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Swings and slides

Ann-Marie Pendrill[1] **and Gary Williams**[2]

[1] Department of Physics, Göteborg University, SE-412 96 Göteborg, Sweden
[2] Institute of Physics, UK

E-mail: Ann-Marie.Pendrill@physics.gu.se and gary.williams@iop.org

Abstract

The use of playground rides as teaching tools is discussed with the emphasis being on slides and swings. A variety of different aspects of physics are covered including force, acceleration, friction, electrostatics and reflection. The physics content would be applicable to most age groups at some level.

Introduction

Readers will have noticed that they are over the age at which many playgrounds will cater for their needs—in fact some playgrounds do not allow older children to use them at all. We have enlisted the services of some young potential physicists, our memories and our ingenuity to offer some ideas for using slides and swings as physics teaching aids. There are numerous benefits to using playgrounds in teaching but probably the two most important are that they relate to something that is very real and exists in children's minds as belonging to their world and also that they exist outside the classroom. Just the act of taking your lesson to a different location can make it memorable, so together with the chance for pupils to enjoy themselves, this must be a recipe for success.

Playground swings

A swing may be the first playground experience. First, a gentle swing, started by a parent; later, demands to be pushed higher and higher; then slowly learning to change the moment of inertia in phase with the motion to keep the swing going, swinging higher and higher, experiencing the interchange between feeling heavy and light, over and over again. When swinging is comfortable, new challenges enter: Can you twin-swing with a friend, or can you swing faster than your friend? How high can you swing? Is it possible to go all the way around? How far can you jump, and when is the best moment to jump?

A swing is an example of a pendulum, familiar to everyone. It provides an abundance of physics examples, and children's questions often enter territories well beyond the curriculum. The experience of the body can be enhanced by visual measurements using simple equipment, which may make more difficult concepts available. Returning to these questions in school helps enforce the notion that physics is not only about equipment in the classroom but concerns everything around us.

Force and acceleration

In a mathematical pendulum, forces act on an inanimate, point-like object. In a swing, the forces act instead on the body that is your own. Close your eyes and recall the feeling. In which direction does the force from the swing act on you? When is this force largest? How large does it get?

The chains holding the swing can exert a force only along the direction of the chain. The force from the swing on the rider will thus always be directed to the suspension point. The length of the chain is constant. As the swing turns at the highest points, the force from the chain counteracts the radial component of the force of gravity. The larger the angle of the swing, the smaller the force of the chain at the turning point.

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The orthogonal component of mg gives rise to an angular acceleration, bringing the swing back down again.

Measuring the experience of the body

The feeling in your stomach tells you that, for an accelerated body, forces do not act only in the contact area, but propagate throughout the body, so that a sufficient net force, $\boldsymbol{F} = m\boldsymbol{a}$, will be exerted on every gram to provide the required acceleration. The body thus experiences acceleration much in the same way as gravity. The concept 'g-force' is useful to describe this experience. Children have heard about the concept, but it is rarely introduced in textbooks, let alone defined. Let us introduce a 'normalized force' $\boldsymbol{f} = (\boldsymbol{a} - \boldsymbol{g})/g$, which is the force acting on an object, in addition to gravity and related to the weight, mg, of the object. For a free fall, this normalized force becomes zero. For an object at rest, the vector $\boldsymbol{f}$ has unit magnitude, and is directed upwards, i.e. in the direction of the force required to counteract the force of gravity. As the swing turns at an angle θ, the magnitude of $\boldsymbol{f}$ is $\cos\theta$, directed along the chain, towards the point of suspension. As the swing passes the lowest point, the chain must counteract mg, but also provide the centripetal force, mv^2/r. For a mathematical pendulum, the acceleration at the lowest point is $2g(1 - \cos\theta)$, independent of the length of the pendulum. The 'g-force' then becomes $(3 - 2\cos\theta)g$.

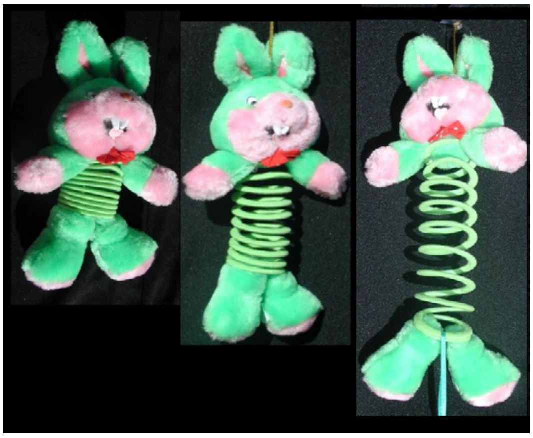


Figure 1. A spiral rabbit has an internal spring scale measuring the force acting on the feet or head. The figure shows the look of the rabbit for weightlessness ($0g$), normal load ($1g$) and for a motion giving $2g$ (e.g. as in an upward acceleration of $1g$). The resolution can be increased by holding the rabbit upside down, since the head is heavier.

Figure 2. A Slinky and a spiral rabbit. Note that they are both short at the turning points, and considerably expanded at the bottom. Air resistance slows the motion of the outer parts of the Slinky.

The experience of the body can be illustrated by bringing along a small Slinky or a spiral toy, as shown in figures 1 and 2, which gives a real-time measurement of the varying forces during a swing. The spirals are shortest at the turning points and most expanded at the bottom.

Student expectations are unlikely to coincide with observation. Often, the acceleration is subconsciously used in the everyday sense of 'increase of speed', or possibly 'change of speed'. Obviously, the rate of change of speed is largest at the turning points and zero at the bottom, where speed has a maximum. The insight that acceleration in physics is the time derivative of velocity, which is a vector, does not come easily to most students, who are likely to have been brought up on an 'acceleration diet' consisting of one-dimensional motion, often starting from rest. Still, the more general concept of acceleration is evident throughout the body, and clearly visible in the simple measurements—or in the accelerometer data described below (figure 3).

Electronic measurements

Figure 3 shows a graph from an electronic measurement of g-forces in a playground swing. The probe is a Vernier 1-D accelerometer [1], held with the arrow in the direction of the chain. The smallest values correspond to the cosine of the angle at turning and the largest values correspond to gravity plus the centripetal acceleration, giving $(3 - \cos\theta)g$ for a point-like pendulum. The period on the graph is only half the pendulum

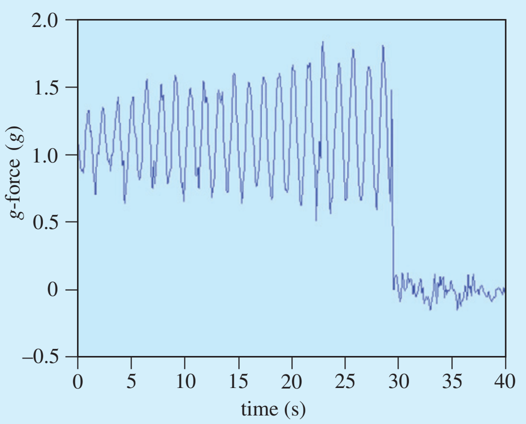


Figure 3. Electronic measurement of the *g*-force in a playground swing. The accelerometer was held with the arrow pointing in the direction of the chain, for nearly 30 seconds. It was then turned to lie along the direction of the motion, measuring the tangential component of the *g*-force.

period, since the swing passes the lowest point twice during a period.

During the last part of the graph the accelerometer probe was held with the arrow in the direction of motion, resulting in very small values, as discussed below.

Tangential components of the acceleration

The changes in the speed of the swing result from the component of gravity along the motion. Still, measuring this component gives very small values, which is quite counterintuitive. However, since gravity is the only force in the direction of motion, that component of acceleration will coincide with the component of $\boldsymbol{g}$, resulting in a zero tangential component for $\boldsymbol{f}$, as seen in the graph. A one-dimensional accelerometer is thus sufficient to measure the forces on the rider in a swing—but it is important to understand that it is not measuring acceleration, but a component of the g-force. A three-dimensional accelerometer would provide no additional information in this case.

The vanishing tangential component of the g-force for the rider in a swing can also be illustrated by bringing along a bottle with a small amount of coloured liquid at the bottom (figure 4). Students who tried it have asked for water to dilute the liquid, so it would flow more easily during the motion—only to discover that the surface of the liquid does, indeed, remain parallel to the swing.

Figure 4. Bringing along a bottle with a small amount of coloured liquid provides a challenging demonstration of forces in a pendulum motion.

The water level is orthogonal to the plumb line, in this case represented by the chain.

A similar experiment can be performed on a pendulum ride in an amusement park, bringing along either a small (soft) mug of water (1 cm is sufficient), or a small cuddly animal on a short string. (Saftey must always come first!) What do you think will happen? Will the result depend on whether you sit in the middle or in the back? Will you come off the ride complaining that there must be something wrong with your water, since it didn't move?

The period of a swing

The period of a pendulum is remarkably independent of the angle, as noted already by Galileo. This 'iso-chronism' forms the basis of a pendulum clock, and it is easy to remember that the second-pendulum (where the half-period is 1 second) is about one metre long, giving us an easy way to estimate the period for pendulums of varying length, using the relation for a mathematical pendulum, $T = 2\pi(L/g)^{1/2}$. The independence of the period on the mass of the pendulum is, of course, a consequence of the equivalence principle. Children can 'twin-swing' reasonably well with an empty swing or with another child essentially independent of size.

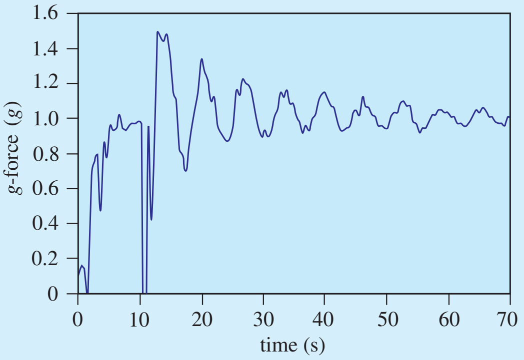


Figure 5. Accelerometer data for a 42 m long swing.

Figure 6. An amusement ride where riders sit about 13 m from the centre, but with a half-period of about 10 s (for small angles). The long period is due primarily to the counterweight, partially hidden behind the tree. Since this pendulum is rigid, rather than suspended in a chain, it is possible to complete a 360° turn, nearly stopping at the top.

Real-life pendulums often have slightly longer periods than given by the formula above. Although large angles lead to longer periods, this rarely accounts for the deviations found by the students, who are also more likely to blame deviations on energy losses. That neither effect has a large influence on the period can be seen in the accelerometer graph (figure 5) from a 42 m long swing hanging from a suspension bridge in the harbour of Göteborg during April 2002 [2]. The length of this swing provides a curious mixture of speed, in the passing of the lowest point, and a very slow pendulum due to the long chains. Swings of similar length can also be found in several amusement parks. The effect of air resistance, proportional to v^2, can no longer be neglected for the high speeds in these long swings, resulting in the strong damping, evident from the accelerometer graph, as well as from observation of the swing.

A more important factor affecting the period is the moment of inertia. Although students are not necessarily familiar with this concept, they understand that an object hanging from its centre of mass will not swing, or that a counterweight, such as in the ride in figure 6, will result in a longer period.

Using swings in physics teaching

The physics teacher may return to the playground, pushing children, reflecting on the equivalence principle, on the forces acting on children, on angular momentum or energy conservation. The experiments in jumping off the swing at various parts of the ride may be replaced by numerical simulations to find the best angle. A collaboration with the PE teacher can invite projects investigating, e.g., the physics of trapeze [4]. Swings come in many varieties, and their physics offers insights into many fundamental principles. Emphasizing the forces acting on the human, accelerated body, shifts the focus from centrifugal to centripetal forces, which may be useful for 'cracking the code' that $\boldsymbol{F} = m\boldsymbol{a}$.

Slides

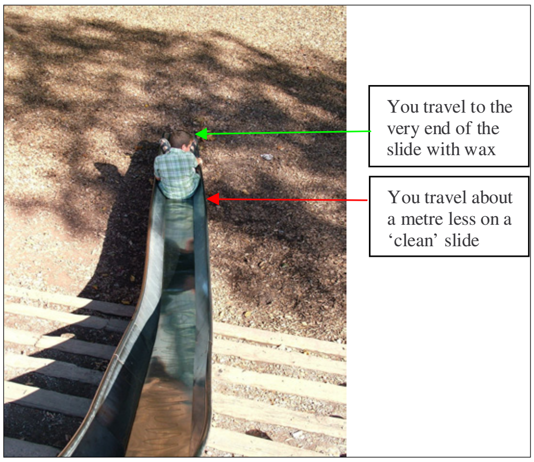
These days slides come in a variety of shapes and forms. As the focus of this article is playgrounds we haven't covered 'drop-slides' because these have yet to make their way into playgrounds as far as we are aware. They do, however, make for a fascinating experience should you come across one at an amusement park etc. They consist of a slide that has an initial vertical drop and which then slowly curves around to the horizontal. The initial drop is stomach-churning but a great way to experience 'weightlessness' in safety.

Figure 7. The longer the slide the better.

Friction

There is more to slides than meets the eye. Of course there are calculations of speed from a basic $mgh = \frac{1}{2}mv^2$. These will give only a crude answer because we have not accounted for losses due to friction and air resistance. Air resistance is harder to change but friction can be easily reduced using wax crayons—'write' all over a stainless steel slide then smear the wax by having several goes down the slide and most pupils will notice that you do go faster—it is a very distinct difference.

Using a slide of the length of that shown in figure 7, there was a difference of about one or two seconds when sliding from a standing start between a 'clean' slide and a waxed one; this is a noticeable difference when it takes 4–5 seconds to come down a 'clean' slide. (Using a light colour of wax crayon or candle wax leaves less of a mark on clothing—old jeans may be useful for this.) Another very noticeable difference was how far the body travelled at the end of the horizontal section of the slide depending on whether the slide had been waxed or not (figure 8). This seems to be a more striking difference for young children than the difference in speed. An extension to this idea would be to use a sandbag and light gates to measure the speed of the sandbag on waxed and 'clean' slides.



You travel to the very end of the slide with wax

You travel about a metre less on a 'clean' slide

Figure 8. The distance travelled on a waxed slide compared to a 'clean' slide is very noticeably different.

As an introduction to friction you can begin with the fireman's pole—we are indebted to Jamie, age 6, for pointing this out. He immediately showed off the palms of his hands after sliding down the pole as they got hot (figure 9). This demonstrates the value in asking pupils to find the

Figure 9. Jamie and his hot hands.

physics in the playground themselves before the teacher starts with prepared examples. An adult's hands would not have become hot in sliding down the pole because their legs are too long!

Mirrors

Stainless steel slides also tend to make good mirrors (assuming they haven't had wax crayon daubed all over them). On a sunny day you can find a rough focal point for some curved slides and show that it's a focus because your hand gets cooler as you move it away from the hot spot, both towards and away from the slide (figure 10). On a very sunny day this can be a very striking demonstration. The sun needs to be in the right place, and as the sun appears to move across the sky the hot spot moves too—all good discussion points for pupils. Some metal slides have a patterned surface, and while these aren't any good for focusing the sun's rays they are useful for explaining the difference between specular and diffuse reflection. If the surface is polished enough to be able to see your own reflection in you can also see how the convex part (usually at the top) and concave part (usually at the bottom) of the slide change the shape of the image.

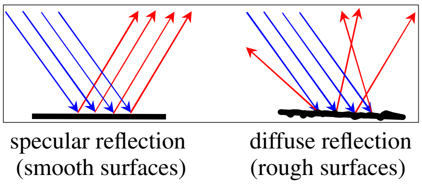


Figure 10. The hot spot can be seen on the lower part of the hand; further up on the face it wasn't as hot.

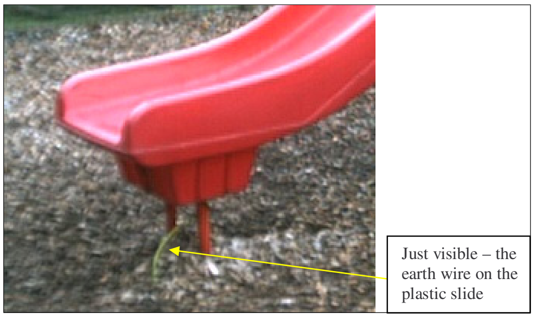


Figure 11. The earth wire on a plastic slide.

Electrostatics

You need a plastic slide for this and perhaps one that hasn't been earthed! It was surprising to see a plastic slide with an earth rod for the first time, but obvious why when you touch a child who has just slid down an unearthed plastic slide (figure 11).

Giving each other shocks at the bottom of the slide makes an obvious impression; seeing that it doesn't work when they touch the ground is also something they tend to find out for themselves. The crack of the sparks is audible and they can also see their hair standing up on end as they become charged.

A simple electroscope can be made using a can, some tissue paper or foil and a rubber band although a gold leaf electroscope would be better because on windy days the movement of the foil due to charge is less convincing (figure 12). Comparing the amount of charge transferred with different speeds down the slide, different clothes and different people all makes for a lively time. Explaining why this doesn't work with a metal slide and linking the electrostatics back to friction round this off nicely. (Another interesting point to be aware of is that pupils with cochlear implants need to take precautions when using plastic slides [5].)

Figure 12. Static from a plastic slide.

Conclusion

Slides and swings are the most common pieces of equipment in playgrounds and offer a lot of scope for discussion of different areas of physics and a variety of experiments. Older children often enjoy an excuse to play on rides that they would like to pretend they are too grown-up to be interested in and younger children just like to play! With secondary school teachers increasingly being asked to provide 'taster' lessons for primary school pupils, the playground can be a friendly starting point. There are many other rides that can be brought into physics lessons—see-saws, merry-go-rounds, witches' hats—probably an endless list, and we hope we have outlined a few ideas to make you want to investigate the physics in your local playground.

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[4] The Physics of Trapeze baltimore.trapezeschool.com/resources/physicsintro.php
[5] See www.bcig.org/public/current_safe.htm for guidelines for those with cochlear implants

Ann-Marie Pendrill is a professor in physics at Göteborg University, with a research background in computational atomic physics.

Gary Williams is Editor of *Physics Education*.