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This is a slightly enlarged version

Fun with household objects and centre of mass

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Some aesthetic household objects deal in a playful way with the use of centre of mass. One salt shaker behaves like a balancing toy, while another wobbles on the table; a special bowl inclines more the less it is filled. Wine bottle holders use the moment of force in a tricky way.

Salt and pepper shakers as balancing toys

Salt and pepper shakers have always been favoured objects for designers. They should be stable, but, if they do turn over, the content should not disperse. The concept of the balancing toy weeble or skip jack comes quickly to mind. The Italian designer Maurizio Duranti, among others, had this idea and created salt and pepper shakers with the name of 'Ercolino', meaning "accident-proof" (figure 1) [1]. A look into the interior shows the function.

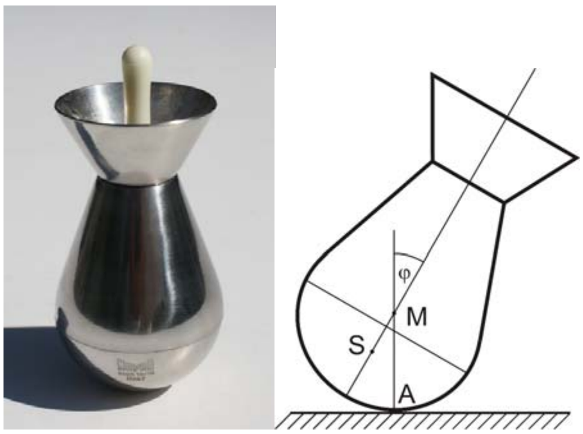

fig.1: Balancing salt shaker Ercolino

The object's centre of mass S, whether full or empty, is located considerably under the centre M of the bottom part of the sphere. If inclining the shaker therefore results in a reverse moment of force which returns the shaker to a standing position. Balancing toys demonstrate principles of classical physics.

Physicists love to experiment, even at the table – not always delighting their all their neighbours. But surprising results can be discovered. If the – empty – saltshaker is released at only a small angle φ from the stable position, it will oscillate at a period of about one second. If it is released at a great angle, the result is a considerably greater period of about two seconds. Similar to the classical string pendulum, the period is no longer independent of the deflection angle. The problem becomes non-linear and therefore complicated, even for such an apparently simple object. In addition, the salt shaker does not oscillate near one point but instead rolls on the surface of the bottom sphere, therefore also changing the moment of inertia with regard to the deflection angle φ.

Even at small deflection angles, the filled salt shaker has greater oscillation periods because the centre of mass approaches the centre of the bottom sphere, thus decreasing the reverse moment of force.

Even physicists who enjoy playing at the table should not try to spin the salt shaker on its symmetry axis like a top. The resulting rotation will be instable, and the salt shaker will start to spin around an axis perpendicular to the symmetry axis, ejecting the contents of the shaker.

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Salt and pepper shakers as wobblers

The salt and pepper shaker set Doublette [2] is based on a completely different principle of stabilisation. Created by the German designer Alexander Schenk and manufactured in massive cast zinc (figure 2), it is explicitly described as a toy and an object with a nice, smooth feeling in your hand, making it obvious that the designer had more in mind than mere practical household use.

fig.2: Salt-/pepper shaker Doublette

Doublette consists of two parts held together by magnets (figure 2, lower section). If the entire object is tipped just a little, it wobbles to and fro without rolling away. When pushed harder, it does roll a bit – not optimal behaviour for such an object because it could fall off the table and discharge its contents.

Due to its shape, this set of shakers belongs to a class of objects whose simplest version was described by A.T. Stewart in 1966 [3]. If two circular or elliptical discs are connected perpendicularly (figure 3), the principle of the basic structure of the shaker can be discovered. The distance between the centre of mass S and the surface beneath remains constant during the rolling only when the distance c between the two centres of these discs fulfils the condition $c = \sqrt{4a^2 - 2b^2}$ [4]. Circular discs with a = b = r result in an even simpler $c = r\sqrt{2}$. The ideal two-disc-roller then wobbles very easily over a slightly inclined plane, e.g. a lop-sided table. The centre of mass describes a sinus-like trajectory parallel to the surface beneath it.

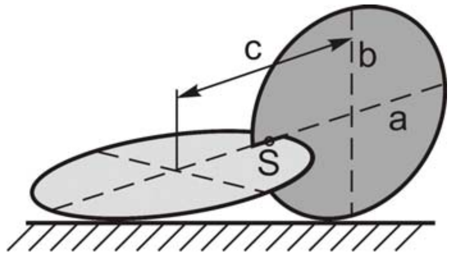

fig.3: Two-disc-roller

Fortunately, the Doublette does not fulfil the condition mentioned above (here is c ≈ 2r; r = 28.6 mm). An interview with the designer revealed that he did not know the mathematical formula but was, however, aware of the up and down movement of the centre of mass and the resulting wobbling. In the case of the Doublette, the deviation of the centre of mass during the rolling is relatively small (≈ 6 mm), so it does occasionally roll off the table.

Drinking bowl Balance

The stainless steel drinking bowl 'Balance' by the German designer Katja Hoeltermann is a very special vessel [5]. When the bowl is empty, it has an inclination of about 23° (figure 4). When full of water or wine, it stands upright. The difference in density between water and wine is not very relevant and can be equalised through more or less liquid.

The bowl appears to be made of solid stainless steel, but measurement of the mass (m = 153 g) and the displaced volume of the empty vessel (V = 75 cm^3) results in a density of ρ = m/V ≈ 2.0 g/cm^3.

fig.4: The drinking cup Balance; full in the foreground, empty in the background.

Stainless steel, however, has a density of about $\rho = 7.9\,g/cm^3$, so the bowl must be hollow.

A cross section through the vessel shows its exact construction (figure 5). The stainless steel is a sheet with a thickness of about 0.7 mm. The thickness of the lines in figure 5 is true to scale to the thickness of the sheet and the whole vessel. M_1 is the centre of the outer spherical cap, M_2 that of the inner spherical cap and A the optimal position of the filled vessel. The centre of mass of the entire, empty vessel should, therefore, be to the right of the line between M_1 and A (the small upper border is irrelevant), and the empty vessel should actually incline to the right. This is not what happens and cannot be the intention of the designer, because, in this case, filling the bowl with liquid would make it incline even more to the right. To prevent this, a hidden mass G has been added to the cavity on the left to assure that the centre of mass of an empty bowl inclined at an angle of less than 23° is shifted to a line 23° away from M_1 (blue cross).

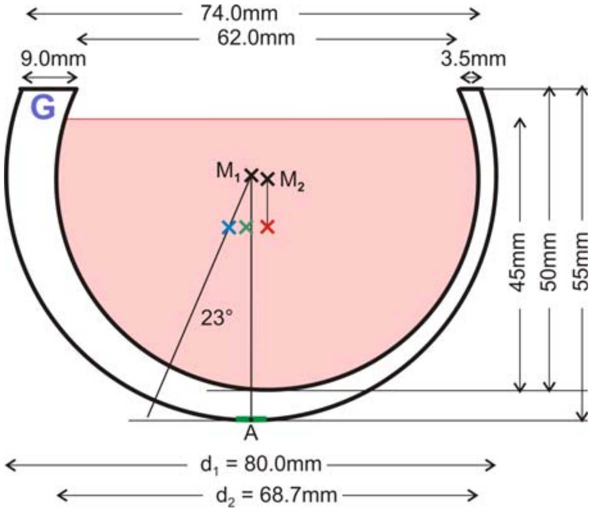

fig.5: Position of the centres of mass of the empty and filled Balance bowl

With enough water or wine in the bowl, the total centre of mass of the liquid and vessel (green cross) shifts to the ideal line between M_1 and A directly vertical to M_1. Then the vessel is in an upright position. The centre of mass of the liquid is marked with a red cross and is dependent upon the level of the liquid.

Calculation of all the individual and total centres of mass mentioned demands several measurements and some reflection. This is an attractive project for students (see the file 'Reflections on the Balance bowl' under www.ucke.de/christian/physik/ftp/lectures/balance.pdf).

A small trick enhances the stability of the filled vessel. The lower pole of the spherical vessel has been flattened by about 0.2 mm. This is not visible at a diameter of 80 mm but can be felt with your fingertips. This small, flat base (green line in figure 5) guarantees an upright position even with deviations in the ideal level of liquid.

Bottle holder

There is a great variety of holders for wine bottles. At least two of these have an interesting physics background. The bottle holder in the upper section of figure 6 demands a relatively precise positioning of the bottle in the holder because the centre of mass of bottle and holder must be located exactly above the small supporting area. The light and floating balance of this wobbly object creates astonishment.

From the standpoint of physics and practical handling, the bottle holder in the bottom section of figure 6 is much more sensible [6]. The drawing in figure 7 shows the individual centres of mass of the bottle

fig.6: Two systems of wine bottle holders

holder S_H (blue cross) and bottle S_F (red cross). Since the total centre of mass of the complete system S_G (green cross) is located under the centre M of the outer circle of the bottle holder, a reverse stabilising moment of force results when the bottle and holder are inclined, for example by pressing the bottle down. The holder inclines to stabilise itself according to the mass of whichever bottle is used

It is interesting to see that it is mainly the less practical bottle holders in the upper section of figure 6 that can be found by surfers in the internet.

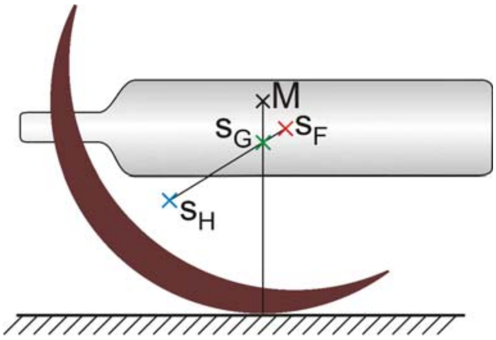

fig.7: Wine bottle holder.
M is the centre of the outer circle of the bottle holder, S_F is the centre of mass of the bottle, S_H the centre of mass of the bottle holder and S_G the centre of mass of the system bottle and holder.

References:

[1] www.mepra.it, *see also* www.silit.de *and google with 'philippi humpty dumpty'*
[2] www.berendsohn.de *and* http://www.grand-illusions.com/acatalog/Wobbler.html
[3] Stewart, A.T.: Two-Circle Roller, American Journal of Physics **34** (1966), 166
[4] Engelhardt, Chr., Ucke, C.: Zwei-Scheiben-Roller, Mathematisch-Naturwissenschaftlicher Unterricht) **48**/5 (1995), 259-263
English: www.ucke.de/christian/physik/ftp/lectures/Wobb3e_2003.pdf
[5] www.carl-mertens.com *google with 'Balance Drinking Bowl'*
[6] www.silkwoodtraders.com

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centre of mass, salt-shaker, balancing toy, two-disc-roller, wobbler, Balance drinking bowl, wine bottle holder

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Christian Ucke (left) and Hans-Joachim Schlichting are the founders of the column 'playground' in the German journal 'Physik in unserer Zeit'.

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