Understanding Gears

Intuitively— Bicycle Experience

Understanding gears is easier if you have paid attention while riding a bicycle.

With a bicycle, if you have a big gear in front and a small gear in back, you pedal slowly and the back gear moves fast. This is because the front gear has more teeth than the back gear. 1 turn of the front gear = a lot of teeth = more than 1 turn of back gear. Ex. Front gear = 20 teeth, back gear = 10 teeth. For each turn of the front gear, the back gear turns twice. The opposite is also true: if the front gear is smaller than the back gear, the back gear turns slower.

But what about the exchange of force from the front to the back? Again from your bicycle experience, if the front gear is bigger than the back gear you know that you have to push hard to move the bike. You would never do this on a hill. It would be almost impossible to accelerate the bicycle up the hill this way. To get up the hill, you know you want a small gear in front and a big gear in back. Why? Read on...

Quantitative—How the Science Works

How this works is about torque and the transmission of force between the gears. First you need to know what torque is.

Torque

Force (*in N*)

Torque (*in Nm*) → $\tau = Fd\sin\theta$ ← Angle between force and the lever (*in °*)

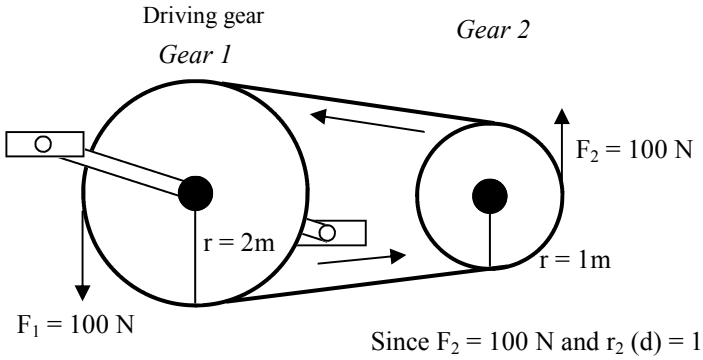
Distance from pivot to where the force is attached (*in m*)

Torque is a twist around an axle. Only the portion of the force perpendicular to the axle gives torque. In gears the force is always at an angle of 90°, so $\sin\theta = 1$ and can be ignored.

To make this easy, let's assume that the radius of gear 1 is double that of gear 2. And we'll make the math easy with giant gears of 2 m and 1 m radii.

On the same gear (pedals to gear 1), the torque is the same. Torque = Fd.

The force at the edge of the gear (at the chain) is transferred to the other gear by the chain. Since the force (tension) in a rope is assumed to be constant: $F_1 = F_2$.



If $F_1 = 100$ N and r_1 (d) = 2m
Then:
$\tau_1 = 100(2) =$ **200 Nm**

Since $F_2 = 100$ N and r_2 (d) = 1m then:
$\tau_2 = 100(1) =$ **100 Nm**

You have lost torque with this configuration. You would have to push twice as hard to get the same torque in gear 2!

BUT you have gained speed. Gear 2 turns twice as fast!!

It should then be obvious that by a smaller driving gear (small-to-big) increases torque, but decreases speed.