published in the Proceedings of the Conference: „Teaching the Science of Condensed Matter and new Materials“, UDINE, Italy, 24.-30. August 1995, FORUM, Editrice Universitaria Udinense, via Palladio, 8, 33100 Udine, Italy 1996, page 437-441

SCIENCE AND TOYS

Christian Ucke, *Physikdepartment E 20, Techn. Univ. Munich, D-85747 Garching, Germany*

Ladies and Gentleman, dear colleagues,

I'll talk about toys, to say it more precisely about physics toys. It is difficult to explain what exactly a physics toy is. I will show toys that I consider physics toys. The explanation of the physics behind some of these toys is very complex and cannot be dealt with satisfactorily in this brief paper. Others I'll try to explain.

There are very old physics toys. You can see in Fig. 1 a greek man playing with a **yo-yo**. Probably he knew yo-yo playing very well but nothing about physics. The yo-yo is a toy for him but not a physics toy. But for us physicists that yo-yo is a physics toy.

The man on the other side appears to be a physicist. Probably he doesn't know how to skillfully play with a yo-yo. The equation in the balloon describes correctly the movement of a yo-yo.[1] This is a short example how it depends upon the point of view what is a physics toy.

Fig. 1. On the left side a greek man plays yo-yo. This is an image from an old vase decoration (450 B. C; Antikenmuseum Berlin). On the right side a physicist plays yo-yo.

A famous picture shows Pauli and Bohr looking amusedly at a **tippe-top**.[2] We do not know whether they have discussed the physics of the tippe-top. There exists no publication from them about this toy. But the tippe-top has interested many physicists for more than hundred years. It was patented in Germany 1890 by a woman who was not a physicist.[3] Surely there are patents for the same toy in other countries too.

There are many publications about the tippe-top. In the last year there appeared at least four more or less complicated articles and as far as I know, there is no simple explanation for the behaviour of the tippe-top. You have to dive deeply into theoretical physics.

I would like to present one more example of a physics toy. The famous **Celt** (Rattleback, Wobblestone) is another toy that has interested physicists for a long time. The first scientific paper on it appeared in 1896 by G.T. Walker.[4] Ninety years later Hermann Bondi[5] dedicated an article to the Celt. He seems to be convinced to have explained the behaviour completely. Possibly. But until today I personally don't know anybody who has read and understood that article fully.

You can create very simply and quickly your own Celt (Fig. 2). But do so discretely, especially in restaurants or cafeterias. Take a spoon and bend the stem back so that it lies unsymmetrically over the spoon (off center). Now you have a Celt. The axis of the elliptical body of the spoon has a small angle with the direction of the stem and this is the reason for the strange behaviour of the Celts.

published in the Proceedings of the Conference: „Teaching the Science of Condensed Matter and new Materials“, UDINE, Italy, 24.-30. August 1995, FORUM, Editrice Universitaria Udinense, via Palladio, 8, 33100 Udine, Italy 1996, page 437-441

I have presented now two well-known toys that are difficult to understand. For many interesting cases it is difficult to find explanations that are satisfactory. For that purpose I have created a database[6] where I have collected all publications that I could find and that deal with physics toys: books, papers in journals, patents etc. I am always looking for collaborators to support this database especially to enlarge the English part. If somebody is interested please contact me.

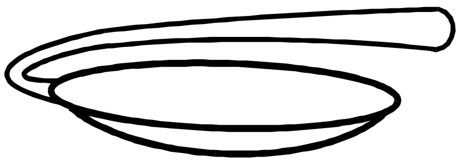

Fig. 2. With a spoon you can create very simply your own Celt. It will even return upon rotation in both directions.

The next toy is also a mechanical one: the so-called **Wobbler** or Two-Disk-Roller. It seems to be a very simple toy, but there are interesting physics and mathematics involved. Let me describe the problem. If a homogeneous sphere rolls down a plane, the distance between the center of gravity and the plane remains constant. The same is valid for cylinders. There are other objects with the same behaviour, for instance two elliptical disks cut out of a cylinder as it is evident in Fig. 3. The path of the center of gravity for these examples describes a straight line.

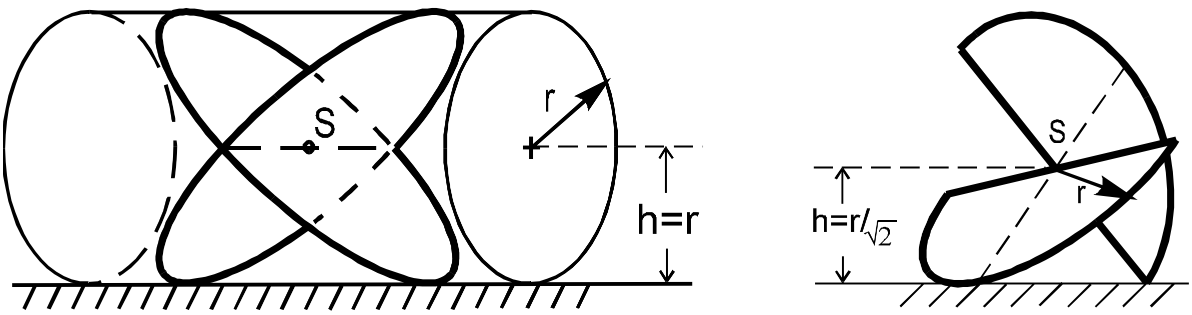

Fig. 3. The center of two elliptical disks cut out of a cylinder holds a constant distance from the plane when rolling down an inclined plane. The same is valid for two half circular disks interlocked perpendicularly.

And the next example is also quite clear. It consists of two half circles interlocked perpendicularly. When descending down an inclined plane, the center of gravity holds a constant distance to the plane's surface but wobbles left and right across the path. The line of the center of gravity is a composition of parts of circles as you can see in Fig. 6.

The Swiss artist Rolf Hergert has produced with this principle a nice object named Go-On (Fig. 4). It is made of a special, quite new plastic material that is normally used for decoration purposes. But it also has interesting physics properties like collecting light on the plane surface and emitting it from the boundaries.

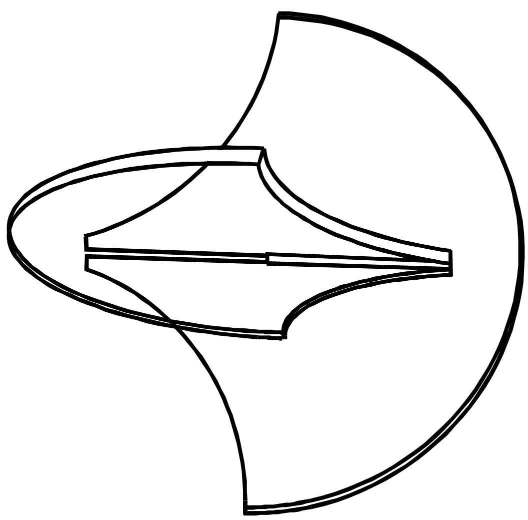

Fig. 4. A Swiss artist has created an disk-roller called “Go-On”. It is based on the principle that two half circles are connected perpendicular.

Now I want to go a step farther. What happens if you interlock two complete circle-disks perpendicularly? You can do this in practice with a radial notch in each disk. You

published in the Proceedings of the Conference: „Teaching the Science of Condensed Matter and new Materials", UDINE, Italy, 24.-30. August 1995, FORUM, Editrice Universitaria Udinense, via Palladio, 8, 33100 Udine, Italy 1996, page 437-441

get a Wobbler that looks like the one in Fig.5.

If the distance of the centers of the two circles fulfils the condition as it is written in the figure caption - and only then - the center of gravity remains at constant height.

When this wobbler rolls on a plane, it executes a fascinating wobbly motion. The curve of the center of gravity (Fig. 6) seems to have a very similar form as the first wobbler with the half-circles. But it has not yet been solved what the analytical form for the curve exactly is or whether there exists at all a closed mathematical solution for that curve.

The principle behind the wobbler is realized in several toys. I show here first the Finnish toy Ensihammas (Fig. 7) for children. The wobbling motion seems to fascinate even small children.

With a construction kit (Fig. 8; available in several countries) you can very easily put together a wobbler that fits almost exactly the required mathematical condition. I have asked a manufacturing company in Germany about this and they told me that they had not intended this behaviour and that they had not known of this condition.

One can go further and ask whether there are other Two-Disk-Rollers that hold the condition that the center of gravity remains at constant height. The answer is yes, and in fact there is an endless variation of wobblers. In a publication which recently appeared in a German educational physics journal, I proved the condition for elliptical disks and showed the way how to construct other forms.[7] I had written this paper with a student of physics who is very interested in the topic and still invents new wobblers.

As the wobbler rolls down a plane, it touches the plane always at two contact points. When you

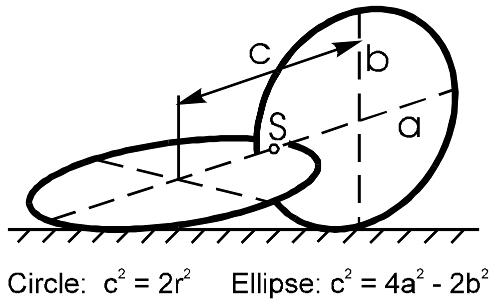

Fig. 5. Two complete circular disks connected perpendicularly form another type of wobbler. If the distance c between the centers fulfils the above condition, the center of gravity S holds a constant distance from the plane. This is also valid for ellipses with the above condition (a = big axis; b = short axis).

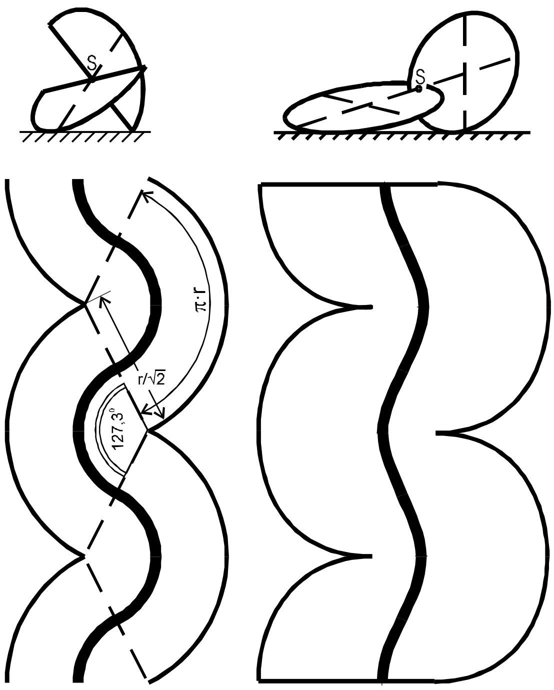

Fig. 6. Curves of the center of gravity of different wobbler types.

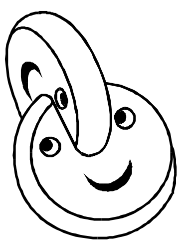

Fig. 7. A Finnish children's toy is made out of two circular disks.

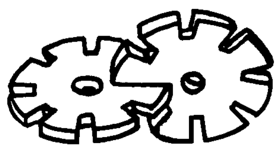

Fig. 8. With a construction kit one can build also a two-circle-roller.

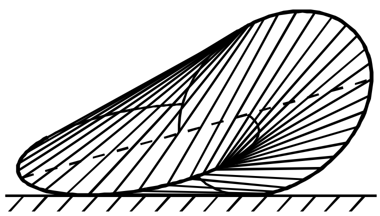

Fig. 9. When one connects all contact points, one gets the convex hull of the wobbler.

published in the Proceedings of the Conference: „Teaching the Science of Condensed Matter and new Materials“, UDINE, Italy, 24.-30. August 1995, FORUM, Editrice Universitaria Udinense, via Palladio, 8, 33100 Udine, Italy 1996, page 437-441

connect all the corresponding contact points, you get a convex hull as in Fig. 9. This is a nice and aesthetical body and it is made also as a toy.

I believe that this simple toy has to do a lot with mathematics and physics and that means with science. And since there are even unsolved problems, it remains interesting.

The next toy is a magnetic game, called **Turn-Over** or Up-Side-Down (Fig. 10). It consists of small magnetic discs. One side of each magnet is green and the other red. Each one is enclosed in a small plastic container in which the magnet can just turn over. There are two possible orientations for each magnet: either the red or the green surface. Because the discs are magnetic they can influence their neighbours. Physicists say of course that they are coupled. When one tries to turn over all the magnets to the same colour with the help of a bar magnet, one will notice the coupling of the magnets. If you have successfully turned over perhaps three or four magnets to the same colour - this means you have created a small domain - a slight movement will cause the other magnets to turn again and destroy your domain of one colour.

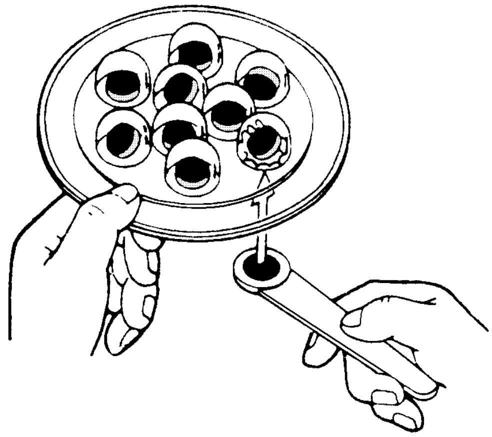

Fig. 10. The magnetic game Turn-Over can serve as a model for the Ising-Model of ferromagnetism.

This small game can serve as a modest model for ferromagnetism - especially for the Ising-Model. This model describes the ferromagnetism as a lattice of coupled elementary magnets with a spin up or spin down. But of course this game should not be overinterpreted. Even without physics this game is still an entertaining puzzle.

A highly interesting toy is the so-called **Levitron**. That is a magnetic top that floats freely and stably in the air over a special magnetic base. Inside the wooden base is a big permanent ring magnet with the south pole up (Fig.11). The top itself has a magnetic dipole in the axis of the big ring magnet with the south pole facing downwards so they repel each other. The magnets are strong enough to allow levitation. Normally a dipole in the inhomogeneous field of another magnet will turn over. But here it cannot turn over because gyroscopic rigidity prevents this. Instead the axis of the top precesses. The top will not flip and continues to float as long as it rotates quickly enough.

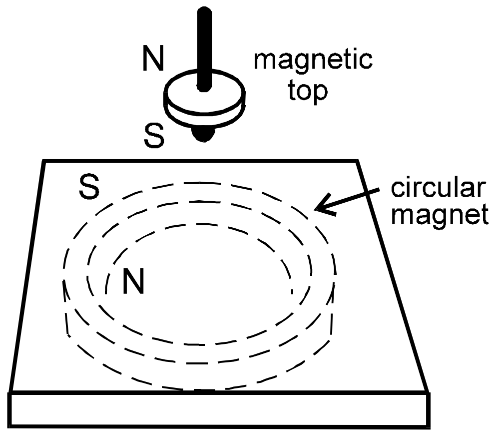

Fig. 11. Setup of a magnetic dipole top supported by a ring magnet.

The rotation of the top is the reason why the Levitron does not violate Earnshaw's theorem.[8] This theorem states that it is not possible to have stable equilibrium in a system with only inverse-square-law electrostatic or magnetostatic forces.

There are some other reasons why the top can stably levitate.[9] For levitation to occur, the lines of constant potential must form a valley. If you compute the lines of constant potential of two dipoles you get a picture like in Fig. 12, where in the middle there is a point where there is a valley. In the case of a ring magnet you get a well and the top can spin stably in the bottom of this potential well.

published in the Proceedings of the Conference: „Teaching the Science of Condensed Matter and new Materials“, UDINE, Italy, 24.-30. August 1995, FORUM, Editrice Universitaria Udinense, via Palladio, 8, 33100 Udine, Italy 1996, page 437-441

How it is possible to stably levitate a body? There are many possibilities in physics with superconductors (expensive), with normal diamagnetic materials (only with a few grams) and with eddy currents in electromagnetic fields (difficult).

There is another possibility with controlled electromagnetic fields. An example is called the **Levitator** and sometimes Abrakadabra. But it is sold as a design lamp, not as a toy. Physicists will like to play with it.

A schematic view (Fig. 13) shows the principle of the controlling system of the Levitator. The distance between the sphere and the magnet (coil) is measured with a position detector. This consists of a light beam created by an emitter and opposite to it is a receiver with the sphere in the middle.

If the sphere goes down a little bit, more light hits the receiver and with the help of an electronic circuit the coil will get more current and attract the sphere and so on.

One can disturb the controlling system by illuminating the receiver directly with a light source such as a laserpointer. As a result, the current in the coil will be amplified and the sphere attracted.

This sort of levitation with controlled electromagnetic fields has an enormous importance in certain technical systems nowadays.

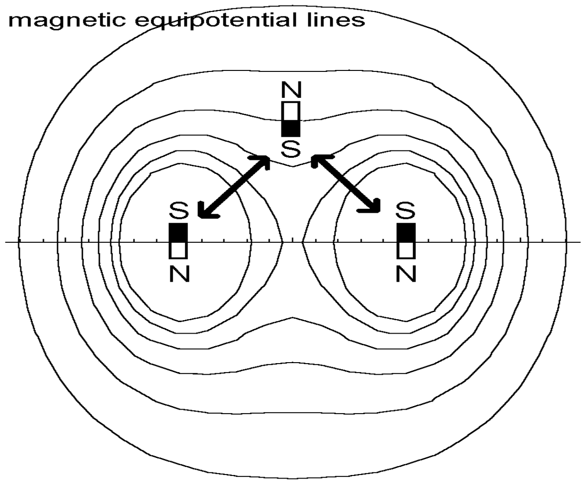

Fig. 12. Magnetic equipotential lines of a ring magnet form a valley respectively a well. The rotating top can float stably in that well.

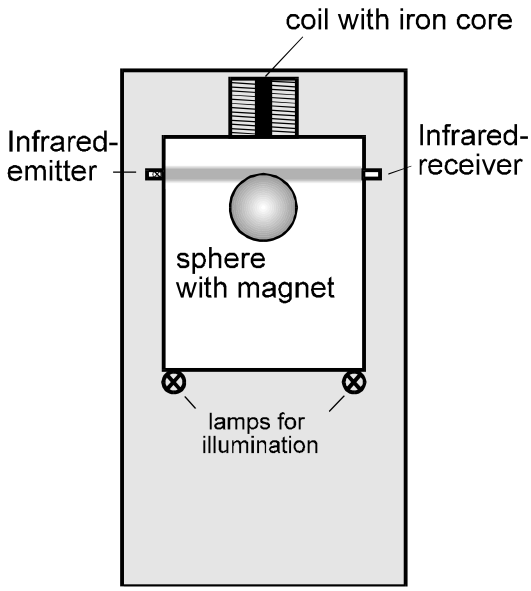

Fig. 13. Schematic view of the lamp ‘LEVITATOR’. The sphere with the magnet inside floats freely and is controlled by a position detector.

published in the Proceedings of the Conference: „Teaching the Science of Condensed Matter and new Materials“, UDINE, Italy, 24.-30. August 1995, FORUM, Editrice Universitaria Udinense, via Palladio, 8, 33100 Udine, Italy 1996, page 437-441

[1]Wolfgang Bürger, “Das Jojo - ein physikalisches Spielzeug”, Physikalische Blätter **39**, 401-404 (1983).

[2]For copyright reasons the picture is not shown here. See for example R. J. Cohen, “The tippe top revisited”, Am. J. Phys. **45**, 12-17 (1977).

[3]Helene Sperl, “Wendekreisel”, Patentschrift No. 63261 vom 7. October 1891, Kaiserliches Patentamt.

[4]G. T. Walker, “On a dynamical top”, Quarterly Journal of Pure and Applied Mathematics **28**, 175-184 (1896).

[5]Hermann Bondi, “The rigid body dynamics of unidirectional spin”, Proc. R. Soc. Lond. A **405**, 265-274 (1986).

[6]One can download the database 'PHYSICSTOYS' via FTP.

Choose from your computer:	ftp.e20.physik.tu-muenchen.de
Username:	anonymous
Password:	your own e-mail-address

With the command "cd pub" go to the subdirectory pub. There you find the subdirectory "physicstoys". In this directory you can see a file (LITPHYS.TXT). This ASCII-text-file contains all the data sets (about 800, 350kB as of August 1995) with authors alphabetically put in order. There are other files you can try to read directly into database programs like Approach (LOTUS), dBase, Oracle etc.

To transfer files first type the command "bin" (for binary)

With the command "get" and the name of the file you can transfer the files. *e.g.* "get litphys.txt" will transfer the file litphys.txt.

With the command "quit" you leave ftp.

Sometimes (during normal working hours in Germany, whatever that means for physicists) it is difficult to get a connection to the FTP-Server of the physics institute.

The database is half german, half english.

[7]C. Engelhardt, C. Ucke, “Zwei-Scheiben-Roller”, Mathematisch-Naturwissenschaftlicher Unterricht **48**, 259-263 (1995).

[8]Samuel Earnshaw, “On the Nature of the Molecular Forces which regulate the Constitution of the Luminiferous Ether”, Transactions of the Cambridge Philosophical Society **7**, 97-112 (1842).

[9]Ron Edge, “Levitation Using Only Permanent Magnets”, Physics Teacher **33**, 252-253 (1995).