

Torque

Just like a net force can change the momentum of an object, a net *torque* can change the angular momentum of an object. A torque is basically a rotational “push” or “pull”. So how do you generate a torque? Well, to generate a torque you need a force and a lever arm (see the reading on angular momentum to see what a lever arm is). The magnitude of the torque $\tau_{\text{something on obj}}$ generated by a force $F_{\text{something on obj}}$ is given by

$$\tau_{\text{something on obj}} = F_{\text{something on obj}, \perp} r$$

Here r is the magnitude of the lever arm and $F_{\text{something on obj}, \perp}$ is the component of the force perpendicular to the lever arm.

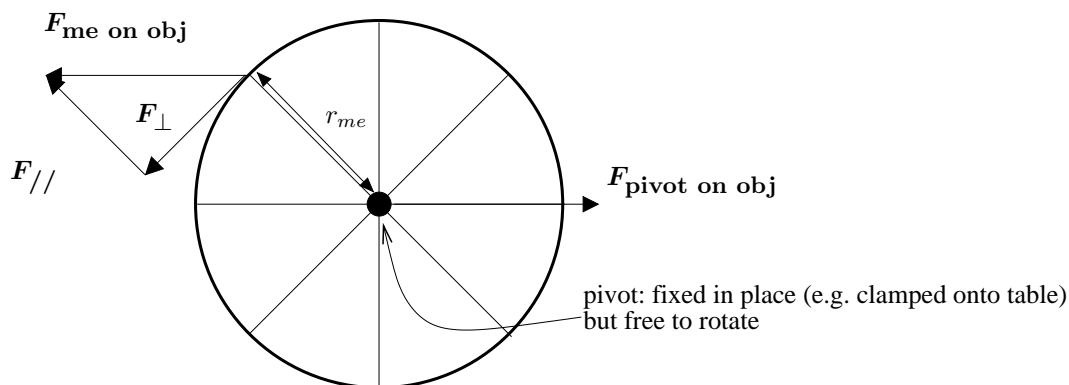
Because torque is a vector, we must also assign it a direction. The way we do this is ask ourselves “if this was the only force acting (except forces at the pivot to keep the wheel in place), which way would we rotate about the pivot?” Once we have a direction of rotation, we can use RHR # 1 to find the direction. The reason we choose to use the same rule as angular momentum is that if we apply a net torque $\tau_{\text{all on obj}}$ then the following relation holds:

$$\Delta L_{\text{obj}} = \tau_{\text{all on obj}} \Delta t$$

Just like for forces, strictly speaking this is the *average* net torque. But for small time intervals Δt the average torque is approximately the same instantaneous torque.

Example:

An example may demonstrate how to use the torque concept. Consider a wheel that is fixed at the centre. Because it is fixed there, we will choose this to be our pivot. Then apply a force at the outer edge of the wheel (we will neglect gravity):



There is a force on the pivot, which keeps the wheel from moving so the net force is still zero (this is the case if the wheel is clamped to the table, for example). Because this force is exerted *at* the pivot point, the lever arm is zero and so the torque from this force is zero.

However, the other force $F_{\text{me on obj}}$ has a non-zero lever arm. To see if it generates a torque, we need to break it into components parallel with the lever arm r_{me} and perpendicular to the lever arm r_{me} . It is the perpendicular component, $F_{\text{me } \perp \text{ on obj}}$ that generates the torque. This is the component labelled F_{\perp} in the diagram, as otherwise it would not fit. The amount of torque generated is thus

$$\tau_{\text{me on wheel}} = F_{\text{me } \perp \text{ on wheel}} r_{me}$$

To find the direction, the perpendicular component of force would try and turn the wheel counter-clockwise. Using RHR # 1 this tells us that the torque would be directed *out of the page*.

Torque algorithm

When given an object, we had an algorithm for making the force diagram:

- Include any contact forces

- Ask if we need to include gravity from any objects (does not need to touch!)
- Ask if we need to include electric or magnetic forces (Physics 7C)

Once we had done this, we were sure that we had included all the forces (although we may not know yet what directions or magnitudes they have; that takes a little more work!)

Is there a similar algorithm for torque? Yes! *Every* force also creates a torque, although in some cases the torque may be zero such as $\mathbf{F}_{\text{pivot on wheel}}$ from the previous example. So if we want to figure out the net torque, we must first be sure we include all the forces. Then, for each force we go through the following steps:

1. Draw the lever arm \mathbf{r} between where the force is applied and the pivot point.
2. Break that force up into a component parallel to the lever arm and perpendicular to the lever arm. Torque only relies on the component *perpendicular* to the lever arm F_{\perp} .
3. The magnitude of the torque for that force is then $\tau = F_{\perp} r$.
4. Find the direction using RHR #1.

After doing this for all the forces, we find all the torques. Add all the torques on an object together to find the net torque and then you are done!

Misunderstandings

Because torque and force are related, and they are both “pushes” or “pulls”, there are some common misconceptions about them. One is that they are somehow “the same”: if the net torque is zero then the net force must be zero. THIS IS WRONG! Instead:

- It is possible to have no net force and a net torque. See the previous spinning wheel example.
- It is possible to have no net torque but a net force. We see this often when we push something to get it to move but not rotate. Notice how this works well with two hands but not with one. See if you can work out why!
- It is true that every torque comes from a force. Therefore, if there are no external forces there are also no external torques.
- If there are external forces that cancel, this does not guarantee no net torque because the torque also depends on the place that the force is applied. (This actually repeats the first point, but in a slightly different way so that third point does not give the wrong impression).