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Physics, Toys and Art

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Physics toys are my hobby for perhaps 20 years. More and more people are interested in this sort of Physics toys have been my hobby for about 20 years. Over the years more and more people have become interested in this sort of toy. The problem that physics is not loved by pupils exists not only in German schools. Toys are one way to stimulate interest.

After a short introduction I am going to show two toys with detailed explanations. The first part of my talk deals with the physics of toys in everyday objects. This means explaining how to use everyday objects such as a paper clip to make physics toys. This is not the same as everyday physics, where you try to explain everyday phenomena with physics. For all the toys which I am going to show today you can find detailed publications on my homepage [1].

I apologize for the fact that I am going to mention toys or artistic objects from only six different countries. I am sure that there are many objects in other countries with connections to the contents of my talk.

For an introduction, it is always good to have famous physicists for support. Here two very well-known physicists, **Wolfgang Pauli** and **Nils Bohr**, are looking at a tippe-top. It would be interesting to know their thoughts at this moment, but nothing has been passed down.

The construction of this top is very easy. The physics background is very complicated. There have probably been more than 30 publications concerning this object in the last 50 years. And it is important to know that there is no simple explanation of the flip-over phenomenon. You have to dive deeply into differential equations to solve the physics. This is, of course, not very satisfying, especially not for teachers.

I want to add only one remark: This tippe-top was patented in Germany by Miss **Helene Sperl** [2] in 1891. Several examples were described in the patent. I have rebuilt these, and it is interesting to know that none of these tops work as they should. What the German patent office explained to me about how it can happen that a patented object does not behave as described is another story for itself.

I want to mention this simple tippe-top idea which you can make with paper clips. I first saw this idea in a publication by **Yoshio Kamishina** [3]. It doesn’t work as well as the classical tippe-top but clearly shows one principle: that the centre of gravity of the whole object does not lie in the centre of the big circle.

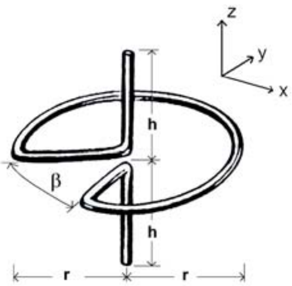
A tippe-top version of the German toy creator and artist **Reinmut Weber** uses the same principle but looks much nicer.

Paper clips are very good objects for doing physics experiments. There is a book [4] which contains many ideas, but not the ones which I will describe here.

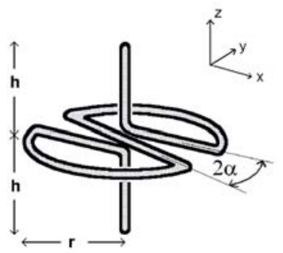
The invention of the paper clip in 1899 is credited to a Norwegian named **Johan Vaaler**, who patented the device in Germany because Norway had no patent law at the time. In 1999 a memorial stamp was published.

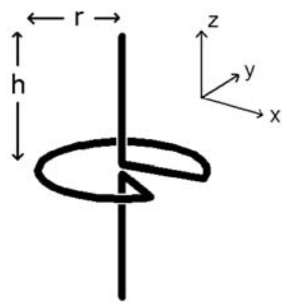
Vaaler did nothing with his invention, however, and a year later a U.S. patent for a paper clip, called the Konaclip, was awarded to **Cornelius J. Brosnan** of Springfield, Massachusetts. In England, Gem Manufacturing Ltd. quickly followed with the now familiar double-oval shaped Gem clip.

Although some people dispute the originator of the paper clip, Norwegians have proudly embraced their countryman, Johan Vaaler, as the true inventor. During the Nazi occupation of Norway in World War II, Norwegians made the paper clip a symbol of national unity. Prohibited from wearing buttons imprinted with the Norwegian king's initials, they fastened paper clips to their lapels in a show of solidarity and opposition to the occupation. Wearing a paper clip was often reason enough for arrest.



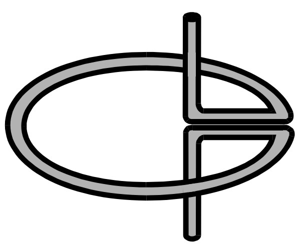
How can you make a top out of a paper clip? 'Paper clip' stands only for an easily available piece of wire. Professor **Takao Sakai** from Japan proposed a nice idea [5]. He used it as an exercise for students of mechanical engineering. I doubt that the students were amused.
This is the solution he proposed. This solution needs no soldering or gluing. One can recognize the axis of the top. To get a big moment of inertia the wire should be at a great distance from the axis. But there also has to be a connection between the arc and the axis – the spokes. The interesting question is the size of the angle! If the angle is too big or too small, the centre of gravity will be not on the axis.
This top is a so-called unsymmetrical top because the moment of inertia I_x is not equal to I_y
The problem of the right angle can be calculated by calculus [6]. The result is the simple equation $\tan\alpha = 0.5$ or $\alpha = 26.57^0$ or $ß = 53.13^0$.
With an approximation it is possible to calculate the problem without calculus. It results in an angle of 60 degrees, which is not very different from 53 degrees.

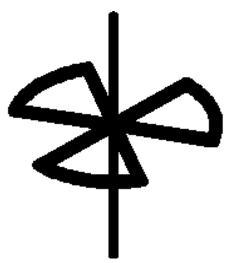


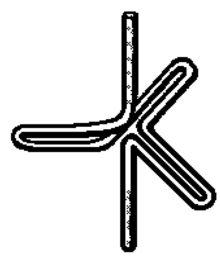


In the figure, the possibility of building a symmetrical paper-clip-top according to Takao Sakai is shown. This case is a little bit more difficult to calculate but results in the surprisingly simple equation $\tan\alpha = 2/3$ or $\alpha = 33{,}7^0$ or $2\alpha = 67{,}4^0$. Thus it is $I_x = I_y$. This paper clip top is not so easy to make because you have to bend the wire many times.
It is well known among physicists and especially engineers that a top can rotate stably only around the axes of maximum and minimum moment of inertia. If the axis of a top coincides with the middle moment of inertia I_z, it is unstable.
This is the case for a paper clip top if the height of the half axis has just the length h = 1.65r. Then it is $I_x < I_z < I_y$

There are many further possibilities for constructing a top out of a paper clip, as you can see from the following examples.







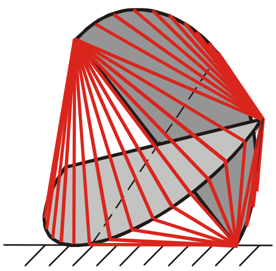
A simple way to build Sakai1-tops is to divide the total length of the straight bended paper clip wire into ten parts. Thus you can start with the first half axis if you bend one tenth in a right angle and then go on bending another one tenth in a right angle. Then bend the arc and at the end repeat the same procedure from the beginning.

To make the tops in reality it is not so important to have exactly this angle. This would be difficult. It is also not so easy to make a perfect arc. It is important to have the centre of gravity in the axis. After making some tops you will get a feeling for how to construct them so that they will rotate well.
As you can see, the arc is not perfect and the angle is also not correct. The only important thing is that the two parts of the axis form a straight line which goes perpendicularly through the centre of gravity of the plane formed by the arc and the spokes.

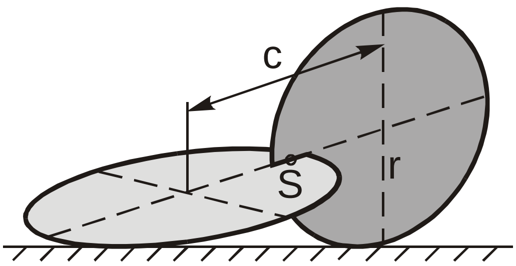
This toy looks like a simple top. And it is a top, created by the German artist **Christoff Guttermann** [7]. But it contains a trick: if you turn one half of the top at a right angle, you get an object which can be described as two half-circle-discs connected to each other vertically. This object has a strange behaviour. If this object rolls down a slightly tilted plane, the distance between the centre of gravity and the plane remains constant. The path of the centre of gravity is more like a serpentine. If you look at it exactly, this line is composed of circular arches, as shown later on. Because of this movement, such objects can be described as two-disc-rollers, and they are called **wobblers** (from the verb: to wobble) in English.

There are so-called beer-mug-mats (stein-stands) that are excellently suitable for self-construction of wobblers. They are easily available, especially in Bavaria in Germany, mostly circular, but sometimes also as ellipses. They can be worked on easily with a knife and some glue. This is a simplified construction where two half-circle-discs are connected to each other vertically.

When rolling down a plane, such a wobbler always touches the plane at two points which can be connected with a straight line. By connecting all corresponding bearing-surface points to each other, a convex hull is obtained, also called a connection torso.



In 1970 the Englishman **Colin Roberts** discovered a nice geometrical object that he called a **Sphericon** [8]. It is exactly the connection torso of a wobbler with two half-circle discs. Sphericon is an artificial word creation from sphere and cone.



for circular discs $c = r \cdot \sqrt{2}$

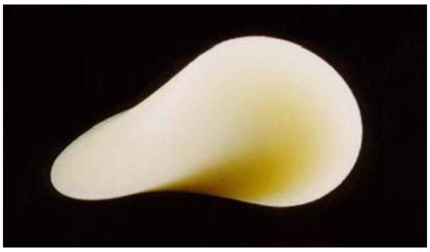
for elliptical discs $c = \sqrt{4a^2 - 2b^2}$

One can now proceed a step further and wonder what will happen if two entirely circular discs are connected to each other vertically. This can be done very easily by cutting radial slits into the circular discs. The result is displayed in the figure.

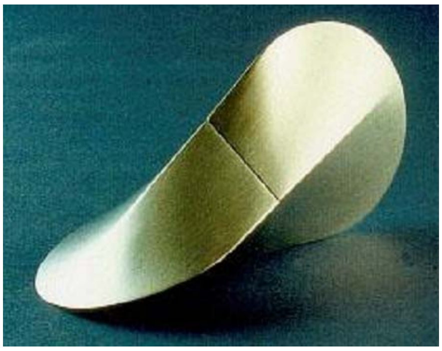
Using such a construction, – with the wobbler rolling along a plane – , the distance of the centre of gravity remains exactly constant if the distance between the centres of the two circular discs fulfills the condition indicated in the figure.

The figure shows an example with beer-mats. The authors forwarded this sample to the corresponding brewery in order to get some more mats. Not only did we obtain several hundred items but two cases of beer were also sent “to facilitate the scientific work”. From this you can see that such labour “can be worthwhile”.

The principle of rollers made of two entirely circular discs has been used in various toys. We will mention here the Finnish children’s toy **Ensihammas**. The shaking movement seems to fascinate children, too. Using two parts of a German construction toy called **RONDI**, one can combine two wobblers immediately. The distance stipulation is well fulfilled. We asked the toy company about this property and it turned out that it was a coincidence.



While rolling along these two-disc-rollers also always touch a plane exactly at two points. By connecting the contact-points of the roller to each other, you get the connecting torsos. This is a completely aesthetic-looking body. The English artist **Rick Flowerday** converted this idea into a toy.



The German designer **Alexander Schenk** converted this idea into a household object which he called **Doublette**. You can separate it into two parts, and then it is a salt and pepper shaker [9].
But here the right condition for a true wobbler is not fulfilled. This makes sense because this object will not roll down a slightly tilted plane easily, for instance a table, and thus won’t fall onto the floor and spread salt and pepper everywhere.

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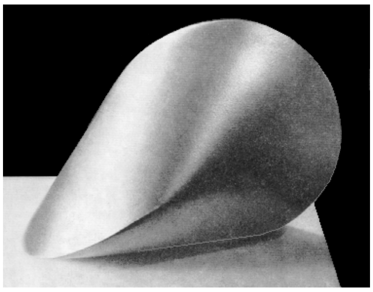
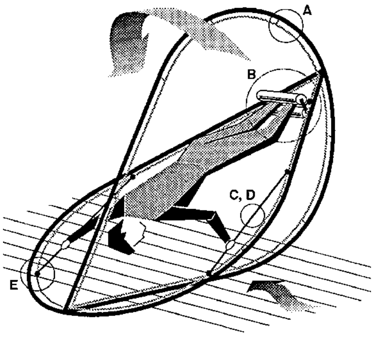
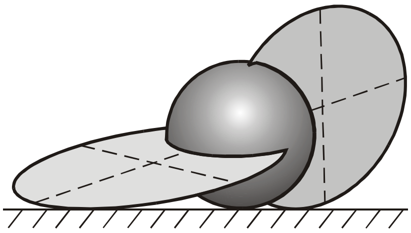


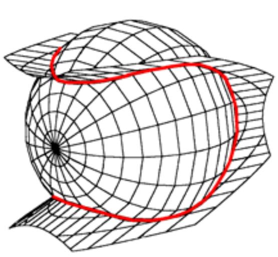
At first glance the **Oloid** looks like a completely identical object. Originally, it was used as the coating body of the so-called upside-down-turnable cube by **Paul Schatz**.
It can be constructed easily under the stipulation that the distance between the centres formed by the circular discs of the Oloid are exactly as long as the diameter of a circle. Since this distance does not correspond to the condition for a constant centre-of-gravity distance, the Oloid shakes back and forth when it is pushed slightly. When pushed more strongly it rolls over a plane fairly easily since the centre of gravity varies only very little in height.



The **Rolodil** is an oloidal sporting device which may be good for fitness. It was never produced in large quantities.



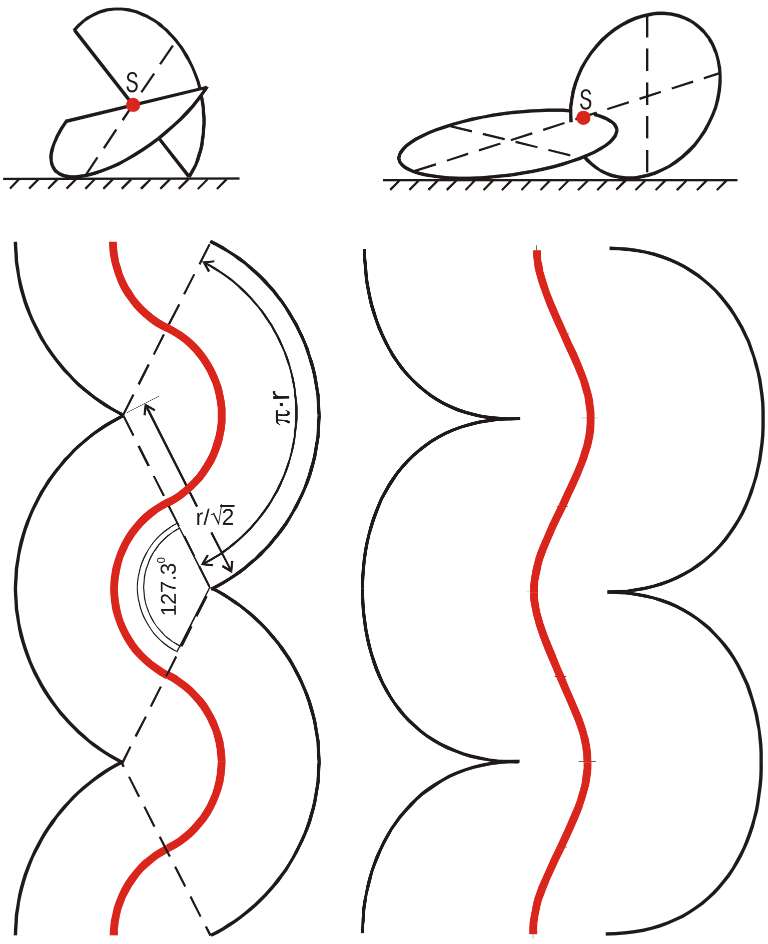
The drawn-in sphere touches the plane while the two-disc-roller rolls along the bearing-plane. We call it the touching sphere.
I mention this only because there is an unexpected connection to tennis balls.



This object (constructed by the program Mathematica®) shows the curve on the touching sphere when the wobbler is rolling.
You can see the similarity to a tennis ball at once.

The curve described for a regular tennis ball (radius h = 3.2 cm) (the *„tennis ball curve“*) is amazingly similar to the touching-line l of a half ellipse-wobbler.

This sculpture was created by the German artist **Vieweger**. It stands in front of a tennis club in Munich and shows the tennis ball curve clearly.



Finally, here is a representation of the paths of the center of gravity of the two-disc-rollers projected on the plane. You can see half-circles or entire circles including the corresponding touching lines of the rollers.

Although the curves look quite similar to each other, the left-hand path, which is derived from the two-half-circle disc wobbler, can be calculated easily, while the right-hand path from the complete-circle-disc wobbler still has not yet been calculated quantitatively. That is only one of the problems still unsolved and worthwhile of consideration in the future.

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