Remember that food Calories (written with a capital "C") are 1000 physics calories (written with a small "c"). One physics calorie is 4.186 J.



   a. Estimate the number of joules you gain from your lunch.

   b. Estimate the number of joules of energy you must use to get to the top of the Water Slide. The slide is <u>60</u> m high. The energy needed to raise yourself a distance h against gravity is your mass (in kg) times the acceleration due to gravity (in m/s^2) times the height:

   Energy Change = mgh

Answers:

1. a. The work to raise the train one time is

$$W = (Mgh)/Eff. = (7200\ kg)\ (9.8\ \frac{m}{s^2})\ (26.5\ m)\ /\ (0.30) = 6.2\ MJ/trip$$

The power is

$$P = W \cdot rate = (6.2\ MJ/trip)\left(\frac{0.5\ trips}{minute}\right)\left(\frac{1\ minute}{60\ s}\right) = 52.kw$$

   b. The electricity to run the ride for 1 trip costs

$$C = (52\ kw)\left(\frac{0.033\ hr}{trip}\right)(\$0.10/kw \cdot hr) = \$\ 0.17/trip$$

There are 28 people per train, so the cost per person per trip is 0.6 cents.

   c. Based solely on electricity costs you would have to ride ~ 1,860 times to recoup the cost of your $11.50 ticket. This, of course, grossly underestimates the cost, since it does not consider personnel costs, maintenance and upkeep, and many other factors.

2. a. The mass is given on the sign next to the entrance as 1.81 x 10^5 kg (400,000 lb). The radius of the main wheel is 21.8 m. The moment of inertia (assuming all the weight is on the rim) $I = MR^2$ is 8.6 x 10^7 kg-m^2. The time for one revolution is 40 s, so the angular velocity $\omega = 2\pi rad/40\ s = 0.16\ s^{-1}$. The rotational kinetic energy KE = 1/2 $I\omega^2$ is 1.1 MJ. Assuming the wheel turns 50% of the time and the motor is 30% efficient, the mechanical power requirement $P_M = KE\ (\frac{50\%}{time})(\frac{1}{30\%})$ is 1.8 MW.

   b. According to the sign next to the entrance, there are 180,000 light bulbs. Assuming each bulb is 40 W and that each bulb is on 20% of the time, the lighting power requirement P = 180000 · 40W · 20% = 1.4 MW.

   c. Based on the calculations above, the lights and mechanical motion consume about the same amount of power. These calculations greatly overestimate the power needs, particularly for the mechanical motion. We have overestimated the mass (much of the weight is in the support structure and does not rotate), the moment of inertia (we assumed all the weight on the rim), and the fraction of time the wheel is in motion. The sign gives the mechanical power at about 100 W and the total power consumption is 280 KW.

3. You move slower due to reduced gravity and faster due to lack of all resistance. The gravity effect is dominant. You can see this by equating PE = mgh = 1/2 mv^2 = KE.

4. a. Two 16-oz drinks = 0.25 gal.

   b. ~ 7000 people or 1750 gal/day

5. a. 32 cars ~20 riders

Each car undergoes ~2 collisions per minute. The cars run about 70% of the time. Therefore, the number of collisions per hour

$$N \approx 1/2 \left(2 \frac{\text{collisions}}{\text{minute-car}}\right) \left(\frac{60 \text{ minutes}}{\text{hour}}\right) (0.70)\ (32 \text{ cars}) = 1344 \frac{\text{collisions}}{\text{hour}} = 0.34 \frac{\text{collisions}}{\text{sec}}$$

b. The average speed of the cars is ~1 m/s. About half this speed is lost in a typical collision. Thus, the change in kinetic energy per collision is

$$\Delta KE = 1/2\ m\ (v_i^2 - v_f^2) = 1/2 \left(350 \frac{\text{kg}}{\text{car}} + 50 \frac{\text{kg}}{\text{person}}\right) [(1 \frac{\text{m}}{\text{s}})^2 - (0.5 \frac{\text{m}}{\text{s}})^2] = 150 \text{ J/collision}$$

The power lost due to collisions is

$P_{collision} = \Delta KE \cdot N = 51$ W = 174 BUT/hr

c. The KE lost in the inelastic collisions is transferred into thermal energy.

The thermal energy produced by the riders is

$$P_{rider} = (20 \text{ riders}) \left(100 \frac{\text{w}}{\text{rider}}\right) (0.70) = 1400 \text{ W} = 4.8 \times 10^3 \text{ BTU/hr}$$

Therefore, the riders produce ~30 times the thermal energy that the collisions produce.

6. a. Area $\approx$ (2m) x (100 m) = 200 $m^2 + 4$

b. $E_{kg} = mC\Delta T + mH_v$ = 1 kg [(4.18 kJ/kg-°C) (100°C-32°C) + 2.3 MJ/kg] = 2.6 MJ = 2.6 x 10^6 J

c. E_{sun} = A · solar constant · time = (200 m^2) (1.4 kW/m^2) (10 hr) (3600 s/hr) = 1 x 10^{10} J

d. Mass Evap = 1 x 10^{10} J/2.6 x 10^6 3/kg = 3800 kg

Volume Evap = 3800 kg/1000 kg/m^3 = 3.8 m^3

7. a. $$390 \text{ Calories} \cdot \frac{1000 \text{ calories}}{\text{Calorie}} = 3.9 \times 10^5 \text{ calories} \cdot \frac{4.2 \text{ J}}{\text{calorie}} = 1.64 \text{ MJ}$$

b. For m = 50 kg · energy = 50 kg · 10 m/s^2 · 60 m = 3 x 10^4 J

$$\# \text{ trips} = \frac{\text{Joules eaten}}{\text{Joules used per trip}} = \frac{1.6 \times 10^6 \text{ J}}{3 \times 10^4 \text{ J}} = 53 \text{ trips}$$

AMUSEMENT PARK PHYSICS ACTIVITIES

CONSERVATION OF ENERGY WITH TUBING COASTERS

This activity sheet describes a qualitative investigation of the concept of conservation of energy using a model roller coaster made from plastic tubing and BB's. Your group should get a 1 m long plastic tube and several BB's. You might also want to get some computer paper. You will construct your roller coaster by taping the plastic tube to any convenient wall.

Use your tube to mark a height 1 m from the floor. Then use your tube, bent in half, to mark a height 1/2 m above the 1 m mark (1.5 m from the floor). The top of your roller coaster should be at the 1.5 m mark, and the bottom, where your BB exits, should be at the 1 m mark.

Try to arrange your coaster so that your BB exits with a strictly horizontal velocity; that way, we can use the equations of projectile motion to figure out how fast the BB is going at the bottom of the coaster. Every time the vertical motion will be the same (the BB will fall 1 m with an acceleration due to gravity downward and air friction opposing the downward motion) so the BB should take the same amount of time to fall on each run. The distance the BB travels horizontally will be the horizontal velocity times the time. So, we can judge the horizontal velocity of the BB by how far it goes horizontally from the exit of the tube; the further it goes beyond the exit, the faster its horizontal velocity.

Build a roller coaster and measure where the BB lands after you release it from rest at the top of the tube. [Hint: Let the BB fall on a piece of carbon paper. The impact will make a small dot on a piece of white paper under the carbon paper. It is much easier to measure the position of the dot than to view where the BB hits the floor.] Repeat three times and calculate an average distance.

Keeping the heights of the start and stop points the same, build a different roller coaster and again measure how far the BB travels horizontally after leaving the tube. Repeat three times and average the distances.

What is your conclusion about roller coaster cars that start from the same height and drop the same distance? Does it matter what path the BB takes? If so, how does the path affect the final speed of the BB?

Now try making a roller coaster that starts at 1.5 m, but goes higher than 1.5 m at some point. How does this configuration affect the exit velocity of the BB? Explain why you think this happens. How much energy does the BB have when it starts? How much energy would it have at the highest point?

Now try raising the starting point of the roller coaster to 2 m, so that the BB now drops more than 0.5 m vertically. How does this affect the exit velocity of the BB? Is it traveling faster or more slowly than when the start of the roller coaster was only 0.5 m above the exit point? Can you explain this result using conservation of energy?

AMUSEMENT PARK PHYSICS ACTIVITIES

CONSERVATION OF ENERGY WITH MARBLE COASTERS

This activity sheet describes a qualitative investigation of the concept of conservation of energy using a marble roller coaster with a ***loop***, using an open channel. This is equivalent to a real roller coaster in which the cars are not attached to the track as a safety feature: they really could fly off!

Make your roller coaster either out of strips of card stock which has been bent to form a U-shaped channel or out of a plastic tube that has been cut in half lengthwise. (Be sure to use the half of the tube that naturally curves in the right direction, if you are using tubing that has been bent or coiled.)

Will the BB make it around the loop if the start of the coaster is level with the bottom of the loop?

What if the BB starts level with the top of the loop?

What happens if you start the BB at the top of the loop from rest? Does the BB have to be moving at the top of the loop in order to make it all the way around?

How high does the start of the coaster have to be before the BB successfully traverses the loop?

Could you have predicted this result from conservation of energy? [Hint: The gravitational potential energy at start of the loop equals mgh and the gravitational potential energy at the top of the loop equals mg D, where D is the diameter of the loop.]

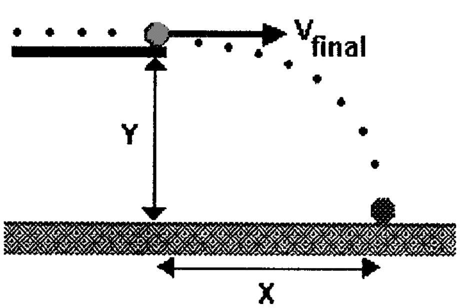
Now make a coaster with two loops and try starting the BB from the same height that worked before. Does the BB still make it? If not, why do you think it doesn't?

AMUSEMENT PARK PHYSICS ACTIVITIES

MARBLE COASTER MEASUREMENTS

This activity sheet describes the measurement necessary to complete the Mathcad worksheets RC_Energy.MCD or BB_Energy.MCD on the quantitative analysis of the motion of a marble coaster based on the principle of conservation of energy.[1]

MEASUREMENTS TO MAKE:	**METHOD:**
Mass of Marble	Mass Scale
Track Length	Tape Measure
Time to Traverse Track	Stopwatch
X- and Y- Positions Along Track	Read from Graph Paper
Horizontal and Vertical Distances for Final Velocity Determination	Carbon Paper (See Below)
Elapsed Time to Positions Along Track (OPTIONAL)	Video Camera and Frame-step VCR



The exit velocity at the end of the track, V_{final}, can be determined indirectly by measuring the vertical distance from the end of the track to the floor, Y, and the horizontal distance from the end of the track to the point where the ball strikes the floor, X. The point where the ball strikes the floor is marked using carbon paper. Treating the marble as it leaves the end of the horizontal track as a projectile motion problem, we find:

$$V_{final} = X \sqrt{g/2\,Y}$$

[1] These Mathcad worksheets are available for downloading from the USU Physics Department Web site, "http://www.physics.usu.edu/."

Amusement Park Physics

Inservice Workshop

Energy Conservation of the Marble Coaster

Objective

The objective of this Mathcad worksheet is to help develop a model of the

describes the motion of the marble. All calculations are based solely on the principle of *Conservation of Energy*.

System Parameters and Measured Values

marble coaster. First, we enter the x- and y-positions of 25 points along

reach each position. Note that entry of the elapsed time data is optional.

Number of data points and related indices: $Num := 25 \quad n := 0 .. (Num - 1) \quad j := 1 .. (Num - 1) \quad t_n := 0$

Enter your data. Simply overwrite the present data. Use commas to separate subsequent data. Do not enter units.

<u>Detail:</u> Delete this entry ===> for t_n if you do not want to include elapsed time data.

$x_n :=$	$y_n :=$	$t_n :=$
0	0	0
0.35	–0.52	.0208
0.95	–1.34	.0416
1.95	–2.76	.0624
3.00	–4.20	.0832
4.35	–5.92	.1040
5.95	–8.04	.1248
7.75	–10.38	.1456
9.80	–12.96	.1664
10.95	–14.15	.1768
12.10	–15.34	.1872
13.97	–16.10	.2080
15.06	–15.48	.2288
15.24	–13.86	.2496
13.78	–13.04	.2704
12.40	–13.04	.2912
12.04	–14.56	.3120
13.84	–15.82	.3328
15.05	–15.96	.3536
16.15	–15.72	.3744
17.00	–15.47	.3952
17.50	–15.36	.4160
17.95	–15.23	.4368
18.45	–15.08	.4576
18.80	–14.92	.4784

Add appropriate units for these data and calculate some limiting values:

$x := x \cdot in$ $\quad x_{max} := max(x)$

$y := y \cdot in$ $\quad y_{min} := min(y)$

$t := t \cdot sec$ $\quad t_{max} := max(t)$

Gravitational Acceleration: $g = 9.8\, m \cdot sec^{-2}$

Mass of Marble: $m_m := 3.0 \cdot gm$

Overall Length of Track: $L_{ex} := 111.8 \cdot cm$

Time to Traverse Track: $T_{ex} := 0.479 \cdot sec$

Initial Velocity: $v_0 := 0 \cdot m \cdot sec^{-1}$

Horizontal Distance from End of Track to Point Where Ball Strikes Floor: $X := 7.6 \cdot cm$

Vertical Distance from End of Track to Floor: $Y := 8.9 \cdot cm$

Analysis

We can use our knowledge of the shape of the roller coaster and the principle of *Conservation of Energy* to develop our model.

PE=mgh.

The gravitational potential energy of the marble as a function of the height, $\mathbf{h=(y-y_{min})}$ is:

.

$$PE_n := m_m \cdot g \cdot \left(y_n - y_{min}\right)$$

Detail: Note, we define the zero of the potential energy at the lowest point on the roller coaster, $\mathbf{y_{min}}$.

The initial total energy, $\mathbf{E_o}$, of the marble at the top of the coaster is:

$$E_o = KE_o + PE_o \quad \text{or} \quad E_0 := \frac{1}{2} \cdot m_m \cdot \left(v_0\right)^2 + m_m \cdot g \cdot \left(y_0 - y_{min}\right)$$

Since the total energy of the marble is conserved (does not change), we can write $E\_total_n := E_0$ for all positions.

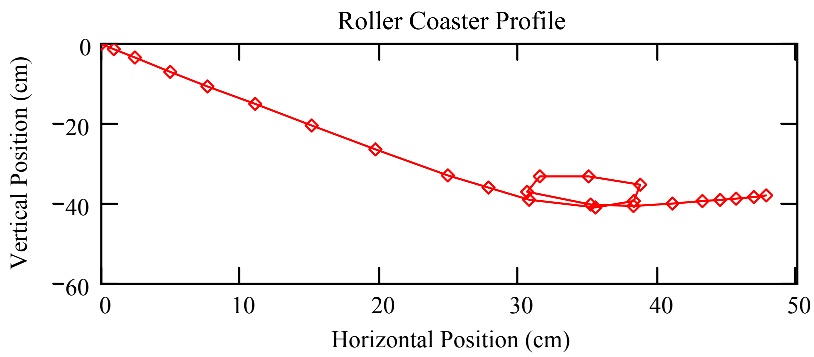
The kinetic energy, **KE**, of the marble at each point is just the total energy minus the potential energy, or

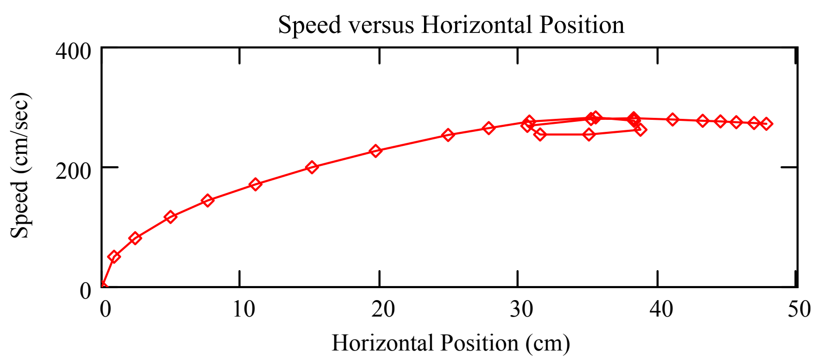
$$KE_n := E\_total_n - PE_n$$

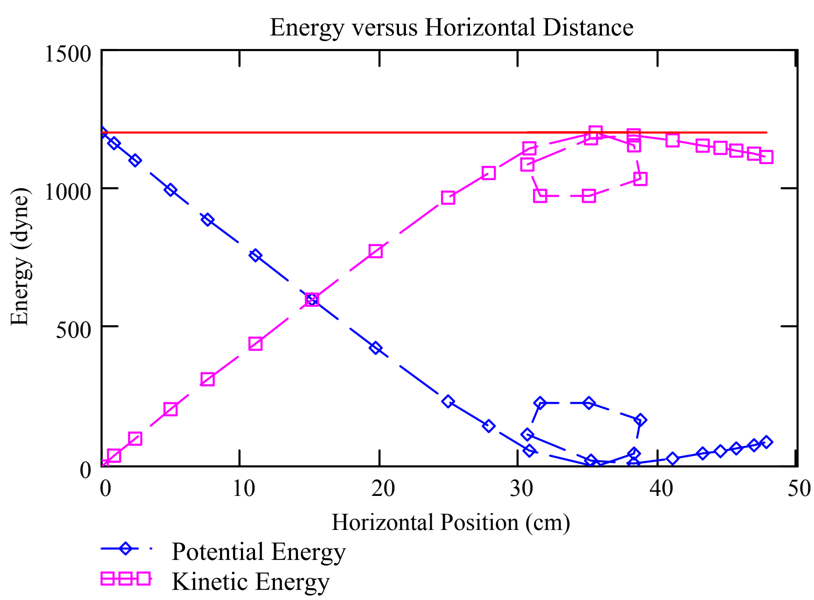
We use this to find the speed, **v**, at each point, since **KE = ½mv²**,

$$v_n := \sqrt{\frac{2 \cdot KE_n}{m_m}} \quad \text{or} \quad v_n := \sqrt{\frac{2 \cdot \left(E\_total_n - PE_n\right)}{m_m}}$$

Results Our calculations yield the following graphical results of the motion of the marble:







Verification of Model

coaster. We will do three calculations based on our model and compare their results with your measurements.

TEST 1: Let's begin by calculating the overall length of the coaster track. Recall that the distance between two points ($\mathbf{x_1}$,$\mathbf{y_1}$) and ($\mathbf{x_2}$,$\mathbf{y_2}$) is simply $[(\mathbf{x_2}\text{-}\mathbf{x_1})^2 + (\mathbf{y_2}\text{-}\mathbf{y_1})^2]^{½}$. The total length of the track, **L`**, is just the summation of the length of each successive section you measured:

$$L_j := \sqrt{\left(x_j - x_{j-1}\right)^2 + \left(y_j - y_{j-1}\right)^2}$$

$$L' := \sum_{j=1}^{(Num-1)} L_j \qquad\qquad L' = 92.4\,\text{cm}$$

The error in the predicted value is:

$$\Delta L := L' - L_{ex} \qquad \Delta L = -0.2\,\text{m} \qquad \text{or} \qquad \left|\frac{\Delta L}{L_{ex}}\right| = 17.3\,\%$$

TEST 2: The time to traverse each segment is just the length of each segment divided by the average velocity for that segment. The total time to traverse the track is the sum of all these times for each segment:

$$T_j := \frac{L_j}{\frac{1}{2}\cdot\left(v_j + v_{j-1}\right)} \qquad T' := \sum_{j=1}^{(Num-1)} T_j \qquad T' = 0.5\,\text{sec}$$

The error in the predicted value is:

$$\Delta T := T' - T_{ex} \qquad \Delta T = 0\,\text{sec} \qquad \text{or} \qquad \left|\frac{\Delta T}{T_{ex}}\right| = 6.6\,\%$$

TEST 3:

$$v\_avg' := \frac{L'}{T'} \qquad v\_avg' = 181\,cm \cdot sec^{-1}$$

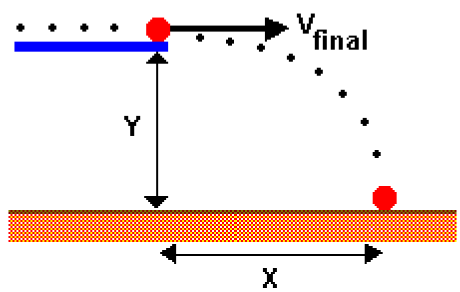
$$v\_avg_{ex} := \frac{L_{ex}}{T_{ex}} \qquad v\_avg_{ex} = 233.4\,cm \cdot sec^{-1}$$

The error in the predicted value is:

$$\Delta v\_avg := v\_avg' - v\_avg_{ex} \qquad \Delta v\_avg = -0.5\,m\,sec^{-1} \qquad \left|\frac{\Delta v\_avg}{v\_avg_{ex}}\right| = 22.4\,\%$$

TEST 4:

The exit velocity at the end of the track, **v_final,** is just the final velocity (assuming a flat stretch of track at the end). It can also be determined indirectly by measuring the vertical distance from the end of the track to the floor, **Y**, and the horizontal distance from the end of the track to the point where the ball strikes the floor, **X.** Treating the marble as it leaves the end of the track as a projectile motion problem, we find:



$$v\_final_{ex} := X \cdot \sqrt{\frac{g}{2 \cdot Y}} \qquad v\_final_{ex} = 56.4\,cm \cdot sec^{-1}$$

$$v\_final' := v_{(Num-1)} \qquad v\_final' = 272.6\,cm \cdot sec^{-1}$$

The error in the predicted value is:

$$\Delta v\_final := v\_final' - v\_final_{ex}$$

$$\Delta v\_final = 216.2\,cm \cdot sec^{-1} \qquad \text{or} \qquad \left|\frac{\Delta v\_final}{v\_final_{ex}}\right| = 383.3\,\%$$

Predictions In addition to verifying measured properties of the marble coaster, we can use our model to predict things not easily accessible to measurement.

You probably found that your calculation of the time to traverse the track was shorter than the measured time and that your calculated **v_final** was faster than the measured **v_final.** One explanation for this (aside from simply an error in the measurement of time) is that we have ignored friction. Frictional forces, such as kinetic friction between the marble and track and air resistance, act to slow the marble down which means it takes longer to traverse the track.

In the presence of friction, we must include the work done due to friction in the energy balance. This work term is the average friction force, $\mathbf{F_f}$, times the length of the track. The statement of *Conservation of Energy* is modified to:

$$E_{initial} = E_{final}$$

$$\frac{1}{2}\cdot m_m\cdot v_0^{\,2} + m_m\cdot g\left(y_0 - y_{min}\right) = \frac{1}{2}\cdot m_m\cdot v\_final_{ex}^{\,2} + m_m\cdot g\cdot\left(y_{final} - y_{min}\right) + F_f\cdot L_{ex}$$

Solving for $\mathbf{F_f}$, we have

$$F_f := \frac{m_m\cdot g\cdot\left[y_0 - y_{(Num-1)}\right] + \frac{1}{2}\cdot m_m\cdot\left[\left(v_0\right)^2 - v\_final_{ex}^{\,2}\right]}{L_{ex}}$$

$$F_f = 954.6\,\text{dyne}$$

We can also use our model to predict how the marble coaster would work on the moon where the acceleration due gravity is 1.6 m-sec^{-2} or on Jupiter where the acceleration due to gravity is 26.5 m-sec^{-2}.

Hint: To try this using Mathcad, simply change the definition of **g** on the first page of this worksheet**.**

Acceleration Due to Gravity for Bodies in the Solar System

Planet	Acceleration due to gravity*	Planet /Body	Acceleration due to gravity*
Mercury	0.37 g or 3.63 m/s^2	Uranus	1.17 g or 11.47 m/s^2
Venus	0.88 g or 8.62 m/s^2	Neptune	1.18 g or 11.56 m/s^2
Earth	1.00 g or 9.80 m/s^2	Pluto	0.25 g or 2.45 m/s^2(?)
Mars	0.38 g or 3.72 m/s^2		
Jupiter	2.64 g or 25.87 m/s^2	Moon	0.17 g or 1.67 m/s^2
Saturn	1.15 g or 11.27 m/s^2	Sun	27.96 g or 274.0 m/s^2

* Acceleration is listed in both MKS units and in terms of the acceleration of gravity on Earth in units of g.

Another interesting way to use our model is to predict the effect of changing the mass of the marble. This has important implications in scaling the model to life size.

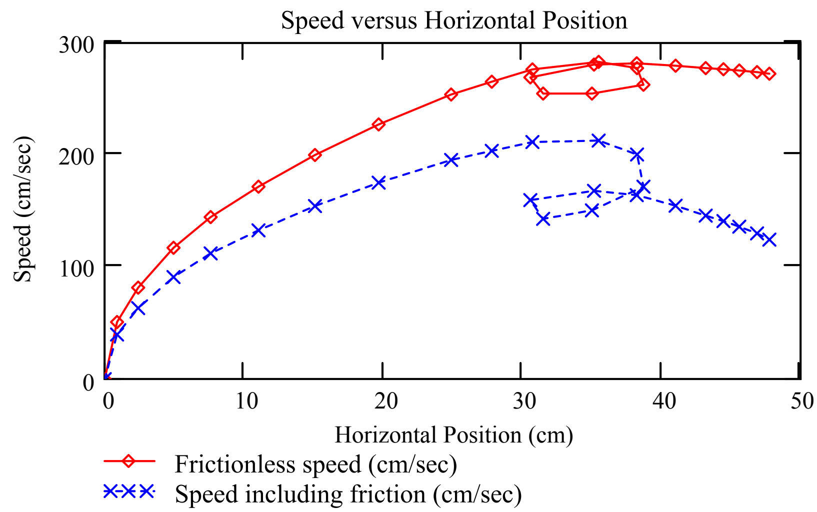
Hint: To try this using Mathcad, simply change the definition of $\mathbf{m_m}$ on the first page of this worksheet.

Finally, let's combine our predictions of the motion and average friction to predict the speeds and the elapsed time it takes to reach each point when we accounted for friction.

The corrected speed includes a dissipation energy term equal to F_f times the cumulative distance traveled:

$$v'_n := \sqrt{\frac{2 \cdot \left(E\_total_n - PE_n - F_f \cdot \sum_{i=0}^{n} L_i\right)}{m_m}}$$

The final corrected speed is: $v'_{Num-1} = 124.5\ cm \cdot sec^{-1}$



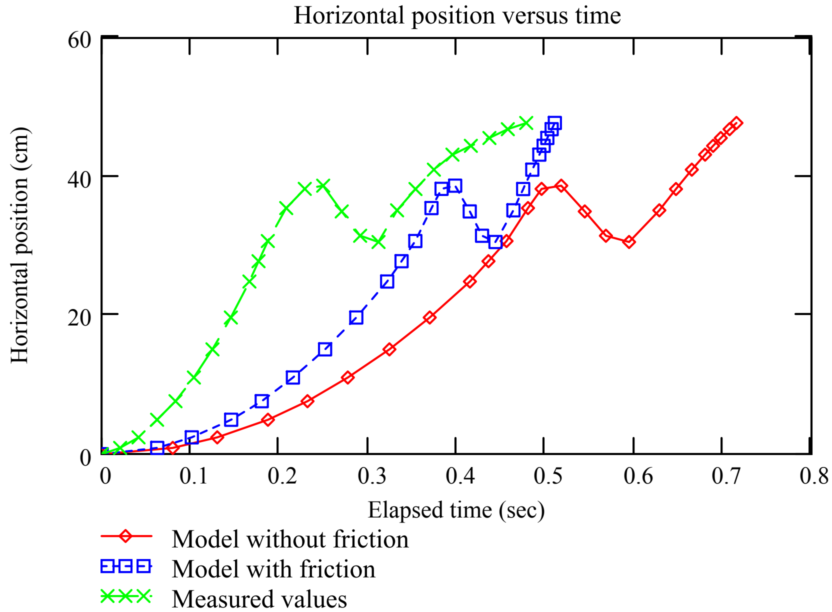
Calculated times using speed prediction which ignore friction:

$$\tau_0 := 0 \cdot sec \qquad \tau_j := \tau_{j-1} + \frac{L_j}{\frac{1}{2}\cdot\left(v_j + v_{j-1}\right)}$$

Calculated times using speed prediction which include friction:

$$T'_0 := 0 \cdot sec \qquad T'_j := T'_{j-1} + \frac{L_j}{\frac{1}{2}\cdot\left(v'_j + v'_{j-1}\right)}$$

Data ≡ "A:\roller_d.prn"



Amusement Park Physics

Inservice Workshop

Scaling the Hot Wheels Track

Objective

scaling factor between the Hot Wheels toy race track and cars and a "real life" model. We approach the problem from several ways to see if there is one consistent answer.

Measurements and Data

model.

Parameter	Hot Wheels Toys	Full Scale Model
Mass of Car:	$m_{HW} := 8 \cdot gm$	$m_{FS} := 1350 \cdot kg$
Length of Car:	$C_{HW} := 7.1 \cdot cm$	$C_{FS} := 6.1 \cdot m$
Height of Track:	$H_{HW} := 74.5 \cdot cm$	$H_{FS} := 100 \cdot m$
Length of Track:	$L_{HW} := 360.4 \cdot cm$	
Time to Traverse Track:	$T_{HW} := 1.3 \cdot sec$	
Height of Loop:	$HL_{HW} := 21.7 \cdot cm$	

Scaling Method

It is tempting to scale simply by the ratio of the three quantities we know for both system. However, as we see below, each scaling leads to different results.

Scale factor from scaling by the ratio of the Car Masses: $SF_m := \frac{m_{FS}}{m_{HW}}$ $SF_m = 1.688 \times 10^5$

Scale factor from scaling by the ratio of the Car Lengths: $SF_C := \frac{C_{FS}}{C_{HW}}$ $SF_C = 85.915$

Scale factor from scaling by the ratio of the Hill Heights: $SF_H := \frac{H_{FS}}{H_{HW}}$ $SF_H = 134.228$

Parameter	Scaled by Mass	Scaled by Length	Scaled by Height
Mass of Car:	$m_{HW} \cdot SF_m = 1.35 \times 10^3\, kg$	$m_{HW} \cdot SF_C = 0.687\, kg$	$m_{HW} \cdot SF_H = 1.074\, kg$
Length of Car:	$C_{HW} \cdot SF_m = 1.198 \times 10^4\, m$	$C_{HW} \cdot SF_C = 6.1\, m$	$C_{HW} \cdot SF_H = 9.53\, m$
Height of Track:	$H_{HW} \cdot SF_m = 1.257 \times 10^5\, m$	$H_{HW} \cdot SF_C = 64.007\, m$	$H_{HW} \cdot SF_H = 100\, m$
Height of Loop:	$HL_{HW} \cdot SF_m = 3.662 \times 10^4\, m$	$HL_{HW} \cdot SF_C = 18.644\, m$	$HL_{HW} \cdot SF_H = 29.128\, m$
Length of Track:	$L_{HW} \cdot SF_m = 6.082 \times 10^5\, m$	$L_{HW} \cdot SF_C = 309.639\, m$	$L_{HW} \cdot SF_H = 483.758\, m$
Time to Traverse Track:	$T_{HW} := 1.3 \cdot sec$	$T_{HW} := 1.3 \cdot sec$	$T_{HW} := 1.3 \cdot sec$
Average Velocity:	$\frac{L_{HW}}{T_{HW}} \cdot SF_m = 467.8\, km \cdot sec^{-1}$	$\frac{L_{HW}}{T_{HW}} \cdot SF_C = 0.2\, km \cdot sec^{-1}$	$\frac{L_{HW}}{T_{HW}} \cdot SF_H = 0.4\, km \cdot sec^{-1}$

assume that the length of the car scales linearly; at the same time we will preserve the density of the materials (e.g., steel) used in making both full

energy by requiring that $\mathbf{PE_{max} = KE_{max}}$. Specifically,

Scale factor from scaling by the ratio of the Car Lengths:

$$SF_C := \frac{C_{FS}}{C_{HW}} \qquad SF_C = 85.915$$

Setting the ratio of full scale to model densities equal and assuming a spherical car, we find how to scale masses:

$$1 = \frac{\rho_{FS}}{\rho_{SM}} = \frac{\dfrac{m_{FS}}{\left(4 \cdot \pi \cdot r_{FS}^{\,3}\right)}}{\dfrac{m_{SM}}{\left(4 \cdot \pi \cdot r_{SM}^{\,3}\right)}} \implies \frac{m_{FS}}{m_{SM}} = \left(\frac{r_{FS}}{r_{SM}}\right)^3 = SF_C^{\,3}$$

Likewise, setting the ratio of PE_{max}/KE_{max} for the full scale and scale model equal, we find how to scale speeds and times:

$$1 = \frac{\dfrac{PE_{max}^{\ FS}}{KE_{max}^{\ FS}}}{\dfrac{PE_{max}^{\ SM}}{KE_{max}^{\ SM}}} = \frac{\left[\dfrac{\left(v_{max}^{\ FS}\right)^2}{2 \cdot g \cdot h_{max}^{\ FS}}\right]}{\left[\dfrac{\left(v_{max}^{\ SM}\right)^2}{2 \cdot g \cdot h_{max}^{\ SM}}\right]} = \left(\frac{v_{max}^{\ FS}}{v_{max}^{\ SM}}\right)^2 \cdot \frac{h_{max}^{\ SM}}{h_{max}^{\ FS}}$$

$$\implies \frac{v_{max}^{\ FS}}{v_{max}^{\ SM}} = \sqrt{SF_C} \quad \text{and} \quad \frac{\Delta t_{FS}}{\Delta t_{SM}} = \sqrt{SF_C}$$

Using this "proper" scaling method, we find much more reasonable and consistent results:

Parameter	**"Proper" Scaling by Length**	**Full Scale Model**
Mass of Car:	$m_{HW}\cdot\left(SF_C\right)^3 = 5073.5\,kg$	$m_{FS} = 1.35 \times 10^3\,kg$
Length of Car:	$C_{HW}\cdot SF_C = 6.1\,m$	$C_{FS} = 6.1\,m$
Height of Track:	$H_{HW}\cdot SF_C = 64.007\,m$	$H_{FS} = 100\,m$
Length of Track:	$L_{HW}\cdot SF_C = 309.639\,m$	
Time to Traverse Track:	$T_{HW}\cdot\sqrt{SF_C} = 12.05\,sec$	
Average Velocity:	$\frac{L_{HW}}{T_{HW}}\cdot\sqrt{SF_C} = 92.5\,km\cdot hr^{-1}$	

Amusement Park Physics

Inservice Workshop

Scaling the Marble Coaster

Objective

The objective of this Mathcad worksheet is to determine the correct marble

results a realistic scale version of a "real life" roller coaster. To do this, you need to determine the "proper" scaling factor between your Marble Coaster and a "real life" roller coaster model.

The specific question to address is, "Which mass marble is the best scale model of the Colossus roller coaster train?"

Measurements and Data

We enter various parameters for your Marble Coaster and a full scale model based on the Colossus roller coaster at Lagoon.

Parameter	Marble Coaster	Colossus
Mass of Car:	$m_{HW} := 3 \cdot gm$	$m_{FS} := 7250 \cdot kg$
Height of Track:	$H_{HW} := 15 \cdot cm$	$H_{FS} := 26.5 \cdot m$
Length of Track:	$L_{HW} := 35 \cdot cm$	$L_{FS} := 631.8 \cdot m$ *
Time to Traverse Descending Track:	$T_{HW} := 0.5 \cdot sec$	$T_{FS} := 32 \cdot sec$ *

a profile like Colossus if they were to be predicted by scaling your coaster.

Scaling Method

W

linearly; at the same time we will preserve the density of the materials (e.g., steel) used in making both full scale and model cars and at the same time retain the conservation of energy by requiring that $\mathbf{PE_{max} = KE_{max}}$. Specifically,

Scale factor from scaling by the ratio of the Car Lengths:

$$SF_H := \frac{H_{FS}}{H_{HW}} \qquad SF_H = 176.667$$

Setting the ratio of full scale to model densities equal and assuming a spherical car, we find how to scale masses:

$$1 = \frac{\rho_{FS}}{\rho_{SM}} = \frac{\dfrac{m_{FS}}{\left(4\cdot\pi\cdot r_{FS}^{3}\right)}}{\dfrac{m_{SM}}{\left(4\cdot\pi\cdot r_{SM}^{3}\right)}} \implies \frac{m_{FS}}{m_{SM}} = \left(\frac{r_{FS}}{r_{SM}}\right)^{3} = SF_{H}^{3}$$

Likewise, setting the ratio of PE_{max}/KE_{max} for the full scale and scale model equal, we find how to scale speeds and times:

$$1 = \frac{\dfrac{PE_{max}^{FS}}{KE_{max}^{FS}}}{\dfrac{PE_{max}^{SM}}{KE_{max}^{SM}}} = \frac{\left[\dfrac{\left(v_{max}^{FS}\right)^{2}}{2\cdot g\cdot h_{max}^{FS}}\right]}{\left[\dfrac{\left(v_{max}^{SM}\right)^{2}}{2\cdot g\cdot h_{max}^{SM}}\right]} = \left(\frac{v_{max}^{FS}}{v_{max}^{SM}}\right)^{2}\cdot\frac{h_{max}^{SM}}{h_{max}^{FS}}$$

$$\implies \frac{v_{max}^{FS}}{v_{max}^{SM}} = \sqrt{SF_{H}} \text{ and } \frac{\Delta t_{FS}}{\Delta t_{SM}} = \sqrt{SF_{H}}$$

Results

Using this "proper" scaling method, we find much more reasonable and consistent results:

Parameter	"Proper" Scaling by Length	Full Scale Model
Mass of Car:	$m_{HW}\cdot\left(SF_{H}\right)^{3} = 16541.9\,\mathrm{kg}$	$m_{FS} = 7.25\times 10^{3}\,\mathrm{kg}$
Height of Track:	$H_{HW}\cdot SF_{H} = 26.5\,\mathrm{m}$	$H_{FS} = 26.5\,\mathrm{m}$
Length of Track:	$L_{HW}\cdot SF_{H} = 61.833\,\mathrm{m}$	$L_{FS} = 631.8\,\mathrm{m}$ *
Time to Traverse Track:	$T_{HW}\cdot\sqrt{SF_{H}} = 6.646\,\mathrm{sec}$	$T_{FS} = 32\,\mathrm{sec}$ *
Average Velocity:	$\dfrac{L_{HW}}{T_{HW}}\cdot\sqrt{SF_{H}} = 33.5\,\mathrm{km\cdot hr^{-1}}$	$\dfrac{L_{FS}}{T_{FS}} = 71.077\,\mathrm{km\cdot hr^{-1}}$

* These values for Colossus are for comparison only; your Marble Coaster would have to have a profile like Colossus if they were to be predicted by scaling your coaster.

Extension

best to use as a scale model of the Colossus roller coaster train:

Marble	Mass
Glass	5.85 gm
B-B	0.354 gm
1/8" steel	0.131 gm
1/4" steel	1.042 gm
3/8" steel	3.521 gm
1/2" steel	8.361 gm

AMUSEMENT PARK PHYSICS ACTIVITIES

PLAYGROUND ACTIVITIES - QUALITATIVE

Learning Objectives:

To allow students the opportunity to explore the inclined plane, rotation, and simple harmonic motion through the use of playground equipment, namely, a slide, a swing and a merry-go-round.

Supplies:

1. Stop watch
2. String tied @ 0.5 m intervals = $ .05
3. Horizontal accelerometer - BB's, cardboard, and tubing = $ .30
4. Pennies = $ .10

Swings - Pendulum : Simple Harmonic Motion:

*1. Which of these factors will affect how long it takes for the swing to go back and forth?

a. How high the swing goes

$\text{Time}_{\text{high}}$ __________ Time_{low}
(< > =)

b. The length of swing

T_{long} ____________ T_{short}
(< > =)

2. a. See how long it takes for someone to swing if they go high. Then time them when they are swinging low. Remember not to move while in the swing (i.e., pump the swing)!

   b. Swing on a long and a short swing, and time both of them. Make sure to sit still and start from the same height every time.

Slides - The Inclined Plane:

1. How long do you think it will take to reach the bottom of the slide?

2. Have somebody time you. Were you close?

3. Now have your friend time you while you are sitting on some wax paper or a nylon jacket. Also, see how long it takes a marble to go down the slide. The reason there are differences in the times is because of friction.

Merry-Go-Round - Rotation:

1. Use an accelerometer to find who can spin the merry-go-round the fastest.

2. If 10 pennies are placed in different places on the merry-go-round, which pennies will fall off first?

3. Spin the merry-go-round. Which fall off first?

4. What happens if several people move from the edge of the merry-go-round to the center of the merry-go-round while it is moving?

<u>Answers - Swings</u>

1. a. $\text{Time}_{high} \underset{(<>=)}{\overset{>}{\rule{2cm}{0.4pt}}} \text{Time}_{low}$

   b. $\text{Time}_{long} \underset{(<>=)}{\overset{>}{\rule{2cm}{0.4pt}}} \text{Time}_{short}$

2. a.

$T_{low} = 28.6$ sec	$T_{high} = 29.3$ sec	
$T_{low} = 29$ sec	$T_{high} = 29.3$ sec	$T_{high} > T_{low}$
$T_{low} = 29.2$ sec	$T_{high} = 29.3$ sec	

   b.

Height	Time
1.75 m	12.75 sec
2.25 m	14.11 sec
2.50 m	14.4 sec

<u>Answers - Slides</u>

2.

Height	Time
1.2 m	2.6 sec
2.7 m	4.0 sec

3. Marble's time: 1.5 sec

<u>Answers - Merry-Go-Round</u>

2. The ones on the outer edge.
3. The ones on the outer edge.
4. It will spin faster.

AMUSEMENT PARK PHYSICS ACTIVITIES

PLAYGROUND ACTIVITIES - QUANTITATIVE

Learning Objectives:

To allow students the opportunity to explore the inclined plane, rotation, and simple harmonic motion through the use of playground equipment, namely, a slide, a swing and a merry-go-round.

Supplies:

1. Stop watch
2. String tied @ 0.5 m intervals = $ .05
3. Horizontal accelerometer - BB's, cardboard, and tubing = $ .30
4. Pennies = $ .10

Terms:

Amplitude:	The maximum angle a swing reaches
Period:	The time for one complete swing
Mass:	How much 'stuff' an object has, measured in kilograms (kg.)
Weight:	The force of an object on the earth F = m a, and a = g, therefore, weight = mg Acceleration due to gravity is g_e, a constant; $g_e = 9.8$ m/s^2, the acceleration of an object falling on the earth. g on the moon = 1.6 m/s^2.

Helpful hints:

To measure the height of a swing, one can use a clinometer (horizontal accelerometer), or string.

1. Place the clinometer on the ground. While keeping the BB's at the 63° mark, move it closer or further away from the swing until you can see the top of the swing through the straw. Measure the distance from the swing to the clinometer, x, and the height, y, of the swing from the ground. The height of the swing is thus: h = (2*x)-y.

2. Attach a heavy object to the end of your string. Throw it over the swing. Mark on the string where the end and the seat meet. Now the length of the swing is the length of the string divided by 2.

Swings - Pendulum: Simple Harmonic Motion

*1. Which of these factors will affect the period of motion?

a. amplitude of motion

T_{60} ____________ T_{30}

(< > =)

b. weight of the rider

T_{little} ____________ T_{large}

(< > =)

c. length of swing

T_{long} ____________ T_{short}

(< > =)

2. Design an experiment to test the validity of your answer to a, b, and c.

3. Perform the experiment.

4. Plot a graph of length (1) vs period (T)

5. Estimate the period of motion for at least four different swings. (Hint: use the length of the swing and g = 9.8 m/s^2.)

6. Time the period on these swings. Calculate the error. $\underline{T} = (T_{experimental} - T_{theory})/T_{theory}$; are the calculations and the experimental data close?

Slides: The Inclined Plane

1. Neglecting friction, estimate the time needed to reach the bottom of the slide.

2. What is the experimental time to go down the slide?

3. What errors are in this experiment? How could this be reduced?
(Hint: ride on wax paper or a nylon jacket, time a marble, lift feet.)

4. Reduce these errors, and redo Question #2.

5. Calculate the coefficient of friction.

*6. Neglecting friction, will a light or heavy person reach the bottom first? (Hint: Does Question #1 depend on mass?)

Merry-Go-Round: Rotation

1. Use an accelerometer to find the maximum acceleration.
   Will the maximum acceleration occur at the outer edge or in the middle?

2. Does your accelerometer read the same when oriented radially and perpendicular to the radius? Why?

3. From $F_{centrifugal} = F_{accelerometer}$, estimate your velocity in Question #1.

4. If 10 pennies are placed in different positions on the merry-go-round, which pennies will fall off first?

5. Spin the merry-go-round. In which order do they fall off?

6. What happens if several people move from the edge to the center of the merry-go-round while it is moving?

Answers - Swings

1. a. $Time_{large} \underset{(<>=)}{\underline{\;>\;}} Time_{lsmall}$

   b. $Time_{light} \underset{(<>=)}{\underline{\;>\;}} Time_{heavy}$

   c. $Time_{long} \underset{(<>=)}{\underline{\;>\;}} Time_{short}$

2. a. Seing a person with a small and large amplitude and time the subsequent motion five times and take the average.

   b. Time a light and a heavy person 5 times paying special attention to keep the amplitude the same.

   c. For the same amplitude and person time their oscillation.

4.

Length	TimeU
2.25 m	2.8 sec
1.9 m	2.6 sec
2.3 m	2.8 sec
2.5 m	2.9 sec

5.

1. 3 sec
2. 2.76 sec
3. 2.6 sec
4. 3.17 sec

$T = 2*\pi\sqrt{(1/g)}$

$1_1 = 2.25$ m — $T_{1Theory} = 2*\pi\sqrt{(2.25/9.8)}$

$1_1 = 1.9$ m — $T_{2Theory} = 2*\pi\sqrt{(1.9/9.8)}$

$1_1 = 1.75$ m — $T_{3Theory} = 2*\pi\sqrt{(1.75/9.8)}$

$1_1 = 2.5$ m — $T_{4Theory} = 2*\pi\sqrt{(2.5/9.8)}$

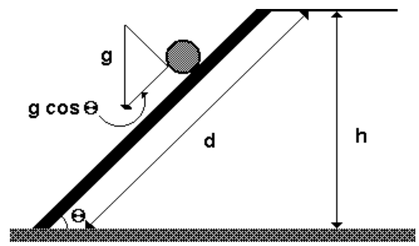
6. $T_{1experimental} = 2.83$ sec   TI = 5.0%

$T_{1experimental} = 2.62$ sec		TI = 5.3%

$T_{1experimental} = 2.55$ sec		TI = 2 %

$T_{1experimental} = 2.84$ sec		TI = 10 %

Answers - Slides



1. h = 2m

   $F = ma = mg/\sqrt{2} \Rightarrow a = g/\sqrt{2}$

   $d = 2*\sqrt{2}m$

   $d = (1/2)at^2 \qquad \Rightarrow t = 0.90$ sec

2. $T_{average} = 1.9$ sec
3. *friction

   *timing errors
4. Roll a marble down it. For a 2 m slide, $T_{average} = 0.90$ sec
5. Referring to the figure at right, $F = ma = \frac{mg}{\sqrt{2}} - \mu\frac{mg}{\sqrt{2}} = (1 - \mu)\frac{mg}{\sqrt{2}}$ which implies, using $a = 2d/t^2$,

   $\mu = 1 - \frac{a}{g}\sqrt{2} = 1 - \frac{2\sqrt{2}d}{gt^2}$. For the marble there is almost no friction. For the rider in Question #2, $\mu = 0.75$.
6. They will land at the same time, since t = 2d/a, independent of mass.

Answers - Merry-Go-Round

1. 0.9 g; on the outside
2. There is a radial acceleration, but no perpendicular acceleration.
3. $mv^2/r = m\,(9m/s^2)$

   $v = \sqrt{9} = 3$ m/s
4. The ones on the outside.
5. Outer ones
6. Conservation of angular momentum:

   $L_{before} = L_{after}$

   $v_b r_b = v_a r_a$

   $v_a = v_b r_a / r_b$

   $r_a/r_b > 1$

   $v_a > v_b$

MEASUREMENT ACTIVITIES

MEASUREMENT AND DATA ANALYSIS TECHNIQUES

Let's pretend it's Physics Day, and we are ready to go. We have our accelerometers built, and we want to go out and make the best measurements and win the accelerometer contest this year. What can we do to improve our chances? In this section, we will talk a little about how we make good measurements and how to make the most of our measurements when we analyze them.

Is there a difference between accurate and precise?
Precision and accuracy are two distinct ideas in measurement and data analysis. Precision is how well you have measured the value. Accuracy is how close you are to some true value.

- *Precision* is related to how well you can make your measurements. For example, if you want to measure the temperature of the room precisely, you would probably use a thermocouple, or digital thermometer which measures to a hundredth of a degree. Then the measurement would be very precise. If you wanted to roughly know what the temperature was, you could just use a cheap alcohol thermometer, where the steps in temperature are shown to only 1 °C.
- *Accuracy* depends on how close your measurement comes to the true value. In the above example, if your digital thermometer was systematically 2 °C too high, you would have a very precise measurement of an inaccurate value. You would know the wrong temperature very well! Most measuring devices have some degree of uncertainty, some plus or minus range around the true value that they measure.

Being accurate and precise: Best ways to improve your measurements.

- *Use well-calibrated equipment*: This means you should make sure your measuring device measures a known value well. For example, on vertical accelerometers you might build, if you can somehow accurately set the 0 g value and the 1 g value, you will make more accurate measurements than if you just guess or approximate where these points are. In general, if you can compare your measuring device to one that is known to measure well, you can find out how accurate your device is. Sometimes you can use this method to calibrate your device.
- *Use equipment with small gradations*: You can more precisely determine a length from a ruler with 0.1 mm gradations than one with just 1 cm gradations. The extra divisions help you read better, or determine the measured value better. For example, you can improve your accelerometer precision by putting in marks for every quarter of a g, instead of just every 1 g.
- *Take several measurements*: If you take several measurements, and average over them, you decrease your uncertainty. This helps minimize the effects of random measurement errors. Your final average value will be more reproducible, that is, known with less uncertainty, and hence you increase your precision.

There are several worksheets in the curriculum manual which help reinforce these ideas.

MEASUREMENT ACTIVITIES

MEASUREMENT AND STATISTICS

One of the key skills a physicist needs is to measure experimental quantities. Often these quantities need to be estimated, either to check the accuracy of the measurements or because accurate measurement is impossible. The following questions provide students experience in this skill. Note that students are required to estimate the uncertainty of their measurements. This emphasizes the importance of knowing how well you know a certain "fact."

Questions:

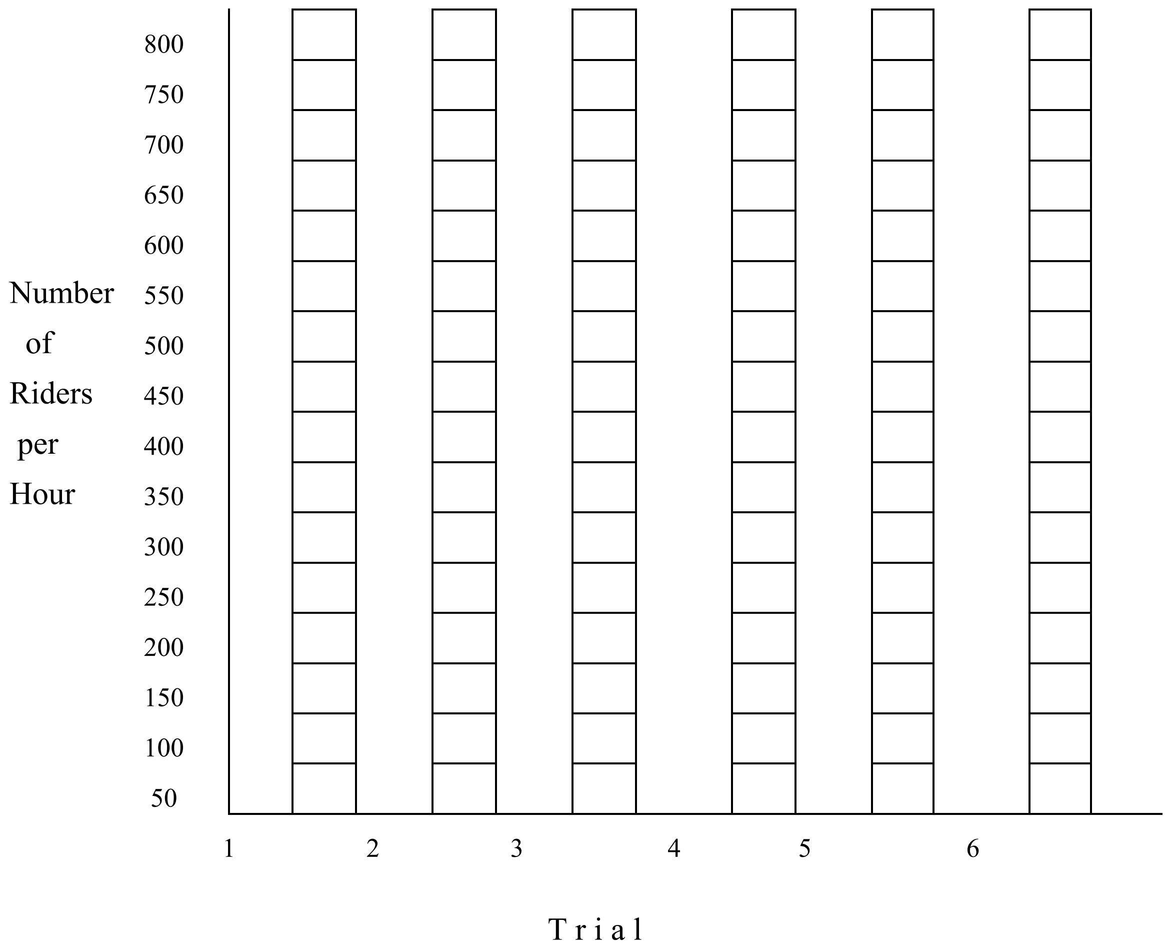
	VALUE:	ERROR:
1. What is the maximum velocity experienced on the Scrambler? Give the answer in meters per second.	______ m/s	± _________ m/s
2. When the Colossus moves in horizontal circles, the train track tips at a steep angle. Estimate the maximum angle between a line perpendicular to the seat and floor of the cars and the vertical. Give the answer in degrees.	______ °	± ___________ °
3. Estimate the total length of the Colossus track. Give the answer in meters.	______ m	± __________ m
4. How many lights are on the Sky Scraper? Include the whole ride: entryway, gondolas, wheel, etc.	______	±____________
5. The Sky Tram carries riders from one end of the park to the other. Estimate its length. Give your answer in meters.	______ m	± _________ m
6. Including the support structure, what is the overall height of the Sky Scraper? Give your answer in meters.	______ m	± _________ m
7. The Turn of the Century has swings that sail out around a central tower. What is the maximum horizontal distance from the center of the tower to the chairs when they are swinging out? Give your answer in meters.	______ m	± _________ m
8. What is the maximum velocity of the chairs on the Turn of the Century? Give your answer in meters per second.	______ m/s	± ________ m/s

Answers:

1. 20 m/s ± 5 m/s (45 mph ± 11 mph)
2. 40° ± 10°
3. 632 m ± 10 m
4. 180,000 ± 1,000
5. 450 m ± 100 m
6. 44 m ± 0.5 m
7. 25° ± 5°
8. 7 m/s ± 2 m/s

MEASUREMENT AND STATISTICS

1. Estimate the number of people per hour that ride the Sky Tram. Count the number of riders passing a certain point in one minute. Enter your result as Trial 1 on the histogram below. Repeat your measurement. Find two friends and "borrow" their results. Finish the histograms and calculate the average number of riders per hour and the standard deviation. The standard deviation tells you how well all the measurements agree with each other.



Average $\left(N_{avg} = \frac{N_1 + N_2 + N_3 + N_4 + N_5 + N_6}{6}\right)$:

Standard deviation $\left(\text{St.Dev.} = \frac{1}{6}\sum_{i=1}^{6} \sqrt{(N_i - N_{avg})^2}\right)$:

2. Now measure the number of riders passing your special point for 3 minutes. Which gives the most precise result: a) the 3-minute measurement; b) Trial 1; or c) the average value from Part 1? Why?

3. Imagine you measure the length of the Sky Tram using three devices: 1) a meter stick; 2) pacing the distance; and 3) a car odometer.
   Which will give you the most precise value? Why?

Answers:

1. 450; 57
2. Measured: 22 riders in 3 minutes.

   (c) This has the largest data set.
3. (1) meter stick. This is the most precise measuring instrument.

MEASUREMENT ACTIVITIES

MEASUREMENT TECHNIQUES - ACCELERATION

Most of the rides at an amusement park produce their breathtaking thrills by causing various accelerations of the riders. Because of this, the amusement park is a most natural place to learn about accelerations. One way to do this is to measure the accelerations a rider feels, and compare that to where a rider feels the most excitement or fear. In this session, we will first talk about different accelerations, discuss how to measure them using accelerometers, describe several different accelerometers, and discuss how they work.

What is Acceleration:

Acceleration is the time rate of change of velocity, or how fast your velocity is changing.

- Remember velocity is a vector: it has magnitude and direction. So an acceleration can result from a change in the magnitude of the velocity (i.e., a change in speed, for example in a car coming to or leaving a stop sign) or from a change in the direction of the velocity (such as going around a curve when you experience centripetal acceleration).
- Accelerations result when forces are applied. For example, there is a gravitational force between any object and the Earth. Therefore, objects accelerate towards the Earth with an acceleration of 9.8 m/s^2, or 1g (this follows from Newton's 2nd law). Refer to the parts of Section A on Gravity Facts and G-Forces. When a roller coaster track whips us through a loop, the track exerts a force on us to keep us going in a circle (centripetal force) which depends on how fast we are moving, how tight the curve is, and our mass.
- Acceleration is also a vector: it has a magnitude and direction. In the above examples, the Earth's acceleration has a magnitude of g, and is directed toward the center of Earth. For circular motion, the magnitude of the acceleration is v^2/r, and is directed toward the center of the turn.

How can we measure these accelerations?

Just as these accelerations act on us, they act on other objects or masses. We can use this interaction as the basis to build simple mechanical accelerometers. These are great for getting a general feel for accelerations, and for making on-site measurements. Some examples follow.

- *Spring accelerometers*: In this case, we attach a mass to a spring. The extension of the spring is directly proportional to the force on the spring (this is Hooke's Law). So, if the mass experiences an acceleration, it exerts a force on the spring. This is registered as an extension of the spring. Newton's third law tells us that the magnitude of the force on the spring is the same as the force on the mass, or is equal to mass times its acceleration. Because the mass does not change, a change in spring extension means a change in acceleration. The extension can be calibrated to correspond to certain accelerations using Hooke's Law.
- *Pendulum Accelerometers*: For these accelerometers, a mass is hung on a string. If the mass experiences an acceleration, the pendulum will deflect from vertical, until the acceleration is counterbalanced by the downward component of the mass's gravitational force. Again, Newton's third law tells us that the force on the mass due to the acceleration is the same as the force on the mass due to gravity, or is equal to the mass times its acceleration. The amount of deflection (or angle) is related to the acceleration experienced by the mass ($a = g \tan\theta$). Often this type of accelerometer can also be used as a clinometer, which is useful for making height measurements in the amusement park.

- *Water Accelerometers*: Put water in a bottle or other container. The water will slosh up to one side as the container experiences an acceleration. The amount of displacement is related to the acceleration, much the same as the deflection of the pendulum is related to the acceleration.

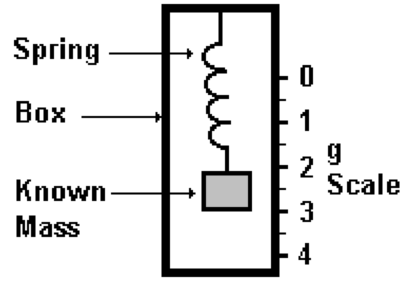
For more quantitative analysis, it is helpful to have some way of collecting data. A data logger (a portable data taking and storing device) is necessary in most cases. Here are some ideas for more complicated accelerometers:

- These are some fancier ideas, which involve electronic acceleration measuring sensors:
    - The Calculator Based Laboratory (CBL) system is a data logger which plugs into a Texas Instruments graphing calculator (TI-82 or better). It can measure voltages, as well as supporting Sonic Rangers, and a stand-alone accelerometer. The data can then be transferred to a PC or Macintosh computer for further analysis and plotting. This is very useful for on-site measurements. Refer to articles listed in the Reference List in Section F.
    - Piezo crystals: An acceleration will deform the piezo-electric crystal (like those used in audio tweeter speakers) causing a voltage proportional to the deflection and to the acceleration.
    - Strain gages: These are resistance devices put into one leg of a Wheatstone bridge. The acceleration will cause a strain, and it will be registered as a current imbalance in the bridge.
    - IC accelerometers, such as those available from Analog Devices, incorporate a strain gauge or other small scale device to measure acceleration. The integrated circuit also contains most of the electronics to detect and amplify the signal from a small transducer.
- Several of the mechanical accelerometers above can be modified so that the accelerations are logged.
    - You can attach a pendulum to a linear variable resistor at the pivot point. As the pendulum moves as a reaction to an acceleration, the resistance changes. By measuring a voltage drop across the resistor, this change can be measured and logged.
    - A Sonic Ranger can be used to track motion, as a function of time. From this, velocity and acceleration can be calculated. This is more practical for linear motion, such as riding a slide, or for simple periodic motion, such as on a swing. [See, e.g., R. Taylor *et al.*, TPT **33**, 332 (1995).]
    - Here is another ingenious idea! You can attach a plotter pen to springs used as an accelerometer, and place a strip of paper under it. This paper is pulled at a constant rate past the pen. The pen moves over the paper in response to accelerations, and the deviations are drawn onto the paper. The data gets logged without any electronics. If the operator has a steady hand (not an easy feat while riding a wild ride), the relative times for the accelerations can be approximated, and data can be analyzed somewhat quantitatively.

MEASUREMENT ACTIVITIES

MAKING SIMPLE ACCELEROMETERS

Spring Accelerometer. Use the extension of a spring with a known mass to deduce the force and hence the acceleration. Calibration is readily done by using different test masses in the one g environment. A scale showing 1g, 2g, 3g, etc. and sub-divisions can be made. In designing this system, care must be taken to ensure the accelerometer can operate under forces other than just vertical!

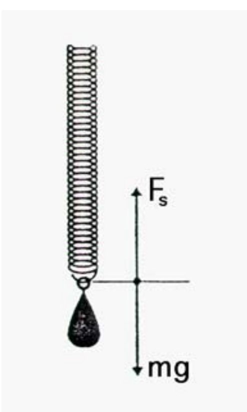


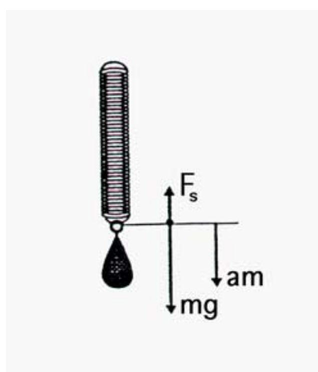
If we have a mass attached to a spring in equilibrium, the force due to gravity on the mass is equal to that of the spring's restoring force.

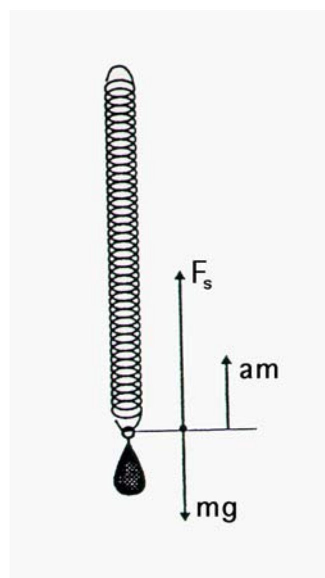
A good model for the restoring force on a spring is given by Hooke's Law: $F_s = -k*d$.

Thus: $F_g = F_s =>$ $m*g = -k*d$

Where F_g = force on the mass due to gravity
F_s = restoring force of the spring
m = mass of weight
g = acceleration due to gravity
k = the spring constant
d = displacement of mass







Now, if we accelerate the accelerometer upward (downward), the force on the bob will be increased (decreased) according to:

$F_a = m*a$
Where a = additional acceleration of the accelerometer

So $F_{total} = F_a + F_g = F_s = -k*d$

Solving for d we obtain

$$d = \frac{F_a + F_g}{-k} = \frac{-m*a + m*|g|}{k}$$

If the acceleration is upward, this implies that a is positive and that d becomes more negative so that the spring becomes longer.

If the acceleration is downward, this implies that a is negative and that d gets less negative so that the spring becomes shorter.

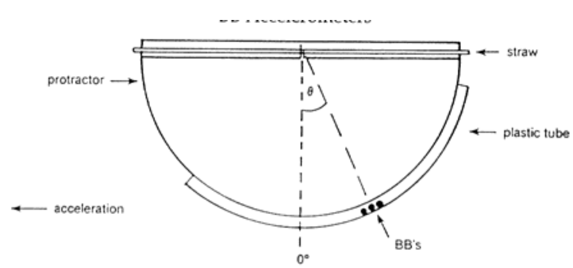
Pendulum Accelerometer.

Note: In this section, the acceleration of gravity is treated as a scalar quantity of 9.8 m/s^2.

You can easily make a horizontal accelerometer from a piece of cardboard, a protractor, plastic tubing, a straw, and three BB's.

You hold this device horizontally, aligned along the direction of the acceleration and held so that the BB's can swing freely. You can use a drinking straw taped along the baseline of the protractor as a sighting tube. As the accelerometer is accelerated, the BB's swing through an angle θ. Applying Newton's Second Law to the horizontal and vertical components of the forces on the BB's, we get:

BB Accelerometers



$$\sum F_{vertical} = T \cos\theta - mg = 0$$

and

$$\sum F_{horizontal} = T \sin\theta = ma$$

where *T* is the tension of the BB's against the plastic tube and
a is the unknown acceleration. Solving for a, we get:

$$\boxed{a = g \tan\theta}$$

Therefore, by measuring angle θ, the acceleration may be determined. It is often useful to mark both angles and corresponding g values on your horizontal accelerometers, as done on the photocopy master found on the next page.

BB Accelerometer.

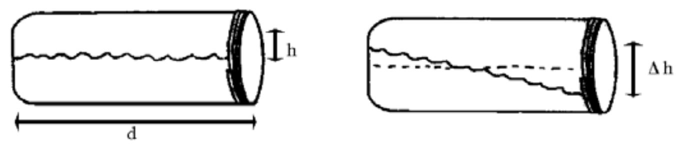
A variation on the pendulum accelerometer is the BB accelerometer.

Water Accelerometer.

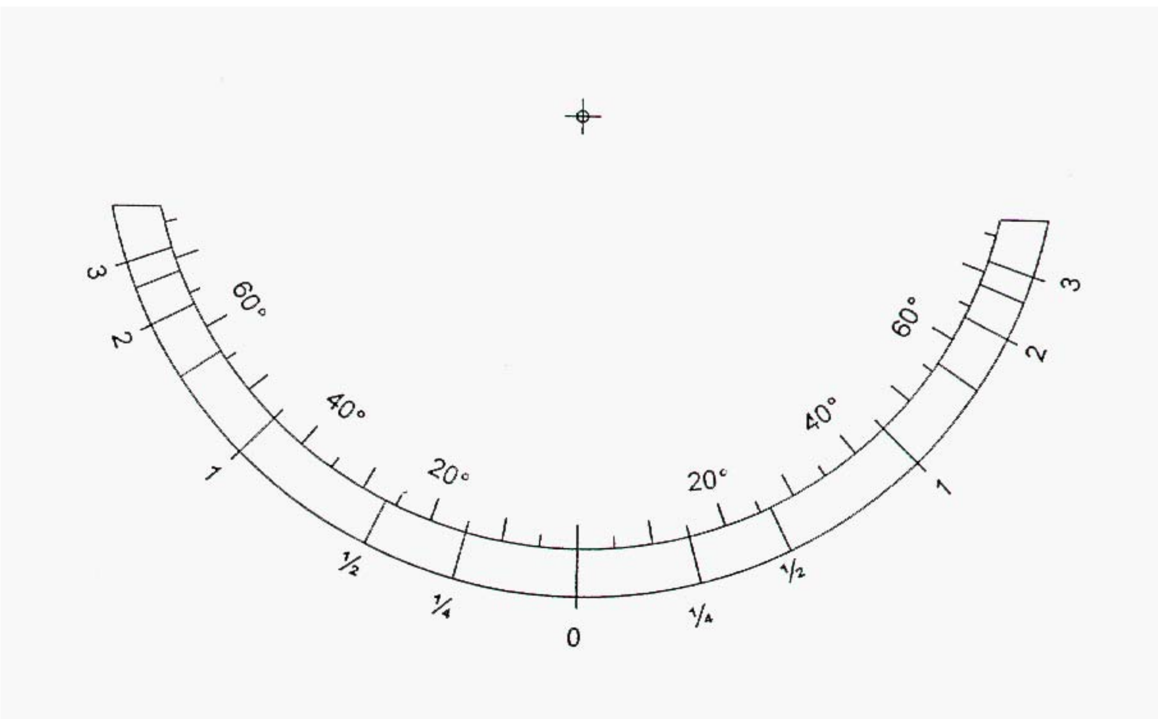
A liquid accelerometer to measure "horizontal" g. Put some colored water in a transparent sealed bottle. When held on its side the bottle should be about 1/3 full. A horizontal force will cause the liquid to tilt inside the bottle. Measuring the tilt or using a calibration scale on the end of the bottle will lead to the desired measure of g.

As a container of water is accelerated, the water will be displaced; the amount of deflection is related to the acceleration by the equation: $\frac{2*g*\Delta h}{d} = a_x$

Sideways g scale



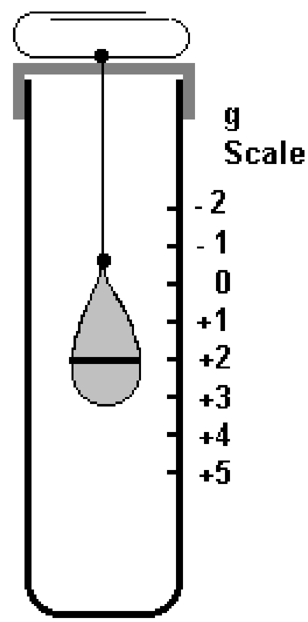
Sealed clear non-glass bottle



MEASUREMENT ACTIVITIES

THE 26-CENT ACCELEROMETER

Designed by Marian Dennison, Mount Logan Middle School



CONSTRUCTION:

1. Mark a thick, bright line across the center of a 1/4 oz fishing weight. Nail polish or permanent markers work well.
2. Tie a 6" piece of thin sewing elastic to the fishing weight. Thread the other end through the hole in the cap of the floral tube.
3. Tie the free end to a paper clip. The string should be about half the length of the tube. You want the bottom of the 1/4 oz weight to just clear the bottom when 1 oz of additional weight is added. See the calibration notes below.
4. Put the cap on the floral tube.
5. Put a piece of removable tape on the outside of the tube for calibration marks.
6. Use two rubber bands to affix the tube to your arm.

CALIBRATION:

Calibration is simple if you use a little physics knowledge. When the spring or elastic is stretched, there is a restoring force $F_S = -kx$; the force increases linearly with stretched distance x for an ideal spring. The force that stretches the spring is the weight $F_W = ma$. When using the accelerometer at the amusement park, the mass is fixed and the acceleration a varies. For calibration we fix the acceleration a = g and vary the mass. Note the spring stretches the same distance whether we have a mass m and 2 g's of acceleration or a mass 2m and 1g of acceleration.

Place your accelerometer in a vertical position. Simply add additional weights and note the stretch with 1/4 oz, 1/2 oz, 3/4 oz, 1 oz and 5/4 oz weights; these correspond to a 1/4 oz weight under 1, 2, 3, 4 and 5 g's. You can add weights in 1/8 oz or 1/16 oz intervals for finer calibration. Finding where to place the 0g and -1g marks is a bit more difficult. If you found the 1-5g marks were evenly spaced (as is to be expected), you can simply use a ruler to mark off equal increments for the 0g and -1g marks.

PARTS LIST:

Floral tube*	10 cents
1/4 oz lead fishing weight	13 cents
Sewing elastic (or rubber band)	1/4 cent
Paper clip	1/2 cent
Removable tape	1/2 cent
Two rubber bands for mounting	1 cent

*Plastic tubing, cigar tubes, candy tubes or tennis ball containers also work well. Longer tubes give more resolution from wider spaced g-force divisions.

MEASUREMENT ACTIVITIES

ACCELEROMETER MEASUREMENT QUESTIONS

The following questions were developed for students to answer using student-made accelerometers. Note the rides on which the measurements may be made are limited. Students are required to estimate the accuracy of their measurements. This emphasizes the importance of knowing how well a measurement is made.

Measurements are allowed only on the following rides:

1. Colossus
2. Wooden Roller Coaster
3. Centennial Scrambler
4. Space Scrambler

Part 1: What is the largest acceleration force experienced on the Colossus ride? Where did it occur?

Location: __________
__________ m/s^2
± __________ m/s^2

Part 2: What is the maximum vertical acceleration experienced at Lagoon?

Ride # ____________
__________ m/s^2
± __________ m/s^2

Part 3: What is the maximum horizontal acceleration experienced at Lagoon?

Ride # ____________
__________ m/s^2
± __________ m/s^2

Part 4: Which ride sustains at least 1.2 g for the longest time?

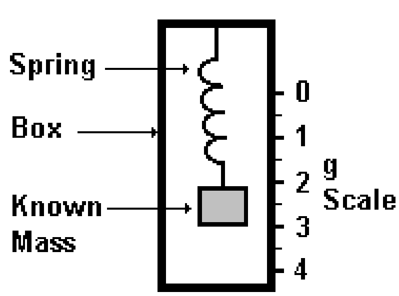
Ride # ____________
____________ sec
± ______________

Part 5: Measure the acceleration at the top of the upside-down phase of the Colossus ride?

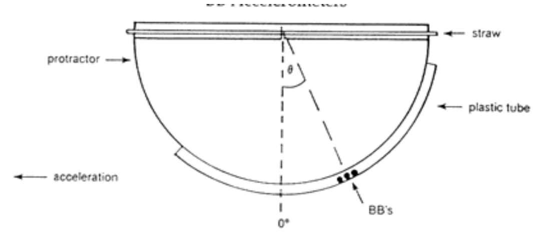
____________ m/s
±____________ m/s

Part 6: Which ride sustains 1-1/4 g for the longest time? How long is it sustained

Ride # ____________
____________ sec
± ____________ sec



BB Accelerometers



MEASUREMENT ACTIVITIES

VELOCITY MEASUREMENTS

The following questions were developed for students to answer using student-made velocity measuring devices. Note the rides on which the measurements may be made are limited. Students are required to estimate the accuracy of their measurements. This emphasizes the importance of knowing how well a measurement is made.

Measurements are allowed only on the following rides:

1. Colossus
2. Wooden Roller Coaster
3. Sky Tram
4. Centennial Scrambler
5. Space Scrambler
6. Skyscraper Ferris Wheel

Part 1: What is the maximum speed at which you can move on the above rides? On which ride?

Location: ___________
__________ m/s
± ___________ m/s

Part 2: What is the maximum vertical speed at which you can move on the above rides? On which ride?

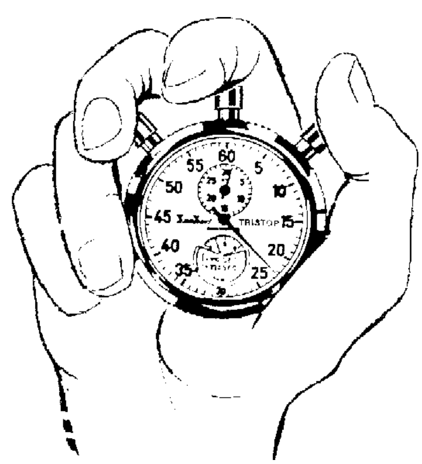
Ride # _____________
__________ m/s
± ___________ m/s

Part 3: What is the average speed on the Sky Tram chair lift?

__________ m/s
± ___________ m/s

Part 4: What is the maximum speed on the Skyscraper Ferris Wheel? What is the difference in speeds (if any) at the top and bottom?

_____________ sec
± ____________ m/s
Difference: _________ m/s



ADDITIONAL RESOURCES

CURRICULUM CONTEST WINNERS

The USU Physics Department and College of Science sponsor an annual Amusement Park Physics Curriculum Development Contest at Physics Day at Lagoon. The goal of the contest is to create curriculum material on Amusement Park Physics for use in your schools. Material developed for the contest can include lessons for use in the classroom either before or after Physics Day or activities and contests for completion at Lagoon on Physics Day. Selection is based on the material's educational value, physics content, and creativity. The curriculum material is limited to a maximum of two pages of teacher handouts and a two-page student worksheet.

Contest winners:

Physics of Miniature Golf`	First Place 1992	Sharon Miya	Davis High School
Laws of Motion and Gravity	Second Place 1992	Robin Parkinson	Clearfield high School
Lagoon-A-Beach, A Physics Paradise	First Place 1993	Ron Cefalo	Box Elder High School
Simple Machines and Newton's Laws at Lagoon	Second Place 1993	Marian Dennison	Logan High School
Physics Makes A Splash	Third Place 1993	Sharon Miya	Davis High School
Marble Coasters	First Place 1994	Paula Scott & Marian Dennison	Mt Logan Middle School
Frequencies and Periods or "Does It Hertz?	Place 1994	Ron Cefalo	Box Elder High School
Triangular Exploration of Lagoon	First Place 1995	Sharon Miya	Davis High School
The Hottest Cars Around and			
Herschel's Experiment	Second Place 1995	David Black	Juab High School
Banked Curves on Rides	Third Place 1995	Ken Wareham	West Side High School
Pendulums and Projectiles	First Place 1996	Ken Wareham	West Side High School
The Inertial Balance	Second Place 1996	David Black	Juab High School
Principles of Physics Used in Miniature Golf	Third Place 1996	Lucinda Bingham	Richmond, UT

ADDITIONAL RESOURCES

LAWS OF MOTION AND GRAVITY

Introduction:

The very best way to help students understand the laws of motion and gravity is to give them some direct experience. The rides at an amusement park help to do just that. In addition students need to see how physics can apply to future careers. The idea behind this activity is to show students how physics can be used in a real-life situation, for example, designing an amusement park ride.

Goal:

Help students understand how the laws of motion are used to make amusement park rides, then use the information to design rides of their own.

Procedure:

1. Before USU Physics Day, divide the students into design teams of two or three. Have the teams build an accelerometer and a clinometer (used to measure steepness of slope). These will be used to help the teams analyze their favorite rides.

2. You might want to have the students do some research on different amusement park rides. Then discuss with the students how the laws of motion and gravity apply to a roller coaster as an example.

3. During Lagoon Day, have the teams pick a favorite ride. Using the two instruments and any other measuring device they can come up with, they will analyze their ride to determine how the laws of motion and gravity were utilized by the designer to make the ride fun and thrilling.

4. After Lagoon Day, have the teams use the information they have gathered to diagram the ride. Have them indicate on the diagram where different laws apply.

5. Assign the teams to design their own rides, either on paper, with a computer, or by building a model.

6. As a possible end activity, have a representative from Arrow Dynamics speak to the students. (This is a local company that designs roller coasters.)

LAWS OF MOTION AND GRAVITY

Pre-Lagoon Day Instructions:

Construct an accelerometer and clinometer to use in the analysis of a ride at Lagoon.

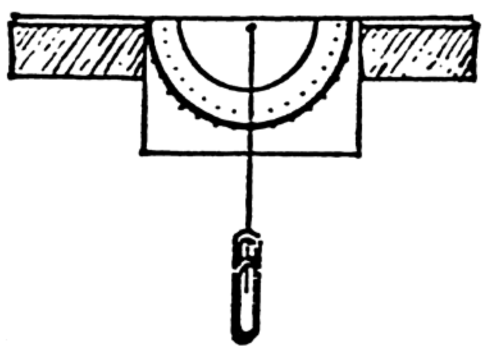
Constructing an Accelerometer:

Refer to the information that comes with the Lagoon Day contest information.

Constructing a Clinometer:

Materials: plastic protractor, ruler, string, paper clip, and straw.

Diagram:



The clinometer is made by mounting the protractor on the ruler and hanging the string with the weight from the midpoint. A straw can be mounted on the top of the ruler to aid in sighting.

Use:

The clinometer is used by sighting something at the top of the slope through the straw. The weight swings the string down to the angle of the slope.

Other Tools:

If your team has other ideas for instruments that might help with the analysis, submit your ideas to the teacher for approval and build those too.

STUDENT HANDOUT
(Page 2 of 2)

LAWS OF MOTION AND GRAVITY

Lagoon Day Instructions:

Analyze one ride to determine how the laws of motion and gravity are used in the ride.

Procedure:

1. As a team, pick a ride.
2. Ride on the ride several times to get the feel of how it works.
3. Make a quick sketch of the ride.
4. Ride the ride again. Using the accelerometer, measure where on the ride acceleration takes place. Note these places on your sketch.
5. Use the clinometer to measure the height of the ride and note it on your sketch.
6. Ask everyone on the team to write down their impressions of the ride.
7. Enjoy the rest of your day. Try to ride your ride one last time at the end of the day.

Post-Lagoon Day Instructions

Finish the analysis and draw conclusions on the data gathered during Lagoon Day. Use these conclusions and date to design your own ride.

Procedure:

1. Look over your data. Make a finished sketch of the ride noting where and what laws were used in making the ride.
2. Write a short paper explaining your procedure and experience.
3. Come up with a new ride. Sketch it, again noting where you think the various laws of motion and gravity would be employed in the ride.
4. Prepare a short oral report to sell your design to the class.

ADDITIONAL RESOURCES

LAGOON-A-BEACH, A PHYSICS PARADISE

INTRODUCTION:

The purpose of the three activities outlined for student investigation is to allow the student to "think" and use his skills already learned in the classroom to solve and identify physics phenomenon related to Lagoon-a-beach. Students should be encouraged to use their own solutions and methods of obtaining data. The enclosed student handout is designed to allow the student latitude to create unique approaches to problem solving.

A special note to the teachers:

The questions asked in these activities are not designed for just one answer; rather they are posed in hopes that they can be used for springboards to greater discussions later in your classroom. While they are not exhaustive by any means, they should serve as a means to spark further interest. These questions are meant to challenge students (and instructors) to THINK, QUESTION, DISCUSS AND ASK OTHER QUESTIONS. THE BEST QUESTION IS NOT ONE THAT IS ANSWERED, BUT ONE WHICH POSES ANOTHER QUESTION OR FURTHER THOUGHT. THESE ACTIVITIES ARE DESIGNED FOR HANDS-ON AND OPEN MINDS.

MATERIALS:

Meter stick or measuring tape (metric)
Graduated cylinder
Food coloring (may want to use 4 colors)
Small wood stick or dowels
Thermometer (Celsius)
THE MIND OF AN INQUISITIVE STUDENT

LAGOON-A-BEACH, A PHYSICS PARADISE

<u>ACTIVITY 1 - WATER MEASUREMENTS</u>:

In this activity students are asked to measure (using the metric system) the volume of three parts of the beach. They will need a thermometer and a meter stick to complete this activity. Note that the pools listed have variations in their depths or have irregular shapes (as in the curvature of the moat area). This should challenge the student to come up with his/her own methods of measurement. The "Fermi question" format is designed to encourage students to THINK in terms of powers of ten rather in specific numbers. Identification of heat versus temperature should help the student recall the physics of energy and molecular motion. It is important to have the student think in terms of mass rather than just temperature when relating the total heat energy. The inclusion of human bodies as a heat factor is designed to have the student extrapolate from the values of human body temperature to calorie heat output. Another interpretation is required when students are asked to THINK in terms of pool strength requirements when determining the capacity or the weight a pool can hold.

<u>ACTIVITY 2 - ELECTRICITY, A SHOCKING PROBLEM</u>:

This activity is designed to have the student identify the information that is important to solve a problem. Remember that PHYSICS IS RELATIVE TO THE CONDITIONS, thus specifying the conditions or the terms of measurement often lends great insight into the solution of the problem. Here students are not asked to solve the problem, but to recognize the factors that are important in the process. This section is also a good refresher for the differences in AC and DC electricity, series and parallel circuits, and voltage, current and resistance. Also included are topics of static charges (Recall static charges are a result of frictional forces and therefore may be found associated with fluid frictions inside pipes as well. However, remember most tubes are grounded, which eliminates this problem) and grounding of electrical devices.

<u>ACTIVITY 3 - FLOW RATES AND LAMINAR AND TURBULENT FLOW</u>:

This section is designed to have the student DESIGN, THINK AND PROPOSE possible experiments to demonstrate a physics phenomenon. With limited resources students should be able to come up with unique approaches to PROBLEM SOLVING. A good review of laminar and turbulent flow characteristics would greatly help the student. Setting up the calculations for a flow rate will indicate that the student recognizes the factors that are necessary to determine proper flow rates of fluids. The last question of Activity 3 is designed to open the minds of the student to the myriad array of physics topics that are found in the beach area of Lagoon. It is hoped that the student would recognize many of the topic, concepts and basic principles that he/she has been taught in physics.

LAGOON-A-BEACH, A PHYSICS PARADISE

INTRODUCTION:

Lagoon-a-beach is a fascinating and exciting place to observe and conduct physics investigations. In this activity you will measure, observe, estimate and calculate, and yes, even "think" about the physics related to the beach area. You will find that there is an interrelationship between all the disciplines of physics represented at the beach. In fact, every chapter in your physics book is represented in these activities; hence, this is a physics paradise.

ACTIVITY 1 - WATER MEASUREMENTS:

FILL IN THE CHART BELOW WITH YOUR ESTIMATES OR CALCULATIONS:

AREA	VOL. (LITERS)	MASS (kg)	TEMPERATURE	HEAT(CALORIES)
HYDROTUBE POOL				
SPEEDSLIDE POOL				
LARGE WATER MOTE				

What is the total volume of water in the beach? Give your answer in powers of ten (Fermi question format).

What is the total mass in kg of the three pool areas? Answer this question as a "Fermi question."

What is the difference between heat and temperature?

Which pool has the greatest quantity of added heat energy according to your calculations? In calculating heat added, assume that all the water was initially at 10° C.

How does the number of human bodies in the water affect the total heat energy of a pool? How much heat does a body release to the water? Is this a function of time or surface area or both?

What is your guess as to how thick the pool floor is in order to support the water mass? Which pool floor is probably the thickest and why?

LAGOON-A-BEACH, A PHYSICS PARADISE

ACTIVITY 2 - ELECTRICITY, A SHOCKING PROBLEM:

In this activity you will be required to identify what information is necessary for you to calculate the answer. (It is not necessary to perform the calculations, but only to identify the needed factors.)

PROBLEM	MEASUREMENTS NEEDED	CALCULATIONS NEEDED
COST OF ELECTRICITY TO RUN THE PUMPS		
HORSEPOWER OF THE ELECTRICAL PUMPS		
JOULES OF WORK DONE BY THE PUMPS		
CURRENT OF THE PUMPS		
KILOWATTS OF ELECTRICITY USED		

How are electrical devices grounded in the beach area?

Are the pumps AC or DC current? Why do you think so?

Are the pumps wired in parallel or series? Why?

What type of safety devices must be used around water?

What are areas of potential danger as far as electricity is concerned and how are these met at Lagoon in the beach area?

Can water flowing through a pipe create static charges? If so, how is this being prevented?

Additional Resources

STUDENT HANDOUT

(Page 3 of 3)

LAGOON-A-BEACH, A PHYSICS PARADISE

ACTIVITY 3 - FLOW RATES AND LAMINAR AND TURBULENT FLOWS:

Using simple means, design experiments that would demonstrate each of the following: (You may use only a stick, food coloring, a stop watch and a graduated cylinder.)

a. laminar flow areas on the slides and pools-

b. turbulent flow areas on the slides and pools-

c. potential energy at the top of the slides-

d. liters of water pumped per minute on each slide-

How do the bends of the slide affect flow rate? Pressure?

Where is the greatest water friction on the slide?

How does the length and slope of the slide affect the flow rate?

Calculate the rate of flow of water in the mote giving your measurements and your method of determination.

How does the density of the water change with temperature?

List as many topics as you can which relate to physics that you find in Lagoon-a-beach. Examples might be wave action, refraction, reflection, polarization, etc.

Additional Resources

ADDITIONAL RESOURCES

SIMPLE MACHINES AND NEWTON'S LAWS AT LAGOON

GRADE LEVEL:

This activity was designed for a high school resource class which covers the basic concepts in physics without much mathematical application. It would also be appropriate for middle school classes.

OBJECTIVES:

1. Students will identify simple machines in the rides and games they observe at Lagoon.

2. Students will demonstrate understanding of Newton's Laws of Motion and Gravitation by applying these concepts to the rides.

PROCEDURES:

In the classroom prior to Physics Day, have students practice analyzing everyday objects to identify simple machines incorporated into such objects. A partial list follows. Also, discuss real-life applications of Newton's Laws of Motion.

While at Physics Day at Lagoon, students participate in a scavenger hunt in which they identify simple machines in action. They will also identify examples of Newton's Laws. This activity may be done individually, but will probably be more fun if students form teams to work (and ride the rides!) together.

Several of my students were enrolled in a photography class the year that they went to Lagoon, so I required photographs of the simple machines in action. This aspect could be eliminated or modified, if desired.

CATEGORIES OF SIMPLE MACHINES:

Lever (3 classes)	Pulley
Inclined Plane	Rollers
Screw (includes propeller)	Wheel and Axle
Wedge	

SIMPLE MACHINES AND NEWTON'S LAWS AT LAGOON

IN-CLASS PRACTICE ACTIVITY

The following activity provides good preparation for the students for the activities to be conducted at Lagoon. Alternately, the following activities could provide a review of the concepts learned at Lagoon.

Analyze the following common items to locate and identify the types of simple machines present: door to classroom, electric fan, pencil sharpener, pop can, stapler, tape dispenser.

Results:

door to room:
- wheel and axle (doorknob)
- screw (holding door to hinges)
- lever (hinges)
- lever (latch to lock double door shut)

pencil sharpener:
- wheel and axle (handle and sharpener device)

electric fan:
- screw (propeller-like fan blade)

pop can:
- lever (pull tab)

STUDENT HANDOUT

SIMPLE MACHINES AND NEWTON'S LAWS AT LAGOON

SIMPLE MACHINE SCAVENGER HUNT:

Identify three or more examples of each of the simple machines we've discussed in class. Each example must provide a good model of the simple machine at work. The scavenger hunt will be judged on the following criteria:

1. accuracy of identification
2. originality of items identified
3. supporting documentation (text and photographs)

For each example, list the following:

1. name of the ride or game
2. specific location of the simple machine
3. one to two sentence description telling what makes this a good example of the simple machine. (This is your documentation.)

You should also select at least ONE example of each machine and photograph or sketch it. Be sure your illustration clearly shows the simple machine and how it relates to the ride or game.

LEVER

INCLINED PLANE

SCREW

WEDGE

PULLEY

ROLLERS

WHEEL AND AXLE

STUDENT HANDOUT

SIMPLE MACHINES AND NEWTON'S LAWS AT LAGOON

NAME: ______________________________

DATE: ___________________________

NEWTON'S LAWS LIST:

Write a description of at least one place at Lagoon where you observe the concepts listed below. (Hint: Some good places to look are the bumper cars, the log ride, the water slide, and the roller coasters.)

Newton's First Law of Motion:
Every object remains at rest or moves at constant speed in a straight line unless acted upon by an outside force.

Newton's Second Law of Motion:
The larger the force, the greater is the acceleration. The greater the mass, the lesser is the acceleration.

Newton's Third Law of Motion:
For every force there is an equal and opposite force. Every action is accompanied by a reaction.

The Universal Law of Gravitation:
Any two objects attract each other with a gravitation force. The larger the masses, the more gravitational force. The lesser the masses, the less gravitational force.

ADDITIONAL RESOURCES

PHYSICS MAKES A SPLASH

OBJECTIVE:

Using the water rides at Lagoon-A-Beach reinforce Physics concepts taught in class. Concepts include work, kinetic energy, potential energy, velocity, and acceleration.

MATERIALS:

- long measuring tape
- stopwatch
- accelerometers made in class
- swimsuit
- tube from tube rental

PRE-LAGOON DAY

PREPARATION:

Lagoon Day should be the culmination for a year-long Physics course. Students must have a good basic foundation in Physics concepts. This should be an opportunity to quantify concepts discussed all year long in a real world situation.

PROCEDURE:

During Amusement Park Physics Day, the students make the measurements necessary to answer the questions on the student worksheet. Students work in teams and enjoy swimming at Lagoon-A-Beach in the process.

EVALUATION:

Students are to complete the calculations required to answer the questions on the student worksheet. The next class day, the answers are discussed and evaluated together as a class to see if the final responses are logical and consistent.

EXTENSIONS:

There is an arcade using a bowling ball and a narrow track where the object of the game is to roll the ball so that it remains in the trough (see illustration). Have the student analyze this game using the principles of kinetic and potential energy. What conditions make the game difficult to win? What conditions would make the game easy to win?

STUDENT WORKSHEET
(Page 1 of 2)

PHYSICS MAKES A SPLASH:

ANSWER THE FOLLOWING QUESTIONS. SHOW ALL DATA COLLECTED AND ALL CALCULATIONS!! HAVE FUN!!

1. How much work must you do in climbing to the bottom level of the tower slides?

   How much additional work must you do to get to the top level of the tower slides?

2. What is your potential energy when you reach the top level?

3. How does the potential energy at the top relate to the work done reaching the top level?

4. Calculate an estimated velocity for yourself at the bottom of "The Drop" slide. What assumptions did you make in making this calculation?

STUDENT WORKSHEET

PHYSICS MAKES A SPLASH:

5. What is the role of friction in this situation? Explain.

6. Calculate the estimated velocity at the bottom of the "Liquid Lightening" slide. How does this compare with the velocity at the bottom of "The Drop"?

7. Compare your potential energy and final velocity with that of other team members. How do these quantities compare? Explain any differences or similarities.

8. When you get tired of waterslides, take a ride on the float tube river. What is your average velocity? Is this a constant velocity? Did you experience any acceleration? Explain the causes of the acceleration.

ADDITIONAL RESOURCES

"MARBLE COASTERS"

INTRODUCTION:

In this activity, students design and construct their "ultimate" roller coaster. Due to funding and liability limitations, marbles will serve as cars and the "track" will be about 2 cm wide. These "marble coasters" provide a motivational medium for students to learn such concepts as speed, velocity, acceleration, and momentum.

Pre- and post-lab activities include viewing the "Physics of Roller Coasters" segment of the video available from USU's Physics Day organizers. Students can also do a wide variety of writing across the curriculum as well as related calculations.

OBJECTIVES:

To gain an appreciation of the complexity of design and construction of roller coasters.

To apply knowledge of acceleration in designing a roller coaster that will have sufficient acceleration to allow a marble to successfully complete a loop.

MATERIALS:

- 4 cm x 1 m cardstock
- lots of tape
- scissors
- marbles
- space

PREREQUISITE CONCEPTS:

- speed = distance divided by time
- acceleration = change in speed divided by change in time
- gravity needed for acceleration
- centripetal force, centrifugal force

VIDEO:

The Amusement Park Videos available from Utah State University contain two particularly relevant segments, "Scientific American: Frontiers in Science 'The Physics of Roller Coasters'" and "National Geographic Explorer: Roller Coaster Physics." The video could be used either before or after construction of the marble coasters. As an introductory activity, the video alerts students to the real-life need for a mock-up as a preliminary step to designing a new amusement park ride. They are also able to gain an awareness of safety considerations and the need for variety and excitement in a successful ride.

"MARBLE COASTERS"

After having constructed a marble coaster, students could watch the video to realize the relevance and realism of the lab activity. Having seen that marble coasters are the real-life first step to designing roller coasters, students could ponder such topics as: Would your roller coaster fit into an amusement park when scaled up? How much track would you need? How much mass would your roller coaster cars need in order to make it through a loop?

<u>MATHEMATICAL CALCULATIONS</u>:

1. Calculate average speed by measuring the length of the track, timing the marble's trip, and dividing. Timing could be done using a stopwatch (be careful to consider operator reaction time), a photogate timer, or by using a video camera.

2. Create a distance-time graph by calculating the average speed at intervals along the track, then graphing the data. A useful trick to help determine distances is to mount the Marble Coaster track directly on a large sheet of graph paper.

3. Calculate velocity by taking the speed in a given direction. Note the changes in velocity that occur due to a change in direction, particularly in the loop.

4. Calculate momentum by taking the mass of the marble and multiplying it by the velocity calculated above.

5. Calculate how much track a life sized roller coaster would need by scaling up the marble coaster. A scaling factor can be determined by comparing the marble to a car large enough to accommodate real riders.

6. Additional calculations could include construction costs (given unit price of raw materials).

<u>ACTIVITIES FOR WRITING ACROSS THE CURRICULUM</u>:

These are some of the writing prompts we've used for self starters, journal entries, and extension activities. We wouldn't recommend using more than a few of these with any one class, but we've found it valuable to have a bank of possibilities.

- **Close your eyes and imagine**:

You are in the car with your mom and she has that devious look in her eye. You know you are in for it. She checks the dashboard, making sure all gauges are okay (typical mother act) and pushes the remote to open the garage door. The sly smile never leaves her mouth as she puts the car in reverse and floors it. As she comes to the end of the driveway, her foot jumps to the brake. Oh, no! She punches the brake to the floor. She checks for traffic, gently backs into the road, stops, then once again the accelerator contacts the floor. You are off. She's going sixty again. It seems your mother only has one speed, sixty mph. Dang! That curve is looming ahead. You know, the 25 mile per hour curve, the sharp one down the street. Unfortunately, your mother only goes one speed: 60 mph. Whew! Thank goodness your best friend lives just beyond the curve. Your mom slams on the brake in front of their house. The smile never left her face. You stagger out of the car and wave good-bye, forever grateful that your friend's mother will take you home.

Now write about this experience, focusing on physical and mental sensations.

"MARBLE COASTERS"

- Write a detailed description of your last roller coaster ride. Include your thoughts, your feelings, etc. Describe the physical responses your body has to the ride.

- Describe the best roller coaster you have ever ridden on. What made it a good one? Why was it better than others you've ridden on? What would the ultimate roller coaster be like?

- What would keep you from wanting to ride a particular roller coaster? What would make you worry about it? Design? Materials? Workmanship? Wildlife (e.g., goats under the wooden roller coaster at Lagoon)?

- Who comes up with ideas for amusement park rides? How are new amusement park rides designed?

- Safety concerns: Did your own roller coaster meet safety standards? Could you design your ultimate roller coaster? If not, why not?

- What steps must be taken when new roller coasters are designed? Describe the procedure, as illustrated in the video and as you experienced here in the classroom.

MARBLE COASTERS

DESIGNING A MARBLE COASTER

OBJECTIVE:

To construct a working model of a roller coaster.

CRITERIA FOR GRADING:

For minimum credit, your marble coaster must successfully negotiate one loop. additional credit will be awarded for more loops, jumps, turns, or anything else you can think of, IF IT WORKS!!!

PROCEDURE:

1. With your partner, pick up the following from the supply table:
   - two strips of cardstock [4 cm x 1 m each]
   - one pair of scissors
   - two long strips of tape
   - one marble
2. Find a location in the classroom for your ride. It may be on walls, bulletin boards, chalkboards, floors, furniture, anything goes!
3. To create a track for your roller coaster, fold the cardstock into thirds the "hot-dog way" (lengthwise for those of you without an El Ed degree).
4. To make a curve or loop, snip the sides of your trash, then curve as needed. Before taping, be sure your loop will work.
5. After your roller coaster has been graded, please salvage all track and place in the recycle basket. Please put all tape scraps in the trash!

ADDITIONAL RESOURCES

FREQUENCIES AND PERIODS OR "DOES IT HERTZ?"

OBJECTIVES:

The purpose of the four activities outlined for the students is to:

1. Allow the students to experience the concepts of frequency and period encountered in the amusement park and on the rides.

2. Teach the student the factors that influence the frequency of a ride.

3. Have the student measure different types of frequencies found at Lagoon, including pendular (harmonic) motions, circular oscillations related to rotations, horizontal and vertical oscillations, and non-regular game frequencies.

4. Encourage students to use their own solutions and data gathering techniques to investigate frequencies and associated periods.

5. Foster the thought process (creative thinking) and to enhance skills and concepts already mastered in the classroom.

NOTE: All the activities can be done by using a watch as a timing device and estimations skills for determining distances. The most important aspect in doing these activities is to let the students use their imaginations and minds. There is no right or wrong way to approach these activities, only different plans of attack.

It would be helpful to review frequency as it relates to periods prior to doing these activities. These activities are designed to teach by experience and to illustrate concepts by doing them.

SPECIAL NOTE TO THE TEACHERS: The student handouts are designed to allow the student to develop new and unique insights and solutions which deal with frequency. It is hoped that they will serve as a springboard to learning and foster the posing of more profound questions. The questions in these activities are open-ended questions not designed for a single answer, but rather inroads to greater and deeper discussions. They are to spark interest and are meant to challenge students to think, discuss, ask and evaluate concepts related to frequency. They are meant to be hands on.

FREQUENCIES AND PERIODS OR "DOES IT HERTZ?"

ACTIVITY 1 - PENDULAR (HARMONIC OSCILLATIONS)

This activity should relate to the simple pendulum in that the rides listed use harmonic oscillations for their basic motions. It is easy for students to see the pendular motion and to imagine themselves as the pendulum bob. A close association with the factors that affect the swing of a pendulum will help the students answer the questions. Such factors as mass, length (radius), and amplitude are used to help the student relate the rides back to simple pendular motion. Question 4 is designed to have the students look at the energy transformations used to power the ride. Comparative frequencies will help the students understand how simple machines play a major role in amusement park rides.

ACTIVITY 2 - CIRCULAR OSCILLATIONS:

As students compare the frequency of each ride they get a feel for the complex nature of some frequencies. They should recognize a difference in start up, normal running and braking during a ride. It is important for them to observe both the power and the braking systems on the rides to understand the forces and physics involved. With larger radii longer periods can be expected and lower frequencies. These rides serve as superb examples to understand the relationship between frequency and period. The total distance traveled per cycle during each ride is used to help them visualize the importance of radius and frequency. Question 4 again is designed to foster thought and observation. The introduction of two or more rotational directions is designed to illustrate that within systems other frequencies may contribute to the overall motion of an object. Thus there can be different frequencies due to different rotational axes. These can be in different planes and different directions of rotation. (The hammer is an excellent example to study for these purposes.) Students are also encouraged to figure the distance traveled during one period; this could be graphed for comparisons of distance versus period.

ACTIVITY 3 - OTHER FREQUENCIES:

The purpose of these activities is to point out that the frequency of any motion can be determined if it repeats. The roller coaster, while it does not swing back and forth or round and round, does complete a cycle that depends on vertical and horizontal distances. The three rides used here illustrate that all rides have a frequency. The pathways may vary and the physics that drives the ride may change, but the return to beginning is a cycle nonetheless. Frictional forces are also more evident in some of these rides, as is the importance of gravitational potential energy.

ACTIVITY 4 - GAME FREQUENCY:

This activity is designed to stretch the mind of the students in searching for, classifying and recognizing different frequencies. From the blinking of lights to the floating of ducks, and even in the arcade games, FREQUENCY IS THERE. Have the students list all the examples that they can find and explain the frequencies they are observing.

STUDENT HANDOUT

FREQUENCIES AND PERIODS OR "DOES IT HERTZ?"

INTRODUCTION:

Lagoon is an amusement park surrounded by oscillation and motions that repeat themselves. Such motions are described by the terms "frequency" and "period." Frequency applies to many physical phenomenon such as waves, electromagnetic radiations, harmonic motions and all cyclic events. Frequency is the number of oscillations (cycles) completed each second. (In some cases an oscillation or cycle may take more than one second to complete; therefore, only a fraction of the cycle may be completed during the second. In other cases many cycles may take place in one second.)

A cycle is considered to be completed when the moving object returns to its original starting position. The SI unit for frequency is called hertz (1 Hz = 1/sec) and is used to quantify such diverse phenomenon as the cyclic nature of pendulums to the cyclic nature of electric currents. Period is a measure of the amount of time it takes to complete just one repetition or cycle. The period is the reciprocal of frequency, that is if the period is 2 sec., then the frequency is 1/2 Hz.

Lagoon is a literal "gold mine" for determining frequency and period. See how many places you can find examples of frequency and period at Lagoon.

ACTIVITY 1 - PENDULAR (HARMONIC OSCILLATIONS)

FOR EACH OF THE FOLLOWING MEASURE AND FILL IN THE CHARTS BELOW.

RIDE	RADIUS (METERS)	PERIOD (SECONDS)	FREQUENCY (HERTZ)	AMPLITUDE (DEGREE OF ARC)
MAGIC CARPET				
TIDAL WAVE				
SWINGS				

STUDENT HANDOUT

FREQUENCIES AND PERIODS OR "DOES IT HERTZ?"

1. What other rides exhibit pendular motion?

2. How does the frequency relate to the radius of the ride?

3. How does the period change with the radius of the ride? Hint: use the equation:
   $T = 2\pi \sqrt{1 / g}$

4. How does the electric frequency of the drive motor relate to the frequency of the ride? Describe the drive mechanism of the ride.

5. Does the mass of the occupants change the frequency? Explain.

6. How does frequency change with the degree of arc? Or does it?

Additional Resources

STUDENT HANDOUT

FREQUENCIES AND PERIODS OR "DOES IT HERTZ?"

ACTIVITY 2 - CIRCULAR OSCILLATIONS:

FOR EACH OF THE FOLLOWING RIDES DETERMINE:

RIDE	RADIUS (METERS)	PERIOD (SECONDS)	FREQUENCY (HERTZ)	DISTANCE TRAVELED PER CYCLE (METERS)
TILT-A-WHIRL				
SKYSCRAPER				
SCRAMBLER				
MERRY-GO ROUND				
HAMMER				
ROCK-O-PLANE				
MUSIK EXPRESS				
CENTENNIAL SCREAMER				
PARATROOPER				

1. How do each of these rides vary in their frequency?

2. How do "kiddie rides" compare with "high level" thrill rides? (in frequency and period)

3. How does the frequency change during start up, during the ride, and the end of the ride? How does the period change?

4. Can a ride have more than one frequency? HINT: Look at the rock-o-plane and hammer. HINT: Look at the axes of rotation.

5. Describe the frequency of the hammer in detail showing rotations.

6. Figure the distance traveled during each period for the above rides.

STUDENT HANDOUT

FREQUENCIES AND PERIODS OR "DOES IT HERTZ?"

ACTIVITY 3 - OTHER FREQUENCIES:

CALCULATE THE PERIOD FOR EACH OF THE FOLLOWING RIDES:

RIDE	FREQUENCY	PERIOD	DISTANCE TRAVELED HORIZONTAL	HEIGHT OF RIDE VERTICAL
ROLLER COASTER				
WILD MOUSE				
WATER SLIDES				

1. How does the frequency relate to the following factors: vertical height of the ride and the horizontal distance traveled?

2. How does the mass affect the frequency of the roller coaster or does it? Qualify your answer.

3. How does the friction of a ride affect its frequency?

ACTIVITY 4 - GAME FREQUENCY:

Watch different games and record your observations concerning frequency such as frequency in hitting baskets with a basketball.

1. How does the frequency of games compare to the frequency of rides especially in predictability and accuracy?

2. Look throughout the park and find other examples of frequency and periods. HINT: look at the games, lights, motors, water park, slides, etc. There are lots of examples. List as many as you can.

ADDITIONAL RESOURCES

TRIANGULAR EXPLORATION OF LAGOON

TOPIC
Review of Trigonometry and calculations dealing with Potential and Kinetic Energy.
Hands-on application of principles taught in class.

ACTIVITY
Using an instrument constructed in class or a transit if available, the students will calculate the height of specific objects at Lagoon using trigonometric functions. This information will be applied to calculations of potential and kinetic energy.

MATERIALS:

- Instrument to measure angles
  - Modified protractor copied on cardstock
  - Straw
  - String
  - Washer or any other small weight
- String of pre-measured length marked with specific increments or a measuring tape
- Calculator with trig functions or a trig chart and standard calculator
- Copy of student worksheets

PREPARATION:

Students must have good basic knowledge of trigonometric functions. They must also know how to use the formulas for kinetic and potential energy. Before arriving at Lagoon prepare the instrument for measuring angles. The students should also have a device (string or measuring tape) for measuring distances from the ride to where the angle measurement is taken.

EVALUATION:

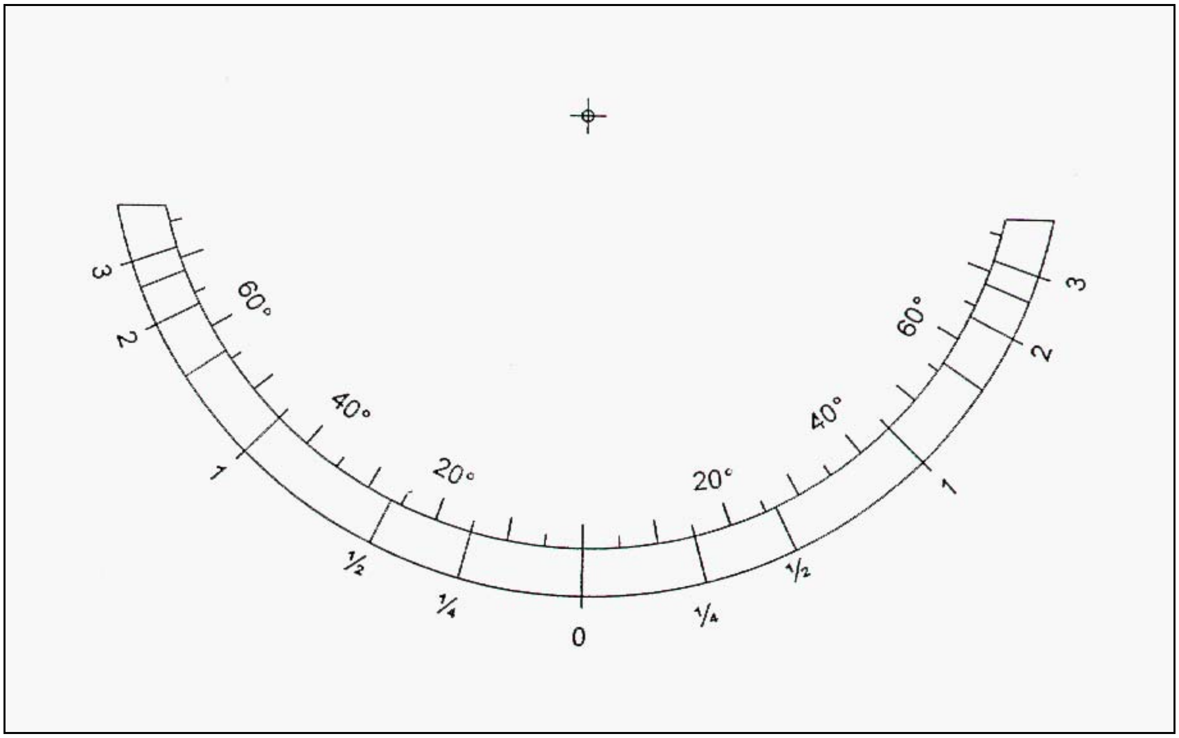
Students will complete the student worksheet. Students could be given an additional problem using another Lagoon attraction. The new ride opening this year would be an excellent choice for determining height and then calculating potential energy and kinetic energy.

EXTENSIONS:

This activity using trigonometry to determine the height of an attraction could be extended to include determining the radii of spinning attractions such as the Ferris Wheel, Skyscraper, Magic Carpet, or Centennial Screamer. The radius could then be used to make calculations involving centripetal force and velocity of the circular motion.

TRIANGULAR EXPLORATION OF LAGOON

<u>Instructions for Building Angle Measurer</u>



1. Copy modified protractor pattern on cardstock.

2. Cut out protractor and make hole at the cross with the dot in the center.

3. Cut approximately 9 inches of string and tie the washer on one end.

4. Thread the string through the hole on the protractor and tie a knot so the string hangs down on the curved part of the protractor.

5. Tape a straw centered over the 90 mark, the center circle and the opposite end mark.
   The straw is used as a sight.

6. To use the device, the string should hang over the zero mark when the straw is horizontal. The straw is then pointed at the top of the object to be measured and the angle is estimated using the scale on the modified protractor. Measure the distance from the bottom and use formula Tanθ = opposite side/adjacent side (height/distance).

STUDENT WORKSHEET
(page 1 of 2)

TRIANGULAR EXPLORATION OF LAGOON

Name ______________________________

Period ______________________________

General Trigonometry Review with Physics Applications

1 . Using the instrument for measuring angles you have constructed, your calculator, and a string of predetermined length or a measuring tape, calculate the height of the skyride seat at its highest point. Draw a picture to show your method.

2 . Using the data from Problem 1, calculate the potential energy of a 60 kg student sitting on the seat.

3 . If a 5 kg ball is dropped from seat level, what will be its velocity just before it hits the ground?

4. In the Lagoon parking lot there is a walkway that passes under the Great White Wooden Roller Coaster. What is the height of the coaster tracks where people are allowed to walk under the track?

STUDENT WORKSHEET

TRIANGULAR EXPLORATION OF LAGOON

5. In Pioneer Village during the Wild West Show, a cowboy falls from the roof to a wagon filled with hay. Determine the height of the roof and the wagon.

   A. If the cowboy has a mass of 72 kg, what is his potential energy on the roof?

   B. What will be the cowboy's velocity as he hits the straw?

   C. What is the new potential energy for the cowboy in the wagon?

   D. After the show when the cowboy jumps to the ground, what will be the cowboy's velocity just before he hits the ground?

ADDITIONAL RESOURCES

THE HOTTEST CARS AROUND AND HERSCHEL'S EXPERIMENT

TOPIC
The relationship between light and pigment colors and heat.

QUESTIONS TO BE ANSWERED
What is the relative difference in heat radiation between different colors (additive colors {light spectrum} and subtractive colors {pigments})?

MATERIALS:

Day 1:
A thermometer for each student or group
Student worksheet ("The Hottest Cars Around")

Day 2:
Thick paper with slit
Cardboard for blacking out window
Triangular glass prism
Thermometers
Wedges (wood or other material)
Large white paper
Student worksheet ("Herschel's Experiment")

ACTIVITY (Day 1) THE HOTTEST CARS AROUND
Student groups will choose cars in the parking lot (at Lagoon or elsewhere) that have pure hues. They will choose a surface perpendicular to the sun and measure its temperature and record it for two cars of each color. They will then answer questions on which colors are hottest and coolest.

CONCLUSION

Black will be the hottest pigment because all wavelengths of light are absorbed by it, causing it to gain the most energy (heat). White will be the coolest because it reflects all light and does not absorb it. Of the colors, blue should be the coolest and red the hottest with green in the middle. See the discussion below for why this is so.

CONCEPTS EMPHASIZED

1. The difference between additive and subtractive colors.
2. The nature and properties of light, including wavelength and its relationship to color.
3. The relationship between wavelength and energy (Planck's equation).
4. Measurement and observation techniques.

DISCUSSION

Light comes in many wavelengths. For example, blue light has a shorter wavelength than green or red light. Paints and other pigments get their colors by absorbing most wavelengths of light and emitting only a small portion of the spectrum. For example, red paint absorbs blue and green light but emits the red wavelengths. Pigments are therefore called "subtractive" colors because they derive their hue by subtracting out all but the color we see. An object appears black by absorbing all wavelengths, whereas white objects absorb no light but re-emit it all.

In the early 1900s, Max Planck discovered a relationship between the wavelength of light and its energy. The longer the wavelength, the less energy the wave had. To put it into an equation, $E = h/\lambda$, where E is energy, h is Planck's constant, and λ is the wavelength. In other words, the energy of a wave is inversely proportional to its length.

Red light will be hotter than other colors because the higher energy wavelengths (blues and greens) are absorbed by the pigment and are converted into heat radiation. Blue, on the other hand, will be cooler because it absorbs longer wavelength red and green, which have less energy than the blue being emitted.

This experiment is an excellent introductory activity to the study of light and colors. Some students will be surprised to learn that wearing black is not a good idea on a hot day as it could lead to sunstroke.

EXTENSIONS

In addition to cars, students can find a wall with various paint colors on it and try the temperature there. The results should be more accurate. Another idea would be to have them measure the temperature of different pieces of cloth exposed to the same sun, or measure the temperature difference between asphalt and concrete on a hot day. For advanced students, this activity could lead into a discussion on thermodynamics or black body radiation.

ACTIVITY (DAY 2) HERSCHEL'S EXPERIMENT

Students will construct the apparatus shown on their handout. They will spread light into a spectrum, then measure the relative temperature of the different colors to see which is hottest. They will record these temperatures in a table and answer questions to put themselves in the position of the original researchers.

CONCLUSION

Temperatures should get progressively hotter as they move from violet through red. However, the hottest place will be outside the red end of the spectrum in the region now called infrared.

CONCEPTS EMPHASIZED

1. The additive properties of light (white light is actually a mixture of all colors whereas black is the absence of light).
2. The principle of diffraction of light through a prism.
3. The presence of radiation beyond visible light.
4. Relationship between light wavelengths and heat.
5. The history of science and the nature of scientific discovery.

Additional Resources

DISCUSSION

Sir William Herschel reported this experiment to the Royal Society in 1800. They were amazed to find the most heat outside visible light, and jumped to the erroneous conclusion that heat and light must be unrelated. It took the work of William's son, Sir John Herschel, James Clerk Maxwell, and Heinrich Hertz to show that light, heat, and other electromagnetic radiation were all one and the same. Infrared radiation is now used for night vision goggles (since most living things radiate heat in the IR band) and for infrared spectroscopy, where IR radiation causes the bonds of molecules to vibrate at specific frequencies. By reading a chart of which wavelengths were absorbed, it is possible to determine the types of bonds and the identity of unknown chemicals. Infrared radiation is also used by satellites to penetrate clouds and get a clear view of the ground, for heat lamps, and many other things.

EXTENSIONS

This activity introduces the concepts of electromagnetic radiation and the various wavelength categories. Further discussions should focus on the entire EM spectrum and how each category of waves is used. Students could do further research on how night goggles work. Advanced students could learn the types of molecule vibrations (flexing, twisting, wagging, etc.) and how to identify the structure of chemicals from their IR absorption spectrum.

FURTHER ACTIVITIES

To carry this unit further, the additive nature of light can be discussed, with reference to color TV screens and RGB monitors. Other properties of light, such as reflection, can be investigated using mirrors, lenses, parabolic dishes, etc.

REFERENCE

Crawford, Bruce Jr., "Chemical Analysis by Infrared," Instrumental Methods of Analysis, Oct., 1953.

STUDENT HANDOUT

(Page 1 of 2; Day 1)

THE HOTTEST CARS AROUND

Name: ______________________ Date: ________________Period: _______

Materials

Thermometer
Pen or pencil

Introduction

In 1800 Sir William Herschel discovered that there is a relationship between the color of light and its heat. He also discovered that the most heat is produced outside of the visible spectrum of light by radiation that we now call infrared. Today, you will conduct the first of two experiments that will explore the relationship between light and heat. You will find out which type of car is the "hottest" car around. Tomorrow, you will recreate Herschel's historic experiment.

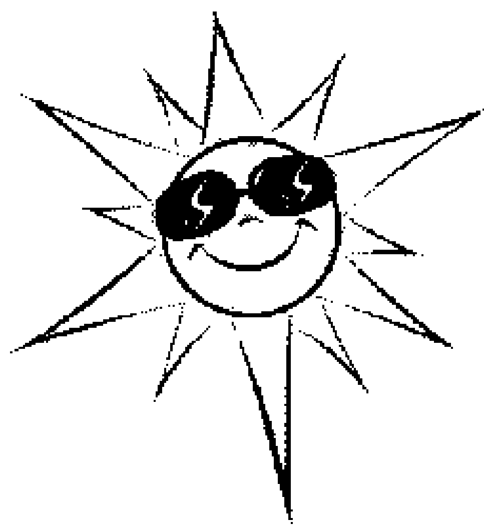
Procedure

Go into a parking lot on a sunny day and choose at least two cars for each of the colors listed in the table below. Make sure that the colors are "saturated;" they aren't light shades or dark shades, but are "pure" colors.

1. Find a surface of the car that is perpendicular to the sun's rays. Place your hand on the surface to get a subjective feel for how hot it is.
2. Place the bulb of your thermometer against the surface with as much of the bulb in contact with the car as possible. Hold it there for several minutes or until the temperature stabilizes. Record the temperature in the table in °C.
3. Repeat the process with another surface on the same car. Then pick another car of similar color and repeat with two surfaces also. Continue until all the colors are complete.

Data Table

	White	Blue	Green	Yellow	Red	Black
Car 1 Surface 1						
Car 2 Surface 2						
Car 3 Surface 1						
Car 4 Surface 2						



Questions

1. Why were two different cars and two surfaces per car measured for each color?

2. Which color was "hottest"? Why do you think this was so? Which was "coolest" and why?

3. On a hot summer day, what color of clothing would be best to wear to avoid sunstroke?

4. Using Planck's equation and the subtractive nature of pigments, show why red is hotter than green or blue.

Additional Resources

STUDENT HANDOUT

(Page 1 of 2; Day 2)

HERSCHEL'S EXPERIMENT

Name: ______________________ Date: ________________Period: _______

Materials

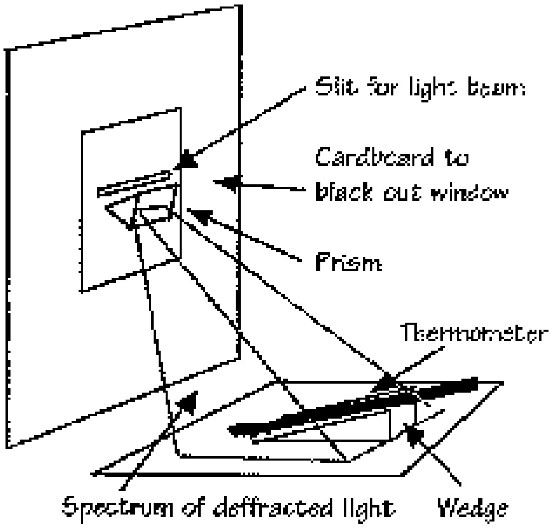
Cardboard for blacking out window
Heavy paper with thin slit cut in it (see diagram)
Triangular glass prism
Large white paper
3-4 thermometers
3-4 wooden or styrofoam wedges
Clear tape
Masking tape

Introduction

In 1800 Sir William Herschel conducted a groundbreaking experiment to measure the temperature of the various colors of the spectrum of light. He passed a beam of white light through a narrow slit and through a prism to diffract it into a spectrum. He then placed thermometers which had been mounted on wedges with their bulbs inside and outside the various colors. He discovered that the hottest place was actually beyond the red end of the spectrum, in what we now call infrared light. You will be recreating his experiment today.

Procedure

Find a window that has the sun shining through it. Tape the heavy paper with slit onto the window, then black out the rest with heavy cardboard. Position the prism so a good spectrum shows, then tape it in place. Place a large piece of white paper under the spectrum so it shows up well. Attach thermometers to the wedges with clear tape so that the thermometers will be perpendicular to the light beam coming from the prism. Place the bulbs of two thermometers in each color band for about 5 minutes each (see the diagram). Record the temperatures in the table below.



Spectrum Color	Temp (°C)
Beyond violet	
Violet	
Indigo	
Blue	
Green	
Yellow	
Orange	
Red	
Beyond red	

Questions

1. How can you explain that the most heat corresponds to no visible light?

2. How might this have led to confusion or errors?

Additional Resources

ADDITIONAL RESOURCES

BANKED CURVES ON RIDES

INTRODUCTION

Over the years there have been significant improvements in the design and construction of amusement park rides. These improvements have not only made the rides more thrilling, they have also made them safer. In this activity students will be able to see and feel for themselves how a modern ride's banked-curve design opposes the forces of the ride by observing a small pendulum's movements during the ride. They will then contrast this with the pendulums movement due to forces around the curves of an older "flat-track" type of roller coaster.

TOPIC

Centripetal acceleration, force vectors, Newton's laws of motion

OBJECTIVE

Students will develop an appreciation for the planning and engineering that go into making a smooth, thrilling, and safe roller coaster ride.

PROCEDURE

QUESTION

Which roller coaster is the most "stressful" to the rider? What causes this stress?

ACTIVITY

QUESTION

Using a simple pendulum compare the net force felt by a rider in a modern roller coaster with banked curves to the net force felt in an older flat track roller coaster.

CONCLUSION

In modern roller coasters the horizontal and vertical components of force exerted on the rider are less stressful as they are counter-balanced by the banked curve (see illustrations). The banking tends to make the riders feel as if they are "pushed down" into the seat bottom. In rides with flat curves, the riders feel as though they are going to slide across the seat towards the outside of the curve.

EXTENSION

Why is it important to design roads with banked curves and safe speed limits?

Materials

A pendulum. This may be as simple as a piece of string with a loop at one end and a washer at the other that could be quickly and easily attached to the safety bar. It could also be as complicated as a rigid pendulum with a bearing pivot that will only rotate in one plane. (See hints on pendulum construction below.)

Preparation

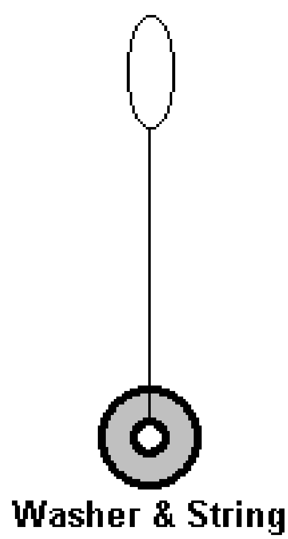
Inspect all pendulums for safe and durable construction. They should also be easily carried and not interfere with the rider's ability to safely ride the ride. Depending on the knowledge and grade level, you may also want to have a class review on vectors and two-dimensional motion.

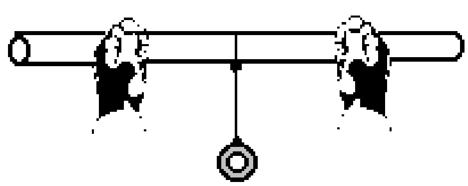
Concepts Emphasized

Centripetal acceleration, motion in two dimensions, vector addition, Newton's laws of motion.

Pendulum Construction

A pendulum will generally hang downward toward the center of the earth. If the pendulum is hung from a horizontal bar, it will form a 90° angle with the bar. The simplest pendulum to use is shown in Figure 1. This set-up should work fine for general observation, however, it will be adversely affected by forward motion. Figure 2 shows a more rigid pendulum that is minimally affected by forward motion. The materials may be purchased at most hardware stores.

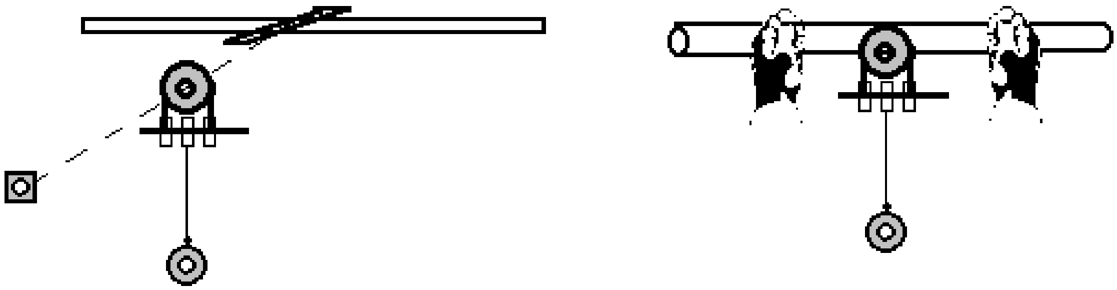




safety bar
w/pendulum
attached

Figure 1

Additional Resources



"T" Bar
U-bolt & bearing with
plate & all thread
pendulum arm & end weights

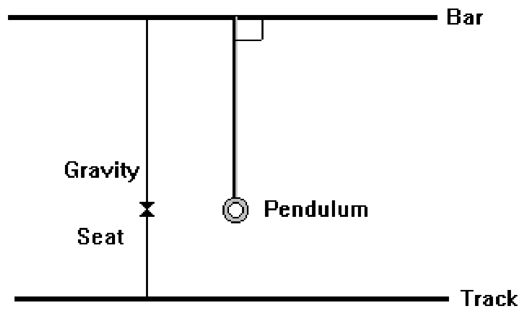
safety bar & pendulum
held by hands

Figure 2

Additional Resources

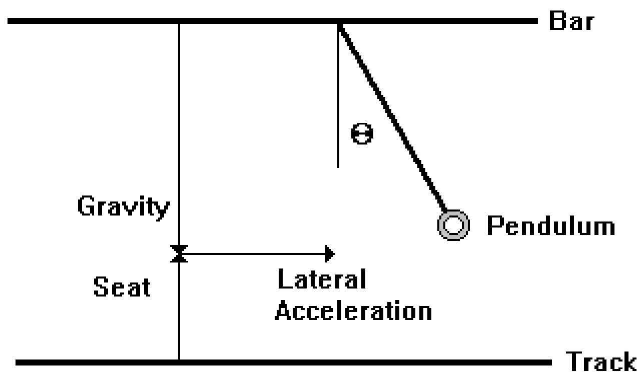
COMPARISON OF FORCE VECTORS ON A ROLLER COASTER

Horizontal and motionless, no centripetal acceleration



Flat track around a curve

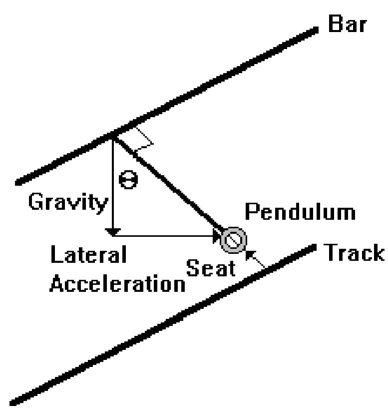
Lateral force causes rider to slide across seat



θ is a function of curvature and velocity.

Banked track around a curve

Banking of track is at a perpendicular angle to the sum of the forces. Rider feels pushed into seat.



θ is near zero due to banking of track.

Additional Resources

STUDENT HANDOUT

BANKED CURVES ON RIDES

For this project you will attempt to get a "feel" for the forces exerted on a passenger during a roller coaster ride. May the force be with you.

Materials

Simple pendulum

Instructions

1. Take a ride on the Colossus and pay attention to how the forces of the ride make you "feel" like you are moving. Pay particular attention to your movement in the curves.

2. Ride the Colossus again, this time using your pendulum to observe its motion as the forces of the ride act upon it. (For safe use of the pendulum, consult your teacher.)

3. Ride the "old" Wooden Roller Coaster and pay attention to how the forces of the ride make you feel like you are moving. Pay particular attention to your movement in the curves.

4. Ride the old Wooden Roller Coaster again, this time using your pendulum to observe its motion as the forces of the ride act upon it.

Questions

1. Compare the feel of your motion to the movement of the pendulum for both rides.

2. In which ride did you feel the most jostled?

3. In which ride did the pendulum move the farthest from equilibrium?

4. What caused the movement of the pendulum? What determines how far it moves?

5. Explain why the pendulum moved more on one roller coaster than the other (if you observed a difference).

6. What design feature of the roller coaster has the most effect on the pendulum's offset?

7. Can you think of other areas where this design feature is used?

ADDITIONAL RESOURCES

PENDULUMS & PROJECTILES

INTRODUCTION

One day my students approached me with the questions, "If you swung off the rope swing at Twin Lakes, how far out will you hit the water?" This question provided an excellent opportunity to expound and apply the laws of motion. At length, the students concluded that the maximum distance of projection would be a function of the angle of release and the velocity of the projectile at that release angle. After several weeks of work with one of the students, Jason Cox, an original equation (previously unknown) was derived to calculate the path of a projectile released from a simple pendulum. We then built a pendulum to test the equation. The experimental results agreed remarkably well with the equation's predictions.

OBJECTIVE

To determine the distance an object will travel when released from a simple pendulum.
To determine the maximum projection of an object released from the Sky Coaster ride.
To determine the maximum projection of an object released from the Tidal Wave ride.

PREREQUISITE CONCEPTS

Period of a pendulum, kinetic and potential energy, conservation of energy, two-dimensional motion, trigonometry and algebra.

PROCEDURE

You may want to begin this lesson by discussing the angle of projection for maximum distance of a projectile (typically 45° for most objects). Then discuss the change in velocity of a pendulum as it oscillates through its cycle. Point out that it may not be possible to have a 45° release angle from a pendulum; if this is the case, what is the optimum angle of release? From here you can begin to decide which is more important, velocity or angle of release. It should become apparent that there is an optimal combination of the two that will produce the farthest trajectory. You may now use the range equation in Figure 1 to determine the angle that produces the maximum trajectory[1]. It is convenient to solve this equation using a convergence method beginning with 10° increments. Once the largest range is found, do a second iteration around it using 5° increments. From there you can go to 1° increments. In concluding the lesson, be sure to review how gravity, pendulum length, initial height, angle of inclination, and angle of release all contribute to the distance the projectile will travel. Once these concepts are understood, it's a matter of simply measuring the length of the "pendulum," its initial height, and angle of inclination for the ride and plugging those values into the equation to find the maximum projection. Though it would be fun to verify by experiment that the equation really works using the Sky Coaster, *Lagoon rules will not allow anyone to throw objects from the ride.*

[1]A related Mathcad worksheet is available from the USU Physics Department web site: http://physics.usu.edu.

Materials

Measuring instruments to determine distance and angle.
A good calculator (i.e., Hewlett-Packard scientific type such as HP48, or a TI programmable calculator).

Methods and Procedure

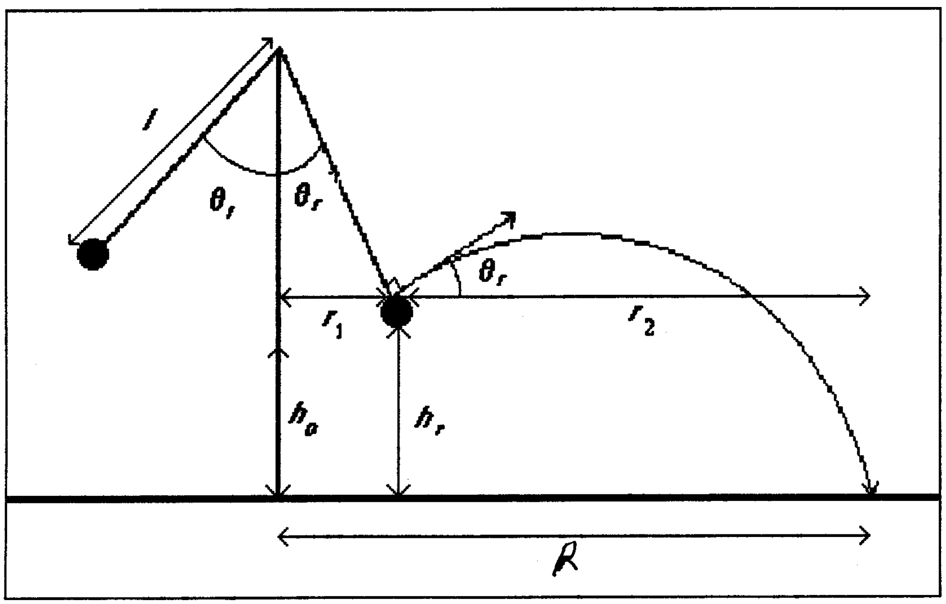


Figure 1

Figure 1 shows the simplified problem. The desired equation is a relationship between r, θ_i, and θ_t, where:

> R + range of projectile from equilibrium ($R=r_1 + r_2$ where r_1 is $\ell\cos\theta_2$ and r_2 is the distance traveled once the mass breaks free and becomes a projectile.)
>
> θ_1 + angle of inclination
>
> h_o + height at equilibrium
>
> θ_r + angle of release
>
> h_r + height at release
>
> ℓ + length of the pendulum

The total range traveled is

$$\frac{\sqrt{2gl(\cos\theta_r-\cos\theta_i)}\sin\theta_r+\sqrt{2gl(\cos\theta_r-\cos\theta_i)\sin^2\theta_r+2g(h_o+l-l\cos\theta_r)}}{g}\sqrt{2gl(\cos\theta_r-\cos\theta_i)}\cos\theta_r+l\sin\theta_r$$

Additional Resources

STUDENT HANDOUT

PENDULUMS & PROJECTILES

Now that you have had a chance to discuss the properties of projectiles released for a pendulum in class, see if you can determine how far a projectile can go if released from pendulum type rides at Lagoon.

The Sky Coaster

H_o = l = θ_i = θ_r

R =

The Tidal Wave

H_o = l = θ_i = θ_r

R =

Extra Credit:

What other rides are there that operate using the properties of a pendulum?

ADDITIONAL RESOURCES

THE INERTIAL BALANCE: USING ROTATIONAL INERTIA TO MEASURE MASS IN FREE FALL

SUMMARY

For medical and other experiments aboard the space shuttle, normal techniques to weighobjects won't work since both the shuttle and the object are under conditions of free fall; they are both falling toward the earth under the same acceleration. NASA scientists have devised a method to measure the mass of an object using its ***inertia***. Since the mass of an object is directly related to its inertia (or tendency to resist a change in motion), comparing the inertia of an unknown object with the inertia of an object of known mass can give you the unknown object's mass. This lesson plan involves two days of student activities, the first at an amusement park to learn the concept of how acceleration and deceleration affect the mass reading of an electronic scale. On the second day, the students will use an inertial balance in the classroom to create a calibration curve for known masses, then use the curve to estimate unknown objects.

DESCRIPTION OF SCIENTIFIC PRINCIPLES

Inertia is a property of matter, described by ***Newton's First Law of Motion*** as the tendency of an object at rest to remain at rest and an object in motion to remain in motion in a straight line until acted on by an outside force. In space, the shuttle and its passengers are trying to move in a straight line with a velocity of about 8 km/s. However, Earth's gravity is a constant force acting on the shuttle to pull it downward. This bends the shuttle into an elliptical path orbiting the earth. At 8 km/s, the shuttle is going fast enough that its path matches the curvature of the earth; it keeps falling around the earth and it keeps missing. Any slower, and the shuttle would spiral downward; any faster, and the elliptical orbit becomes more eccentric until escape velocity is reached.

It is common for students to say that the astronauts aboard the shuttle are weightless. This is incorrect, since gravity is still acting on the shuttle and the astronauts, they do have weight. It is more accurate to say they are in free fall under conditions of microgravity (which is why many astronauts suffer from motion sickness; their inner ears send a continuous message to their brains that they are falling). Conditions of free fall can be simulated by dropping objects in a tower, such as is done at NASA Marshall Space Flight Center, or aboard the KC-135 aircraft (a modified Boeing 707) dubbed the "Vomit Comet" and used for filming much of the movie *Apollo 13*.[*] The KC-135 flies a parabolic path; while pushing over the top of the parabola, conditions of microgravity are experienced (as low as 0.001 g). This is similar to the feeling of rising out of your seat as a roller coaster goes over the top of each hill.

Since a normal scale on the shuttle would also be in free fall, it would be pointless to use it to weigh an object. A device called an inertial balance is used instead. First, the object to be weighed is placed in a padded container to prevent it from oscillating. The container is vibrated by a spring mechanism. As the container vibrates, it is forced to change direction many times. The more mass (inertia) the object has, the more it will resist this change in motion and the slower it will vibrate. By comparing the rate of vibration for different known masses, a calibration curve can be constructed and compared with the unknown object to find its mass.

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[*] Refer to the film "Diversions in Microgravity" listed in the USU Amusement Park Physics Video Log for an interesting account of the NASA KC-135.

Lesson Plan, Day One: How Well Will a Scale Work?

MATERIALS

Bathroom scale (LED/digital readout preferred) for each team of students
Worksheet for each student
An amusement park ride with vertical acceleration/deceleration (or an elevator)

OBJECTIVE

To show students conceptually that ordinary scales won't work to weigh objects under conditions of acceleration or deceleration (such as on the space shuttle under free fall).

DESCRIPTION

Have a student in each team place the scale on the seat of the ride, then sit on the scale so the readout is visible between his/her legs. Record the rest weight before the ride begins. As the ride progresses, have the student sitting on the ride call out the readings on the scale at each change of vertical velocity (such as going over a hill or coming out of a downward slope) and have the others on the team write these down as best as possible. They may need to ride several times in order to get all of the readings. Then have each student fill in the rest of the description and answer the questions. For an elevator, have one student stand on the scale and call out readings as the elevator goes up and down.

Lesson Plan, Day Two: Using an Inertial Balance to Weigh Objects.

MATERIALS

Inertial balance
Two C-clamps
One flexible metal yardstick
Nuts/bolts to fit through the blocks and yardstick
Empty film canister with lid
Foam cut to fit film canister (slightly larger than canister) and cut in half
Tape
Electric drill and bits to fit bolts

MEASUREMENT

Standard weights (5 grams, 10 grams, 20 grams) to fit in canister, unknown objects small enough to fit in canister, worksheet for each student, scale, stopwatch.

CONSTRUCTION OF INERTIAL BALANCE

Drill two holes through one end of the yardstick and both blocks of wood so they can be bolted together as shown in the diagram below. Tightly tape the film canister with foam inside to the other end of the yardstick, then clamp the blocked end securely to a table or other non-moving object. Place the object to weigh in the film canister wedged between the foam.

USING THE BALANCE

Without an object in the canister, pull back on the canister end of the yardstick and let it go. Use the stopwatch to time the number of seconds for 25 complete vibrations of the yardstick, and record this time in the data table on the worksheet as zero weight. Do two more trials and find the average, then plot the average as zero weight on the graph. Next, place the 5-gram standard weight in the canister and repeat the process, recording the time for 5 grams. Then repeat again for 10 grams, 15 grams, 20 grams, and 25 grams. Connect the data points to create a calibration curve. Finally, place an unknown object in the canister and record the time for 25 vibrations. Compare the time with the calibration curve to determine its weight (see the sample data on the answer sheet provided with this lesson). Use the scale to find the actual weight of the unknown objects and have the students calculate a percentage error for each project.

STUDENT WORKSHEET
(Page 1 of 2)

THE INERTIAL BALANCE: AN ACTIVITY FOR PHYSICS DAY AT LAGOON

Name: ______________________ Date: ________________Period: _______

HOW WELL WILL A SCALE WORK IN SPACE?

INTRODUCTION

Many people don't realize that astronauts on the space shuttle actually do have weight; gravity acts on them just like it does on people on the ground, though it is weaker since they are further from the earth. The reason they appear to be weightless is that both they and the shuttle are in a condition called *free fall*. Just like a sky diver jumping out of an airplane is being accelerated toward the ground by gravity, the astronauts and shuttle are also accelerated toward the ground. They are going so fast around the earth, however, that they fall all the way around the earth and miss it when they are in orbit. They would have no weight on an ordinary scale because they and the scale are continuously falling, so the scale would read zero if they stood on it.

To prove this, you will conduct an experiment using a bathroom scale on one of the rides at Lagoon. A good choice would be the Wooden Roller Coaster, Colossus, the ferris wheel, or any other ride that has a lot of up and down motion.

INSTRUCTIONS

Before the ride: Get permission from the ride attendant to take the scale on the ride before getting in line. While in line, decide what spots on the ride you will take measurements for; choose five spots where the ride changes direction, such as going over a hill or coming out of a drop. Write down these spots (such as "Top of first hill") in the table below.

When you get on the ride: When you get on the ride, have one person place the scale on the seat and then sit on it so the readout can still be seen. Before the ride begins, record the rest weight in the table.

During the ride: The person sitting on the scale will call out the readings when the ride gets to the spots you selected. Try to remember the numbers so you can write them down after the ride ends (you will probably have a hard time writing them down during the ride!). You may need to ride several times to remember and write down all the spots. When you have the table completed, answer the questions at the bottom.

STUDENT WORKSHEET

Data Table:

Location on Ride	**Reading of scale**
Before ride (rest weight)	

QUESTIONS

1. Where was the reading heaviest? Where was it lightest? Why didn't the scale read the same at all locations?

2. If a sky diver strapped a scale on the bottom of her feet as she dived, what would she weigh? Why?

3. Use the data gathered today to explain why an ordinary scale can't be used to weigh objects in space.

4. From the information gathered here today, prove that weight and mass are not the same thing.

STUDENT WORKSHEET
(Page 1 of 2)

THE INERTIAL BALANCE: USING ROTATIONAL INERTIA TO MEASURE MASS IN FREE FALL

Name: ______________________ Date: ________________Period: _______

THE INERTIAL BALANCE

INTRODUCTION

To weigh objects in space, a device called an inertial balance is used. It is based on the property of inertia: all matter has inertia, which is a resistance to a change in motion. In an inertial balance, an object is vibrated back and forth by a spring drive mechanism. As the object vibrates, it changes direction many times. The more mass an object has, the more it will resist these changes in motion and the slower it will vibrate. To find the mass of an unknown object, you must first create a calibration curve using standard weights by measuring the time for 25 vibrations for 0, 5, 10, 15, 20, 25, 30, and 35 grams.

INSTRUCTIONS

Use two C-clamps to bolt the inertial balance to the edge of a table or other immovable object.
With the film canister empty, pull back on the metal yardstick six inches and let it go. Use the stopwatch to find the length of time for 25 vibrations and record in the table below. Repeat two times and record the average, then graph the average for zero weight in the graph. Place the 5-gram weight in the canister and secure with the foam pads so it won't slosh around inside. Time it three times, record, and graph. Continue with 10 g through 35 g in 5 g increments. Connect the points of your graph; it is now a calibration curve. Place unknowns 1 through 3 in the canister and find their vibrations. Use the calibration curve to find the objects' masses. Finally, use the scale to find the objects' actual masses and calculate their percentage error using the formula:

$$\% \text{ error} = \frac{|\text{actual - exp.}|}{\text{actual}} \times 100\%$$

Additional Resources

STUDENT WORKSHEET
(Page 2 of 2)

THE INERTIAL BALANCE

Data Table: Times (25 vibrations)

Weight:	Trial 1	Trial 2	Trial 3	Average
0 g				
5 g				
10 g				
15 g				
20 g				
25 g				
30 g				
Unknown 1				
Unknown 2				
Unknown 3				

Percent Errors:

	Exp. Weight	Actual Weight	% Error
Unknown 1:			
Unknown 2:			
Unknown 3:			

QUESTIONS

1. How could you make your measurements more accurate?

2. Why was it important to prevent objects from sloshing around inside the canister?

Additional Resources

ADDITIONAL RESOURCES

PHYSICS PRINCIPLES USED IN MINIATURE GOLF

OBJECTIVES

1. Students will practice applying the principle of reflection to the game of miniature golf.
2. Students will practice measurement and scaling calculations.
3. Students will also use their knowledge of friction, conservation of momentum, kinetic energy and potential energy to explain the motion of a golf ball in miniature golf.

LEVEL

This activity would be applicable to a seventh or eighth grade level physical science class.

PROCEDURE

Divide the class into groups of three or four students. Assign each group two or three "holes" or stations at the miniature golf course. Have each group measure the basic dimensions of the assigned holes and sketch them to scale on graph paper. Mark on each sketch the path the ball should follow to give the best route for a hole-in-one. Label the appropriate angles of reflection for each impact with a sidewall. Also, have them note any other significant factors that influence their ability to play the hole, such as inclined planes, curves, and tunnels, etc.

It would also be possible to encourage the students to integrate as many other physics principles as they have learned; such as kinetic energy versus potential energy, friction, conservation of momentum (when one ball hits another), electrical usage, revenue from entrance fees, or use of simple machines.

CONCEPTS EMPHASIZED

1. The angle of incidence = the angle of reflection.
2. Scale drawing and measurement techniques.
3. Forces of friction.
4. Kinetic energy versus potential energy.
5. Conservation of momentum.
6. Electrical power usage and cost. (opt.).
7. Simple machines.

MATERIALS

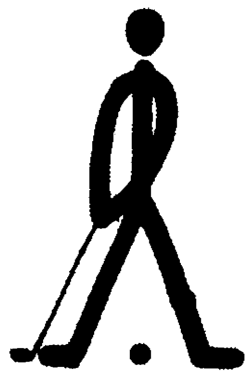
Each group of students will need graph paper, a large protractor, two rulers or yardsticks, and a measuring tape or a piece of string marked in 10 cm intervals. If using the string, you would only need to mark the first meter in centimeter increments.

The students could make a large protractor from a piece of posterboard. The rulers just need to be any good straight edge to line up the angles of incidence and reflection. A watch or clock would be needed to calculate total income from entrance fees for a given period of time.

STUDENT HANDOUT

PHYSICS PRINCIPLES USED IN MINIATURE GOLF

Name: ______________________ Date: ________________Period: _______



MATERIALS

A large protractor
Two rulers or straight edges
A measuring tape or marked string
A watch
Three or four sheets of graph paper
Paper
Pencils

PROCEDURE

For each hole or station that you have been assigned, measure the basic measurements and draw them to scale on graph paper. Write what your scale factor is. Using the principle that an angle of incidence equals the angle of reflection, sketch the best path and direction that the ball should follow to obtain a hole-in-one. Measure what the angles should be for each impact with a sidewall barrier, and mark them on your graph in the appropriate places. Note any other significant factors that affect the motion of the golf ball that apply to each hole.

After you have completed your assigned holes, you may play the rest of the course and answer the remaining questions.

QUESTIONS

1. When the hole involves an inclined plane, does it change the angles of incidence and reflection compared to playing on a flat surface? (If so, why?)

2. What other factors does an inclined plane affect?

3. Does the speed of the golf ball change significantly upon impact with the side barriers? (If so, why?)

4. How does friction affect the ball?

5. What other factors determine the route the ball takes?

Additional Resources

6. When do you observe conservation of momentum? Explain.

7. Calculate the average time it takes to complete the course. ________________________

   Estimate the average number of golfers per hour. ___________________________

   Find out what the normal admission price is. _______________________________

   Estimate the maximum income from admission fees from 2:00 p.m. to 9:00 p.m., assuming an average of three people per hole. ______________________________

   Show all your calculations:

8. Which holes did you enjoy the most? Why?

9. Which holes did you think were the most difficult? Why?

ADDITIONAL QUESTIONS

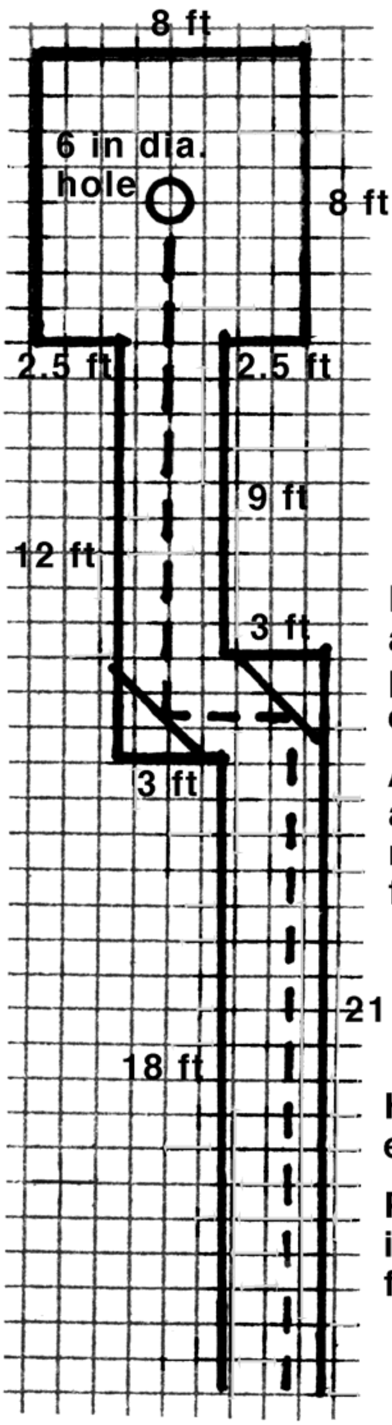
10. List some examples of kinetic energy versus potential energy.

11. Give examples of simple machines used in the course.

12. Calculate the cost of electricity used to run the course, including the lights.

13. Calculate the speed of the ball on the longest runway in meters per second. Convert this speed to miles per hour.

Example for Hole in One



Scale:
1 square = 1 foot

Both crossboards are 3.5 ft long, placed 2.5 ft from each corner.

Angle of incidence and angle of reflection are 45° for both collisions.

Hole one is entirely flat.

Playing time is 7 minutes for 3 people.

Additional Resources

ADDITIONAL RESOURCES

USU AMUSEMENT PARK PHYSICS VIDEO TIME LOG

Time	Subject	Description
0:00:00	Evening Magazine: Roller Coaster Physics	An excellent short segment on an Amusement Park Physics activity at a park near San Francisco. (5 minutes)
0:05:30	Scientific American: Frontiers in Science "The Physics of Roller Coasters"	A nice presentation on the design and physical principles of roller coasters. Presents highlights of a new roller coaster built by Arrow Dynamics of Clearfield, UT. (14 minutes)
0:19:45	National Geographic Explorer: Roller Coaster Physics	A presentation of the design and physical principles of roller coasters. There is material on roller coasters built at Arrow Dynamics in Clearfield, UT. (19 minutes)
0:38:45	The New Explorers: Rock-n-Roll Physics	An excellent spot on two high school physics teachers who do it right! Newton's Laws, Amusement Park Physics, and more. (26 minutes)
1:04:30	Roller Coaster Thrill	Experience the thrill of riding nine twisting, turning roller coasters without leaving the classroom. (29 minutes)
1:33:45	Perceptual Physics at Cedar Point	Some film clips from specific rides at Cedar Point Amusement Park. Many rides are similar to those at Lagoon. (10 minutes)
1:43:15	Diversions in Microgravity	Film featuring USU Adjunct Professor Don Pettit describing some fun experiments in zero gravity physics done on the NASA k-bird. (10 minutes)
1:53:00	Physics Day at Lagoon	Clips promoting USU and Physics Day at Lagoon. (3 minutes)

ADDITIONAL RESOURCES

USING COASTER

<u>What is Coaster:</u>

Coaster is an exciting cross between Amusement Park Physics and a video game, distributed by Disney. **Coaster** is actually a detailed simulation of the physics and engineering that go into the creation of the grandest, and most feared, of all amusement park rides: the roller coaster!)

You are given a blank slate and all the tools necessary to design and construct a realistic roller coaster. When you have finished designing the ride, you'll have the chance to take a ride in a front row seat around the park. You'll have a diverse panel of critics at your disposal to rate your coaster on such aspects as speed, turns, length, loops and overall elegance and performance. You will also have a two-axis accelerometer, speedometer, odometer and chronometer available to analyze the ride on your coaster. While you'll find that you do not have to know a thing about physics or engineering to build a great coaster, you may find yourself learning a great deal about force, acceleration and motion despite all the fun you are having.

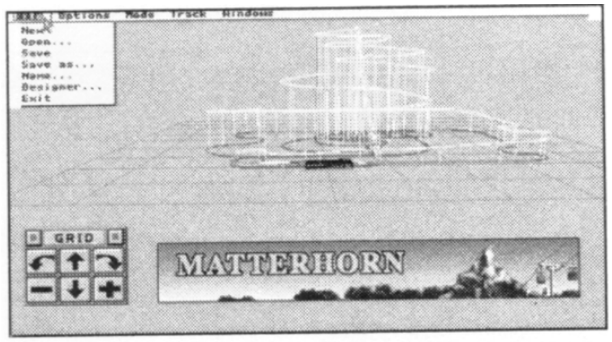
We suggest you start by riding some of the coasters which have already been designed.

<u>Accessing the Coaster Program:</u>

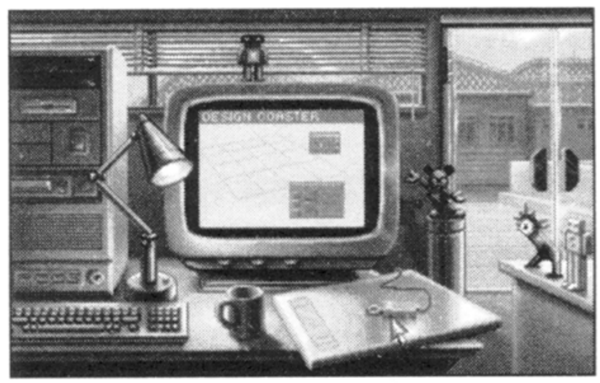
To access **Coaster**, simply double click on the **Coaster** icon in Windows. You will find yourself inside the Coaster Office. To design a coaster, click on the computer screen. To ride a coaster, click on the view outside the sliding doors. To exit the program, click on the keyboard. To load a file describing a previously designed coaster, click on the sliding doors, choose **"Open..."** under **File** from the menu bar, and select the file name. To ride this coaster choose **"Ride..."** under **File** from the menu bar. After you have ridden this coaster, you may obtain a more detailed analysis of your coaster by selecting **"Examine..."** under **Evaluators** from the menu bar.

Help is available from the instructors or from the printed manual.

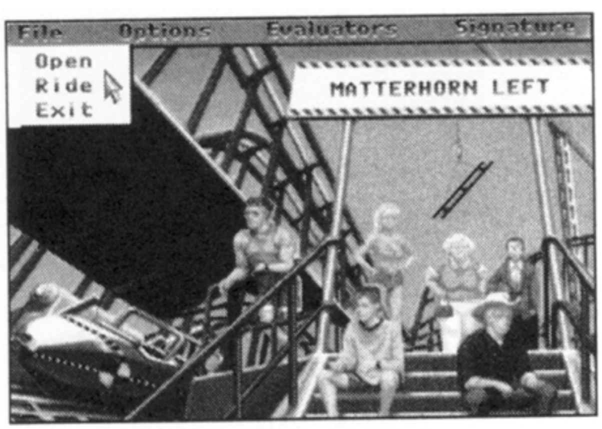
Have fun!!!!



The Matterhorn: *One of many Preprogramed Roller Coasters.*



Inside the Ride Office in Coaster



Getting Ready to Ride ***The Matterhorn***

ADDITIONAL RESOURCES

USING MATHCAD

What is Mathcad:

Mathcad is a versatile computer-aided mathematics program used to enter, analyze and plot data from various experiments and demonstrations. Mathcad allows data entry, calculations, graphing, text and graphics documentation, and even symbolic calculations, all intermixed in an attractive and easy-to-learn format. The program has several advantages: (1) it is extremely easy to use, with a very short learning curve, (2) it produces nice output, suitable for preparing overheads, class handouts, lab reports or analysis sheets, (3) it covers a full range from a glorified graphing calculator, through a useful problem-solving tool at the secondary level, to a full-blown state-of-the-art scientific/engineering analysis package, and (4) it is inexpensive (~$50 for the latest version).

Accessing the Mathcad Program:

To access **Mathcad**, simply double click on the **Mathcad** icon in Windows. You will bring up the **Mathcad** environment, which has the standard Windows "look-and-feel." To load a file, choose **"Open..."** under **File** from the menu bar, select the A: drive and double click on the file name (see list below). To save your modified file, choose **"Save as..."** under **File** from the menu bar, and store your file with a new name on the A: drive.

Help is available from the instructors, the **Mathcad** printed manual or under **Help** from the menu bar.

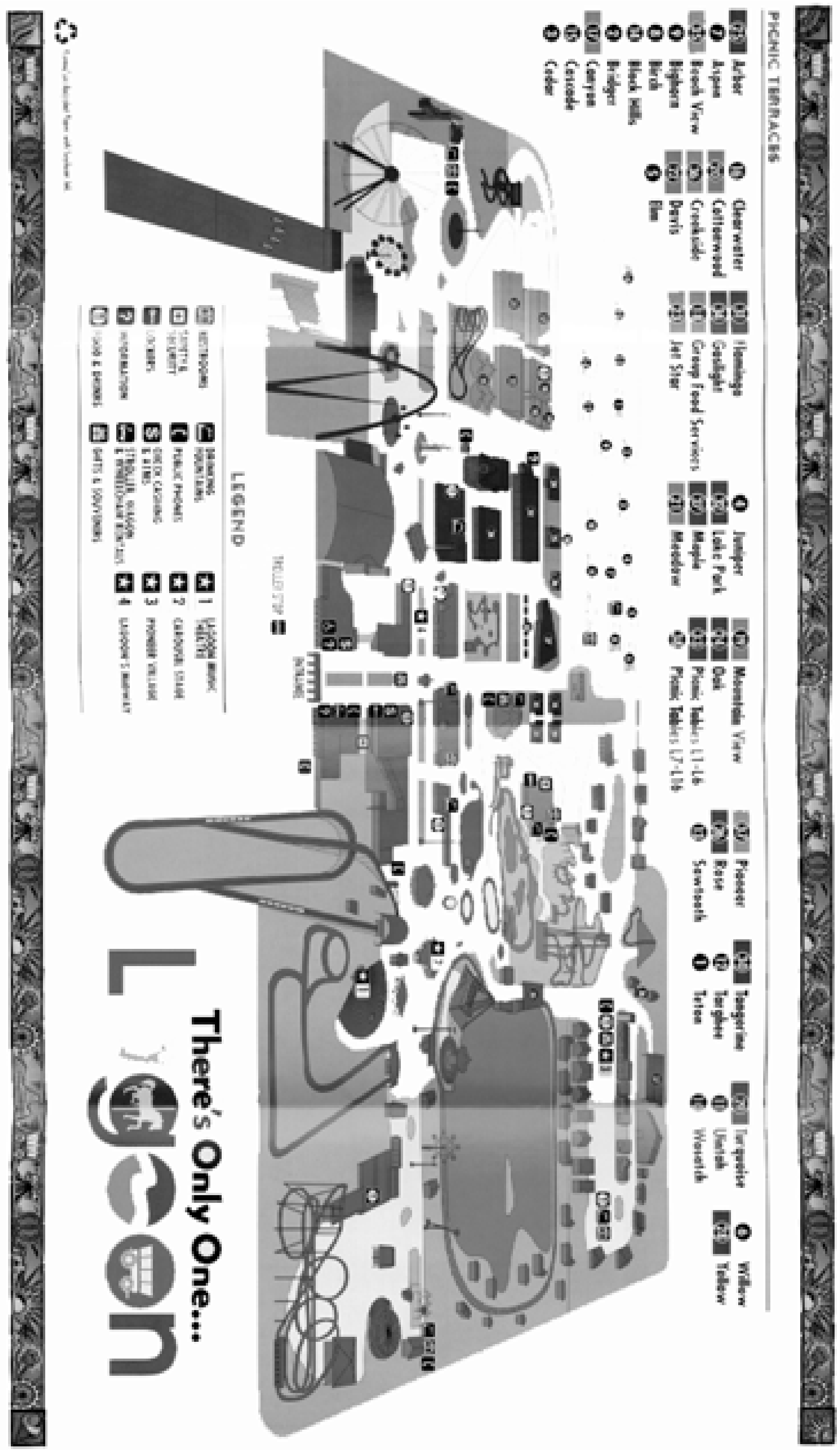
Entering Data into Mathcad

To enter data lists (i.e., x- and y-positions), position the cursor on the n at the end of the defining equation (e.g., x_n:= n) and click to highlight the n. Type in the numbers, separating subsequent values with commas. To edit the data, click on the number to be changed and click and use the standard "delete" and "backspace" keys to modify the number.

Mathcad Files Available from the USU Physics Department Web Site[1]

bb_energy.mcd	Conservation of energy based calculations for the BB/Tubing Coaster.
bb_scale.mcs	Calculations of the scaling of a BB/Tubing Coaster to "Real" size.
el_motion,mcd	Forces, accelerations and motion of an elevator determined by accelerometer measurements.
hw_scale mcs	Calculations of the scaling of a Hot Wheel Loop track to "Real" size.
rc_energy.mcd	Conservation of energy based calculations for the Marble Coaster.
rc_motion.mcd	Calculations of the displacement, velocity and acceleration of the Marble Coaster based on position and timing measurements.
rc_scale mcs	Calculations of the scaling of a Marble Coaster to "Real" size.
Temp_app.mcd	Data analysis of temperature versus time data for various colored cans exposed to intense light.

1 http://www.physics.usu.edu/


PICNIC TERRACES
Arbor
Aspen
Beach View
Bighorn
Birch
Black Hills
Bridger
Canyon
Cascade
Cedar
Clearwater
Cottonwood
Creekside
Davis
Elm
Flamingo
Gaslight
Group Food Services
Jet Star
Juniper
Lake Park
Maple
Meadow
Mountain View
Oak
Picnic Tables L1-L6
Picnic Tables L7-L16
Pioneer
Rose
Sawtooth
Tangerine
Targhee
Teton
Turquoise
Uintah
Wasatch
Willow
Yellow
LEGEND
There's Only One...
Lagoon

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Videos about Amusement Park Physics:

Perceptual Physics at Cedar Point, Robert Spears, Assoc. Professor, Firelands College BTGSU, Huron, OH 44839 (send blank beta or VHS tape and self-addressed, stamped Jiffy #1 envelope)

The Science Connection, Amusing Physics, by Joseph DePuglio, Steinert HS, Trenton, NJ. Videos of Great Adventure Rides, Laboratory Exercises, Problem Sets. Available for $29.95 from Dr. Thomas Ebeling, Dept. of Curric and Inst., Hamilton Township Public Schools, Hamilton Square, NJ 08690. Checks to Hamilton Township Board of Education.

Roller Coaster Thrills, Wood Knapp Video, 5900 Wilshire Boulevard, Los Angeles, CA 90036.

World's Greatest Roller Coaster Thrills in 3D, America's Greatest Roller Coaster Thrills in 3D, available from Wood Knapp Video, 5900 Wilshire Boulevard, Los Angeles, CA 90036.

Software Sources

Disney Software, P.O. Box 690, Buffalo, NY 14207-0690, Tel. 1 (800) 688-1520. Makers of "Coaster" software, for modeling and building roller coasters on the computer.

MathSoft, 101 Main Street, Cambridge MA 02142, Tel. 1 (800) MATHCAD. Makers of MathCAD software, a versatile and powerful math program. This can be used to mathematically model rides and analyze data, for example.

Physics Academic Software, North Carolina State University, Box 8202, Dept. of Physics, Raleigh, NC 27695-8202, Tel. 1 (800) 955-8275. Source of many different physics application programs, as well as video logging software.

Texas Instruments, contact 1 (800) TI CARES (842-2737) for local distributor, such as Vernier Software. Makers of the TI-85 graphing calculator, and the CBL data logger, which allow easy and portable data collection. Very useful for making accurate measurement outside the classroom in the playground or in the amusement park.

Vernier Software, 8565 S.W. Beaverton-Hillsdale Hwy., Portland OR, 97225-2429, Tel. 1 (503) 297-2429. Distributor of the Texas Instrument graphing calculator, and CBL system, as well as manufacturer of many CBL compatible sensors, such as a microphone, accelerometer, pressure sensors, and temperature sensors. Other software and equipment available.

TV Clips about Amusement Park Physics:

3-2-1-Contact Programs: Space Monday (#301), and Measurement Friday (#310) Check with local PBS for airing dates.

Scientific American Frontiers - The World of Science: PBS, 8:00 p.m. October 10, 1990.

National Geographic Explorer - Physics of Roller Coasters, 1991.

Evening Magazine, Roller Coaster Physics, An excellent short segment on an Amusement Park Physics activity at a park near San Francisco.

Scientific American: Frontiers in Science, "The Physics of Roller Coasters," A nice presentation on the design and physical principles of roller coasters. Presents highlights of a new roller coaster built by Arrow Dynamics of Clearfield, UT.

The New Explorers: Rock-n-Roll Physics, An excellent spot on two high school physics teachers who do it right; Newton's Laws, Amusement Park Physics, and more.

Equipment Sources:

Arbor Scientific, P.O. Box 2750, Ann Arbor, MI 48106-2750. Tel. (800) 367-6695. Source of Night Spectra Quest diffraction cards, World-in-Motion Physics Video Analysis Software, as well as other physics demo equipment.

Bandai America, Inc., 12951 E. 166th Street, Cerritos, CA 90701. Spacewarp Set 30, Advanced Coaster. A model coaster kit made from plastic tubes, with automatic coaster start mechanism for continuous display.

Edmund Scientific, 101 East Gloucester Pike, Barrington, NJ 08007-1380. Tel. (609) 573-6250. Source of various scientific equipment, including diffraction grating sheets, which can be cut up and distributed in class.

K'NEX, Education Division, P.O. Box 700, Hatfield, PA 19440. Tel. (800) 563-KNEX. Roller Coaster Physics Education Set. K'NEX construction set for model roller coaster and inclined plane. Comes with physics curriculum support.

Mattel Toys, Consumer Affairs, El Segundo, CA 90245. Tel. (800) 524-TOYS. Hot Wheels G-force Stunt Set. Comes with pieces for setting up loops and jumps.

Pasco Scientific, 10101 Foothills Blvd., Roseville, CA 95678. Tel. (800) 772-8700; FAX (916) 786-8905. Kits for construction of very inexpensive vertical and horizontal accelerometers ($61.00 for 15 vertical and 15 horizontal accelerometers, includes handout material for playground and elevator physics) are available here, as well as other lab equipment. By Jan. 1996, their equipment should also interface with the CBL system (the necessary connectors will become available).

The Science Source, P.O. Box 7237, Waldoboro, MA 04572. Tel. (207) 832-6344; FAX: (207) 832-7281. Inexpensive accelerometers (dual, horizontal and vertical) are available here.

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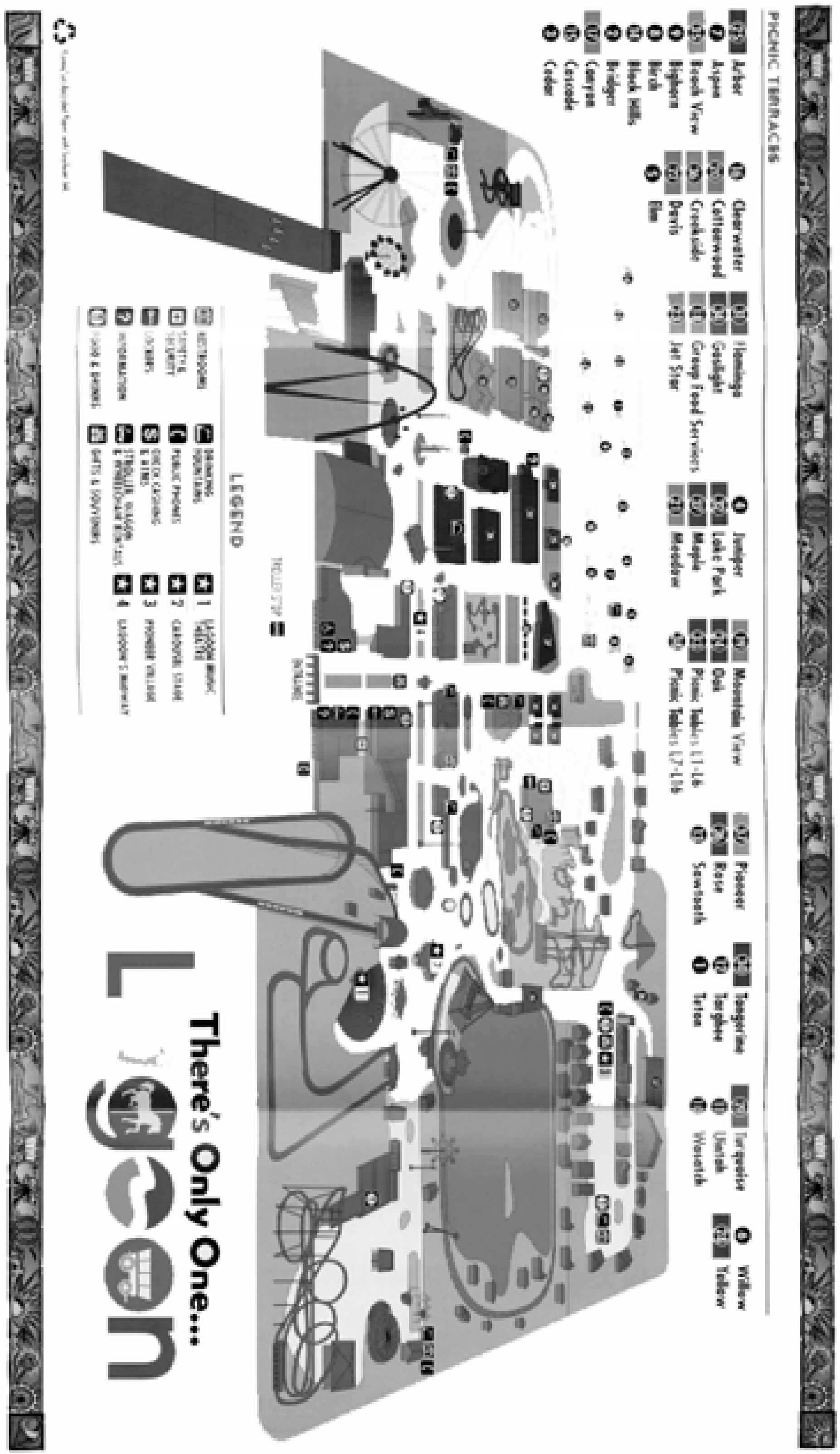
CURRICULUM CONTEST WINNERS

Physics of Miniature Golf`	First Place 1992	Sharon Miya	Davis High School
Laws of Motion and Gravity	Second Place 1992	Robin Parkinson	Clearfield high School
Lagoon-A-Beach, A Physics Paradise	First Place 1993	Ron Cefalo	Box Elder High School
Simple Machines and Newton's Laws at Lagoon	Second Place 1993	Marian Dennison	Logan High School
Physics Makes A Splash	Third Place 1993	Sharon Miya	Davis High School
Marble Coasters	First Place 1994	Paula Scott & Marian Dennison	Mt Logan Middle School
Frequencies and Periods or "Does It Hertz?	Second Place 1994	Ron Cefalo	Box Elder High School
Triangular Exploration of Lagoon	First Place 1995	Sharon Miya	Davis High School
The Hottest Cars Around and Herschel's Experiment	Second Place 1995	David Black	Juab High School
Banked Curves on Rides	Third Place 1995	Ken Wareham	West Side High School
Pendulums and Projectiles	First Place 1996	Ken Wareham	West Side High School
The Inertial Balance	Second Place 1996	David Black	Juab High School
Principles of Physics Used in Miniature Golf	Third Place 1996	Lucinda Bingham	Richmond, UT

<u>Useful conversion factors:</u>

1 in = 2.54 cm	1 J = 2.78×10^{-7} kw hr = 9.5×10^{-4} BTU
1 km = 0.621 miles	1 W = 1J/s = 1.3×10^{-3} horsepower
1 liter = 0.264 gal	1 g = 9.8 m/s^2 = 32 ft/s^2
1 hr = 3600 sec	1 N = 0.225 lb
1 fortnight = 1.728×10^6 sec	1 atm = 1×10^5 Pa = 14.7 lb/in^2
1 m/s = 3.6 km/hr = 2.24 mi/hr	1 kg/liter H_2O = 8.35 lb/gal H_2O


PICNIC TERRACES
Arbor
Aspen
Beach View
Bighorn
Birch
Black Hills
Bridger
Canyon
Cascade
Cedar
Clearwater
Cottonwood
Creekside
Davis
Elm
Flamingo
Gaslight
Group Food Services
Jet Star
Juniper
Lake Park
Maple
Meadow
Mountain View
Oak
Picnic Tables L1-L6
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Pioneer
Rose
Sawtooth
Tangerine
Targhee
Teton
Turquoise
Uintah
Wasatch
Willow
Yellow
LEGEND
There's Only One...
Lagoon