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Classical physics experiments in the amusement park

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Abstract

An amusement park is a large physics laboratory, full of rotating and accelerated coordinate systems. The forces are experienced throughout the body and can be studied with simple equipment or with electronics depending on age and experience. In this paper, we propose adaptations of classical physics experiments for use on traditional rides.

Introduction

In an amusement park, Newtons's laws are experienced throughout the body. Scandinavia's largest amusement park, Liseberg, is conveniently located just 15 minutes' walk downhill from the university physics department in Göteborg and provides a wide variety of experimental possibilities. Examples from Liseberg have been used in university physics courses, but in addition, about 2000 school children (mostly aged 12–19) and 500 teachers have been given guided experimental visits to the park during the years 2000 and 2001 [1]. One day in spring 2002, 600 school children and 60 student teachers were allowed exclusive use of selected rides two hours before the park opened to the public.

In this paper on using an amusement park in physics education, we propose adaptations of the classical experiments by Foucault and Eötvös, using rides commonly available also at travelling carnivals or at the seaside fairground.

Many of the rides in an amusement park involve high elevations, fast movements and strong forces. Safety issues must therefore always be taken seriously. In the first experiment described, however, the park may be more concerned about the well-being of the antique horses in the merry-go-round. Whenever planning experiments for a class, find out the rules of the park and, if needed, negotiate possible exceptions in advance. The experiments proposed in this paper require only very simple equipment that is unlikely to harm anyone, even if dropped.

How do we know?

Have you ever tried asking your students "How do we know that the Earth rotates?"[1]? Most of the time, you'll get a reply referring to the fact that we have day and night. Press the students a bit: "But maybe it is the Sun that goes around the Earth?", and they tell you that it would require the Sun to go around many different planets. You might like to continue by telling them something about pre-Copernican views. Depending on the age of the group, someone may point out that the Sun is much heavier than the Earth. If you tell them that there

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[1] One of us (AMP) has used this question for several years as part of an introductory "How do we know?" questionnaire to new students at the university, and on a few occasions with school classes. Answers other than "day and night" are rare for all groups. A few university students mention weather systems, whereas recalling the Foucault pendulum on the questionnaire is extremely rare.

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is *one* classical experiment, you may sometimes find a student who can describe in detail a Foucault pendulum they have seen in a Science Centre. The rotating Earth, of course, also drives the weather systems, although this evidence is less direct.

“A scientist is completely isolated inside a smoothly moving box that travels in a straight-line path through space and another scientist is completely isolated in another box that is spinning in space” [2]. Can either or both of the scientists detect their motion? The students may have learnt that it is impossible to detect uniform rectilinear motion, but the question still creates considerable discussion in a class of new students, especially with the added proviso that “Each scientist may have all the scientific goodies she likes in her box for the purpose of detecting her motion in space” [2]. A common reaction is that it must somehow be possible. Students might suggest, e.g., that the air would tend to stay behind. Not all are convinced by a mathematical demonstration of the translational invariance of Newton’s laws. Can the scientist detect whether the box is spinning? Here students quickly suggest using the centrifugal force—the Foucault pendulum is certainly not part of their experience. Distinguishing the fundamental difference that translation is relative whereas rotation is absolute is not easy for the students—let them try this experiment!

A slowly rotating coordinate system

Find a merry-go-round (or a rotating panorama tower or any other slowly rotating system). A cuddly toy on a string is a useful multi-purpose piece of equipment for experiments in the park. In this experiment, the toy is used as a pendulum. Set it in motion, hold your hand still and observe (figure 1).

“It made a star, it made a star,” an excited nine-year-old tells his teacher and his friends and anyone who will listen. He draws the figure with his hand. Many children, in fact, do observe, and those who do are happy to share and discuss their observations—others just let the animal swing and look everywhere else.

The miniature Foucault pendulum is a striking experiment, even more so for more slowly rotating systems. It is usually appreciated by the older students, but can small children really learn anything from it? In December 2001, a class of ten-year-olds visited the park, doing a number of experiments, starting with this one, and using their own toys, so they knew that no-one had cheated. One of the teachers brought up the question of why we would do this, so the question “How can we know that the Earth rotates?” was discussed. The visit took place just before Christmas, and the class teacher had no time to follow up on their experiences. Three months later, we visited the class and interviewed the children. Many of them recalled the pendulum in the carousel, and also that it had something to do with the rotation of the Earth, commenting, for example,

Figure 1. What happens to the swinging toy as the carousel starts?

> “In the Pony Carousel, the cuddly toys on the strings started to move like this. I think it was to prove that the Earth is rotating.”
>
> “I learned that when going in the Pony Carousel, the cuddly toy kept going in the same direction while I was going around.”

How does a teacher move on from here to make use of the children’s observations, which

Figure 2. What determines the angle in the Wave Swinger?

also involves taking different systems for reference. One possibility is to find a carousel on a local playground and try it with, for example, a water pistol or throwing balls to a friend. A difficulty may be that safety regulations seem to make carousels on playgrounds few and far between. A more serious concern, however, is that the teacher may not share the children's excitement. Russell Stannard [3], who interviewed several scientists, observes that "An essential ingredient for appreciating science is the sense of wonder. . . . I am struck by the marked change that comes over young people as they enter their early teens. Too often an air of bored indifference sets in and the precious sense of wonder is to a large sense lost, never to be regained. . . . The scientists I have spoken to still possess it."

We have found that adults without physics training often have difficulties with this experiment. If they remember anything about inertial forces, it is certainly not the Coriolis force. Instead of letting the object swing, they typically let it hang still and wait for the centrifugal force to make it hang to the side. However, the centrifugal force is not very eye-catching in slowly rotating coordinate systems. Visual studies of horizontal acceleration are more rewarding in other rides, e.g. in the Wave Swinger discussed below.

Eötvös and the Wave Swinger

Eötvös experiments comparing the inertial and gravitational mass for different materials are less well known than the Foucault pendulum. The main idea is illustrated in the Wave Swinger, which is a carousel with swings on long chains (figure 2). As the carousel rotates, the swings hang out from the vertical, thereby enabling the chains to provide the force giving the required centripetal acceleration, while still counteracting the force of gravity. If you take a group around a park, try to arrive at the Wave Swinger as it loads and ask the group to guess which swings will hang out the most: the empty ones or the ones loaded with a child or with a heavy adult! In this situation students usually pick the most heavily loaded swings. If you ask them why, they often refer to it being harder to pull the heavier swings around. Others may protest and argue that the stronger gravitational force of the heavy adult will make that swing hang out less. They watch the ride start, and have difficulties deciding who was right. To their surprise they find that all swings (at the same radius) hang at the same angle, independent of the load.

The Wave Swinger is a beautiful illustration of the equivalence principle. The angle between the swings and the vertical is determined by the ratio between the centripetal force and the weight.

Since the inertial mass (determining the centripetal force, ma) and the gravitational mass (determining the weight, mg) are equal, the angle is independent of the mass. Eötvös used the rotating Earth as a giant wave swinger by letting weights of different material balance from a rod suspended as a torsion balance. Refined Eötvös experiments are still performed, e.g. at the Eöt-Wash group at the University of Washington in Seattle, giving lower and lower limits for possible deviations from the equivalence principle [4]. The most well-known classical test of the equivalence principle is, of course, Galileo's experiment of dropping balls of various sizes from the leaning tower in Pisa. Many large parks now have drop towers that give the riders a chance to experience a long free fall. Experiments utilizing these rides will be discussed in a later paper.

Children are naturally interested in their weight and often ask how heavy they feel in various rides. For the case of the Wave Swinger the apparent weight can be estimated easily by using a protractor to measure the angle between the swings and a suitable vertical line. Older children may divide the reading on the bathroom scales by the cosine of the angle. Younger children can draw their normal weight as the vertical leg of a right-angled triangle, using the reading from the protractor for the top angle. The horizontal leg corresponds to the centripetal force and the hypotenuse to the total force exerted by the chain on the rider. The apparent weight can thus be read directly from the hypotenuse in the diagram. We will return to the question of g-forces in a later paper.

A simple experiment in the Wave Swinger is to take along a small mug of water. This violates the general rule of 'no loose objects' and thus requires some negotiation. During a class visit, we asked a nine-year-old if she had had problems in taking the mug along. She proudly told us that the guard had asked if she was really going to take the mug on the ride, but that she had told him that she came from a school and was going to do an experiment. Nevertheless, this experiment may be better saved for later years—we saw a number of mugs break as excited children squeezed them in trying to hold on during the ride.

What happens to the water level in the mug? During the year 2001, about ten classes of 14–16-year-olds who visited Liseberg during the Gothenburg International Science Festival filled in a quiz that included this question (without doing the experiment). About a third of the pupils thought that the water level would be parallel to the ground, half of them thought that it would be parallel to the seat and the rest chose the alternative that the direction would be between the horizontal and the seat. Later interviews with children indicate that many believe that the water level would lean more than the swing. For the experiment to be rewarding, it seems essential to have first made a guess. An adult came off the ride wondering if she had done something wrong, because nothing happened to the water. Some children are surprised to see that the water stays in the mug (and are happy to drink it on a hot day). Others exclaim: "It is amazing. The water level remained absolutely still." Yes, indeed, the water level is orthogonal to the plumb line, represented in this case by the chain, but even if you know this, you may be surprised by the extent to which it is true.

Planning a visit

Doing unknown experiments with unfamiliar equipment on exciting rides in an unknown park is very unlikely to lead to any physics learning. If there is a park nearby that children are likely to have visited before, that is the obvious choice. Find out if the park arranges special days or hours for experiments (such as the Physics Day in Adventure World, described by Shelley Yeo [5]). If not, find out suitable days and times from the park when the queues are likely to be short. Divide the class into smaller groups that focus on experiments in two or three rides and present their findings to the rest of the class after the visit. Use the park's website to find information about the rides and plan what experiments to perform and what equipment to use. Do not forget safety considerations, and if in doubt about the equipment, consult the park before the visit. Let the class try the equipment in quieter conditions, such as a local playground [6]. Remember that the more exciting rides may require a number of turns before the pupils can concentrate on the equipment. Those turns may be seen as occasions when the body is used as a measuring device and the experience is discussed before the next turn on the same ride. To find out more about 'the forces behind the fun', visit Annenberg/CPB's site about

'Amusement Park Physics' [7]. If the students are familiar with CBL equipment, it should obviously be used in the park, as described, e.g., in reference [8].

The preparations are essential. Without them, the originally intended use of an amusement park is too tempting for the students to be able to concentrate on the physics. Physics is fun—but it is also important to help the students discover that 'the fun is physics'.

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