Torque

So far the explanation of forces and motion has treated objects as if they are a single point, or as if the force acts through the middle of the object; that is, its centre of mass. However, nature is more complicated than this. Friction acts at the rim of the front tyre of a bike to make it roll, the thigh muscle straightens the leg, a billiard cue hits the bottom edge of a ball to make it spin backwards, the wind blows over a tree, a pull on a handle opens the door. All these actions involve rotation, and a force has made the object turn.
The turning effect of a force is called a torque. The symbol for torque is τ, the Greek letter *tau*.

The size of a torque about a point or pivot is determined by the product of two factors:

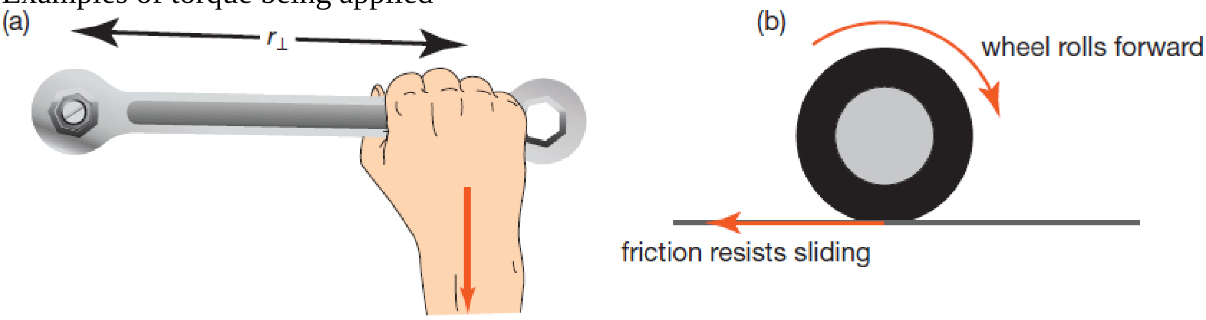
- the size of the force, $\boldsymbol{F}$, and
- the perpendicular distance between the line of action of the force and the pivot, $r_{\perp}$.
  $\tau = r_{\perp}\boldsymbol{F}$

Also, and it is often more convenient to solve the problems torque can be found using the formula $\tau = \boldsymbol{F}_{\perp} r$, where r is a lever arm (distance from the point of force application) and $\boldsymbol{F}_{\perp}$ is the resolution of the force perpendicular to the lever arm.

As a product of force and distance, torque has the units of Newton metre (Nm).

It is also a vector, but because its effect is rotation, the direction of the vector is set by a rule. The rule is: 'If the rotation in the plane of the page is clockwise, the direction of the vector is into the page.'

Examples of torque being applied



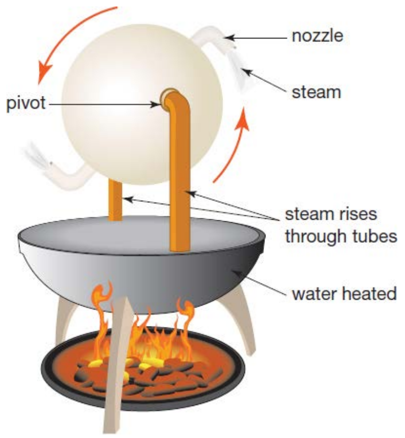
Equilibrium or keeping still
Earlier in this topic, if the net force was zero and the object was at rest, it would stay still. The forces were considered as acting on a single point.

However, if the forces act at different points on the object, it is possible to have a net force of zero, but the object can still spin. In the diagram below, the force upwards equals the force downwards, so the net force is zero, but the sphere rotates. In this case there is a net torque. The torques of the two forces about the centre add together.

In cases such as car engines and electric motors, the production of a torque is essential for rotation and movement. But torque, and the rotation and movement it causes, can be detrimental. In bridges and buildings, the torque effect of a force can't be avoided, but needs to be controlled if the structure is to remain standing. Such structures need to be designed so that not only is the net force equal to zero, but the net torque is also zero, and importantly this is true about every point in the structure.

For a structure to be stable, two conditions need to apply:

1. net force = zero
2. net torque about any point = zero.



Strategy for solving problems involving torque

Questions regarding torque will often involve determining the value of two forces, so the solution will require generating two equations, which can then be solved simultaneously.

First, draw a diagram with all the forces acting on the structure. Label each force. If its size is given in the question, write the value, e.g. 10 N. If the size of the force is unknown, use a symbol such as ***F*** or ***R***.

1. Net force = zero. Choose axis and find resolution of all forces into the each axis which will be equal to 0.
2. Net torque about any point = zero.

Choose a point about which to calculate the torques. That should be point about which rotation can take place. The torque of the force acting at this point will be zero as its line of action passes through the point.

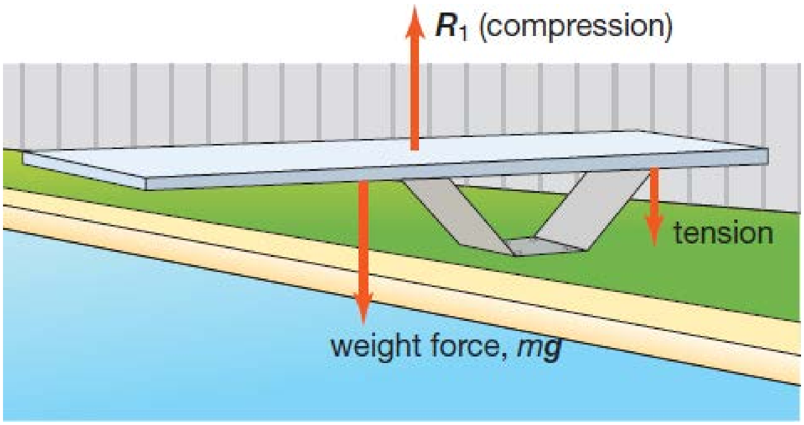
Sum of clockwise torques = Sum of anticlockwise torques.
Now you will have two equations with two unknowns; one equation from 2, above and one from 1.

Types of structures: cantilevers

A cantilever is a beam with one end free to move. A diving board, flagpole and a tree are examples of cantilevers.

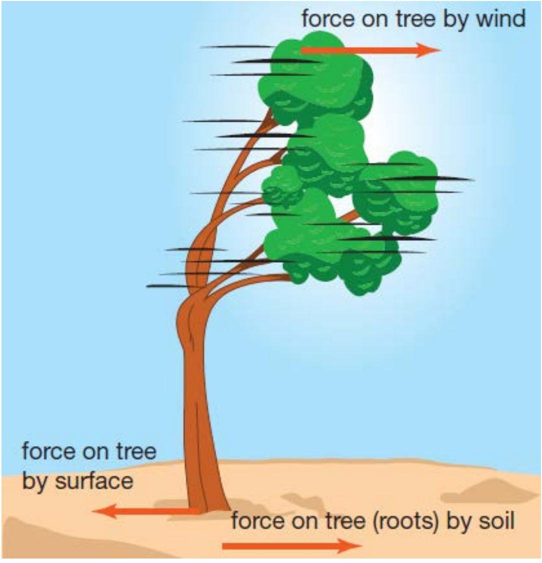
The diving board shown below is supported by an upward force, R_1, from the bracket. The weight force acts down through the middle of the board at a point further out. If these were the only forces on the diving board, the board would rotate anticlockwise. To prevent this rotation, the other end of the bracket pulls down on the diving board. The board is bolted to each end of the bracket.

At which end are the bolts not needed?



A diving board is an example of a cantilever.

The tree shown below is buffeted by winds from the left. The soil on the right at the base of the tree is compressed and pushes back to the left. The combination of these two forces pushes the roots of the tree to the left, and the soil to the left of the roots pushes back to the right.



A tree buffeted by winds is a cantilever.