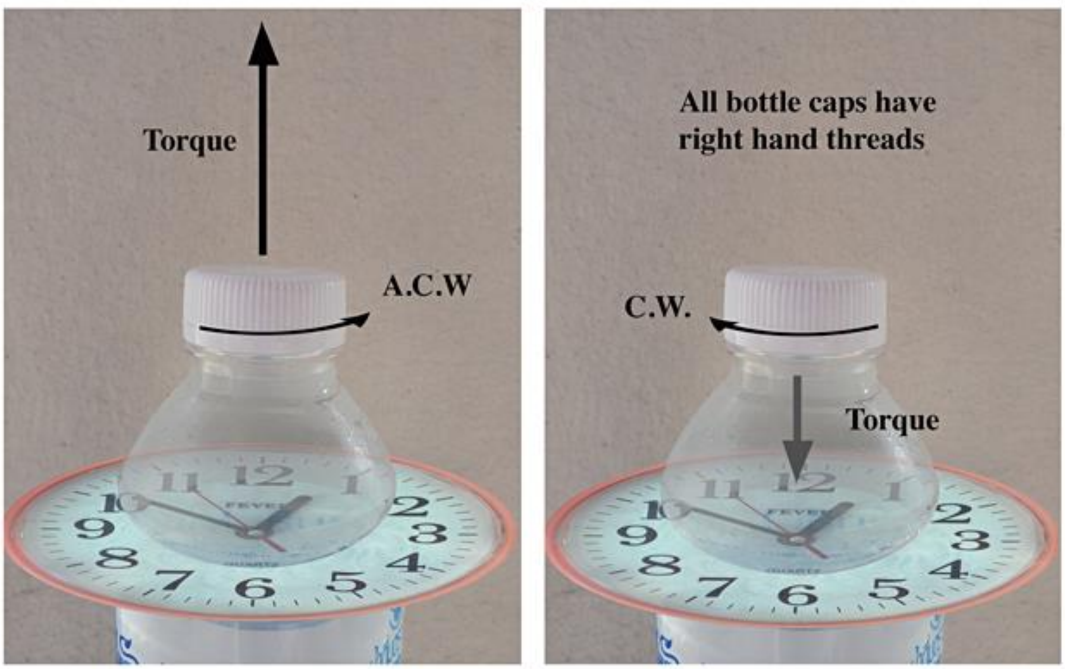
Torque

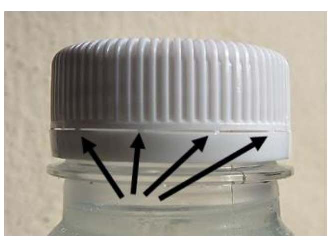
Definitions

Millions of water bottles have tops with right-hand threads. *Turn anticlockwise to remove*. A three year old knows that.

The tangential force *f* applied to the cap times the radius *r* is defined as torque. The direction is clockwise or anticlockwise. Because torque has magnitude and direction we define a torque vector (*in simple terms without using the cross product*) as being along the axis of rotation in the direction of travel of a right hand screw.



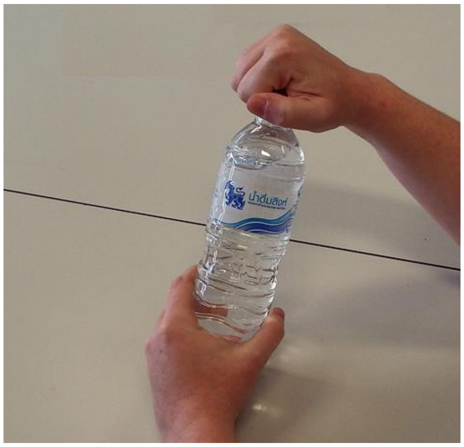
As the cap is taken off the torque vector is vertical (outside the bottle). As the cap is replaced the torque vector is reversed (inside the bottle).

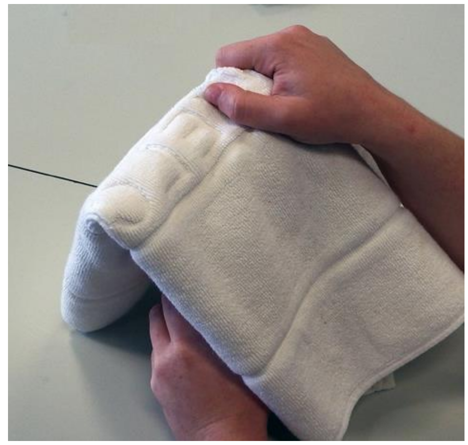


The initial torque required to remove the cap is large because the tags must be broken.

1 Water bottles

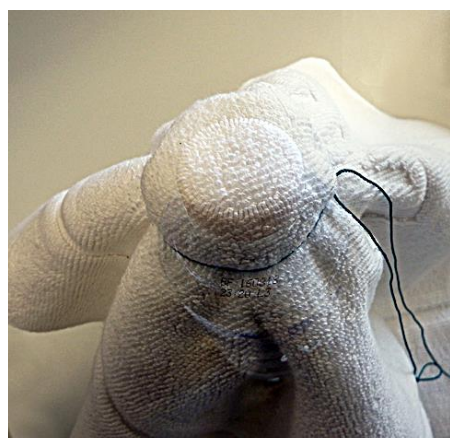
Some people, older people and children mostly, have trouble opening water bottles. One trick that works is to cover the top with a thick towel.





We asked M4 (advanced class) why this works. They said *friction*. They *all* said friction. The vote was 47 to nobody. To be fair, most people rightly think friction has something to do with it, and the writer remembers thinking it was all about friction when he was in M4, but friction between the towel and plastic is less than between skin and plastic.

The problem is not that grandma can't grip the cap. The problem is that she can't apply enough torque. The solution is to increase the radius. The same tangential force applied to a disc of twice the radius gives twice the torque.



For demonstration we use a double thickness of toweling floor-mat. The right hand image shows the increase in radius.

2 Screwdrivers

Fat handles allow enough torque to be applied by hand to turn a large screw in soft wood.

The screw driver below has a hole in the handle and the blade is broken.

The two unusual things are linked.

The hole is for inserting another screwdriver so more torque to be applied by hand, and greatly increased torque broke the blade.

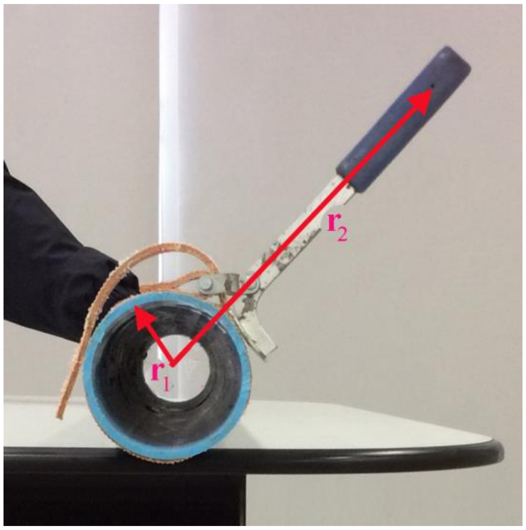
3 Screwcaps

Older people have trouble opening taps that grandchildren have closed. They have the same trouble with screwcaps.

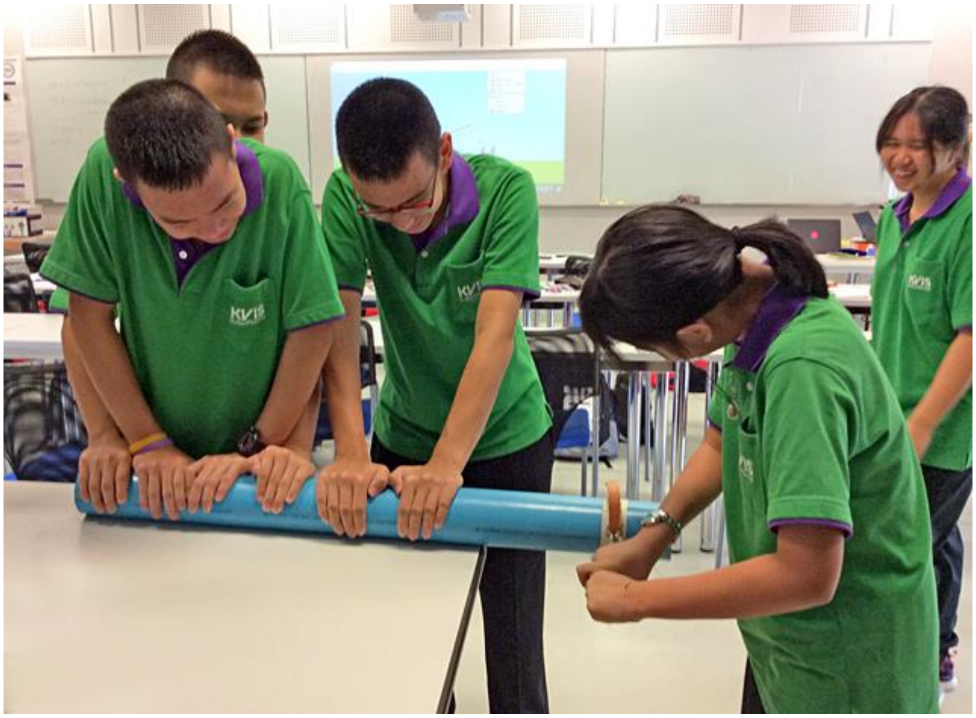
The tool with the serrated inner edge makes things easier.

For demonstration we have the largest boy screw the cap on and the smallest girl take it off.

A leather strap and a lever do the same job. For demonstration we use a pipe. The leather strap grips the pipe on a layer of masking tape and the lever multiplies the torque for a given force perpendicular to the handle by about five times.



The girl turns the pipe against the combined grip of three boys.



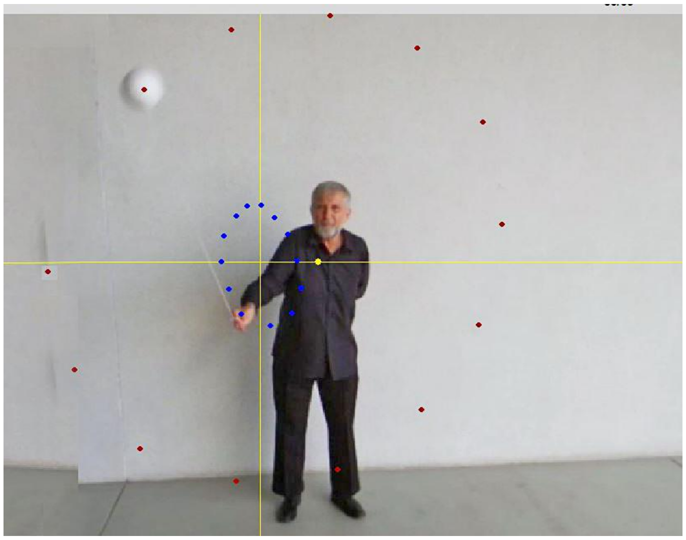
She can just turn the pipe against four sets of hands, but five sets lock it in place and make rotation impossible.

4 Prayer wheels

A prayer-wheel turns when we rotate the handle.

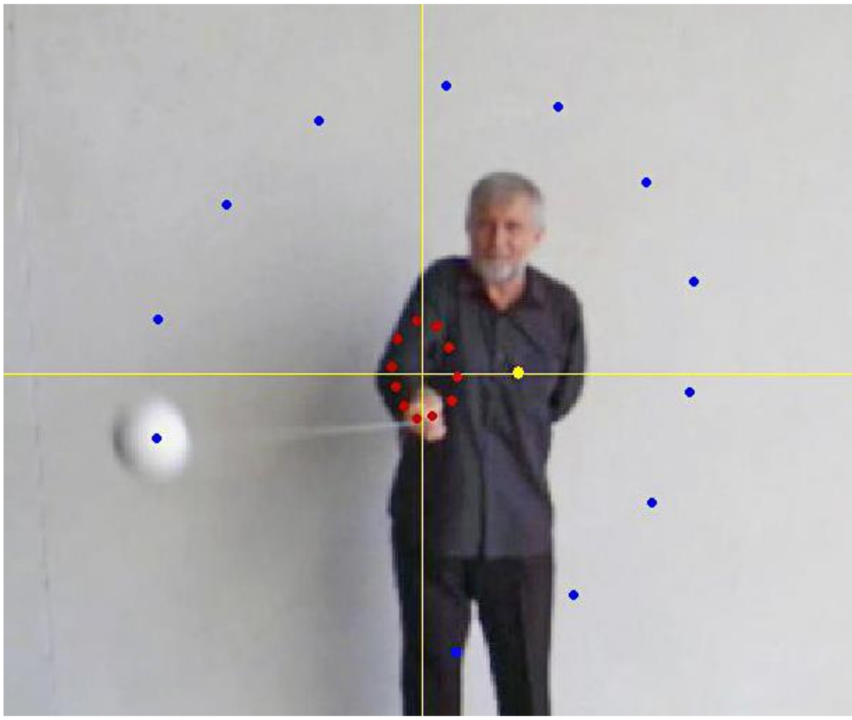
Could you draw a vector diagram and explain where the torque to drive the wheel against friction comes from?

To make things more obvious we swing a large light ball on a string, take video, insert the video into Logger Pro, and plot positions for the hand and the ball.

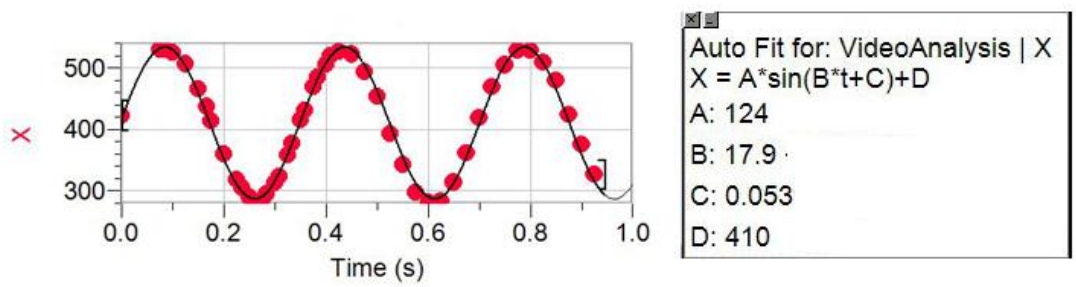


The hand leads the ball by about 80°. The paths are elliptical (or nearly so) because the motion is vertical and affected by gravity.

Swinging the ball faster on a shorter string improves the approximation to circular motion at constant speed.

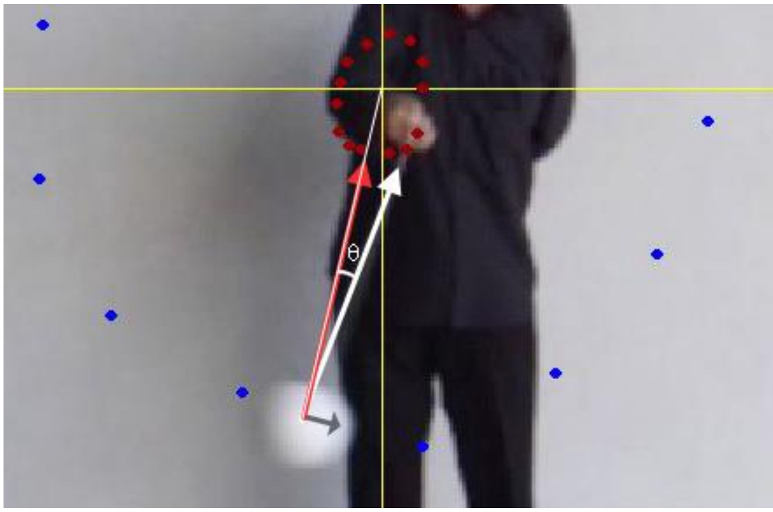


The average radius of the near circular motion of the ball is 60 cm, the mass is 16.5 g and the angular frequency, found by plotting the horizontal displacement is 18 rad/s.



Notice again that the hand leads the ball by a phase angle of around 80°. The single unbalanced force on the ball is due to tension in the string *T*. That force is not directed towards the centre of the circular motion.

A vector diagram has been drawn over the completed analysis in Logger Pro.



The centripetal force f (red arrow) for circular motion at constant speed is $mr\omega^2$. Substituting values for m, r, and ω gives f = 3.20 N. The angle between the radial force and the tension in the string is measured as 7.4°. The tension force can be resolved into two components, the centripetal force f and a tangential force opposing air resistance. The tension in the string in this case must be 3.23 N. The force opposing the drag due to air resistance is 0.42 N. Multiplying this force by the radius gives the torque applied to the motion as 0.24 Nm. The values are approximate, but they serve to identify the source of the torque applied to the motion.

To answer the question …

The circular motion of the handle leads the motion of the swinging mass by a phase angle of close to 80°. The tangential component of the inward force due to tension in the chain applies torque to the prayer-wheel to overcome friction.