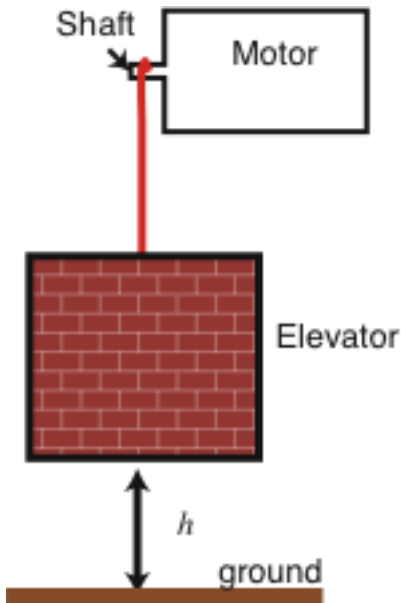


LEGO Mechanisms: Gears and Motors

A **motor** converts electrical energy into mechanical movement.



Try grabbing onto a spinning LEGO motor. Can you make it “stall”? Compare the behavior of the “old gray motor” and the “new gray motor”.

There is a:

“Stall Avoidance” vs. speed *tradeoff*

The concept of **tradeoffs** is one of the “big ideas” of engineering.

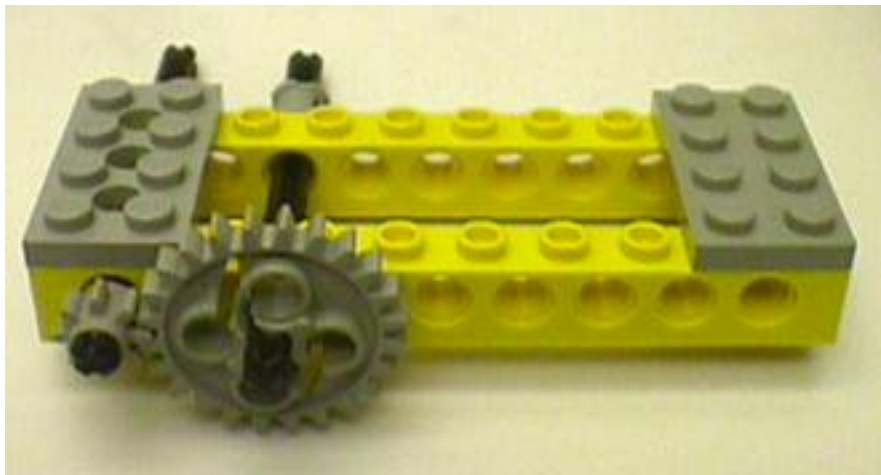
More technically: A given motor is capable of providing a certain maximum amount of **torque** before stalling. (“Torque” is a measure of the motor’s ability to cause an object to spin, much as “force” is a measure of ability to cause an object to move.) So when designing a motor there is a fundamental:

torque vs. speed *tradeoff*

Building a Gear Train

We can use **gears** to change the amount of torque supplied by a motor. (Inevitably the speed at which the output shaft spins will change as well.)

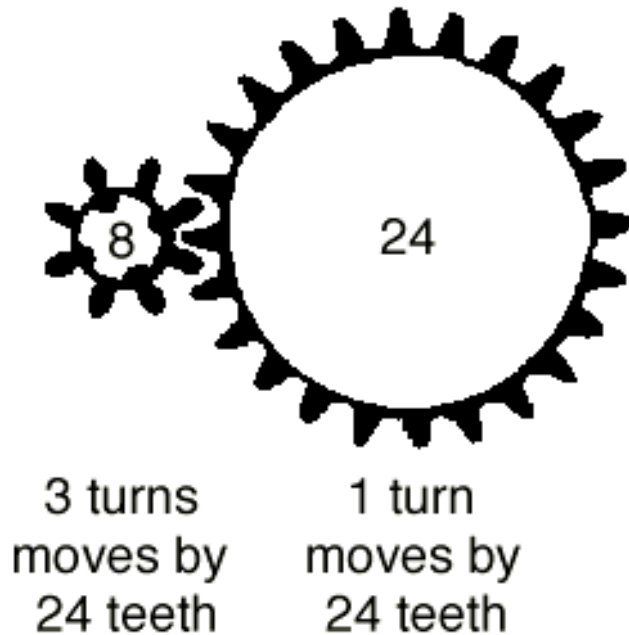
Use axles, beams, and gears to build a simple gear system using an 8-tooth gear and a 24-tooth gear:



Try rotating the shaft with the small gear with your fingers. Note that the relative rate of rotation of the two axles is different, by a factor of three, which is equal to the ratio of number of teeth on the gears (24:8).

Question: What's the difference between the old and new LEGO motors?

3 to 1 ratio

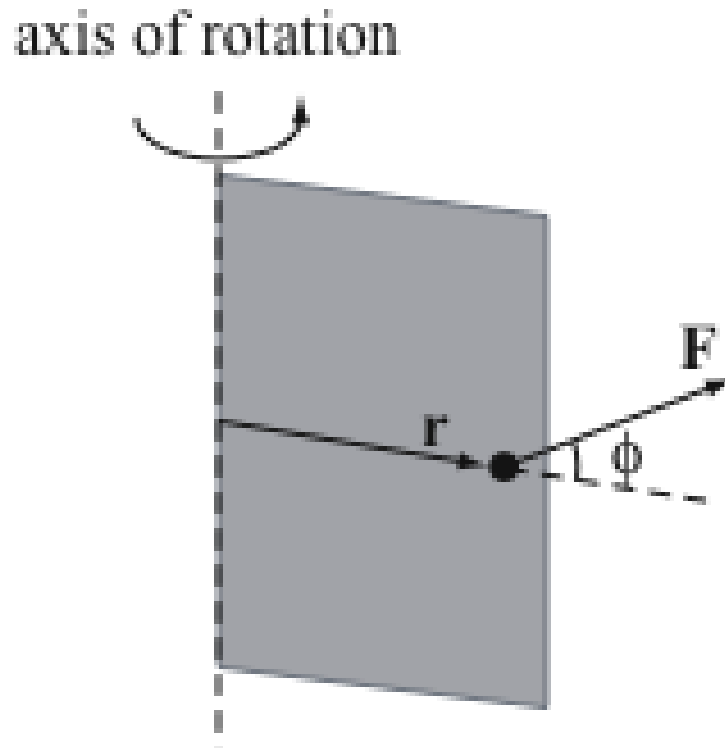


When the 8-tooth gear rotates 3 times, it advances the meshed gear by a total of 24 teeth. Since the meshed gear has a total, it rotates exactly once. (We say this configuration has a **3:1 gear ratio**.) Thus the 24-tooth gear rotates *three times slower* than the 8-tooth gear.

Going from small gears to big gears lowers the speed of rotation by a factor equal to the gear ratio.

Let's Talk About Torque

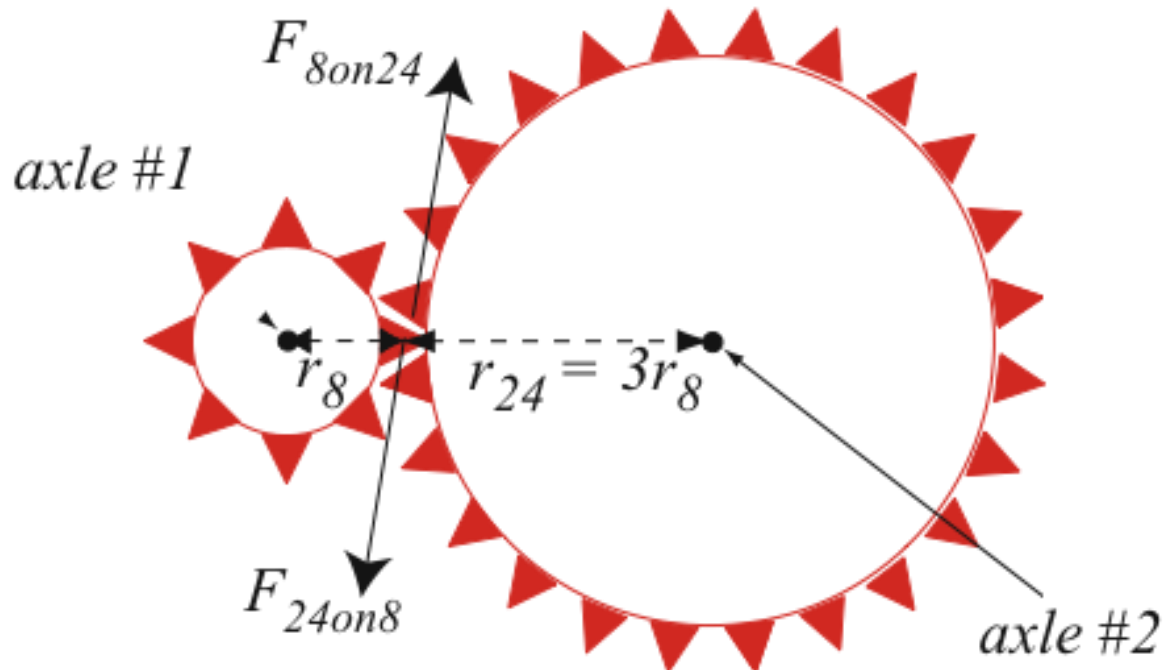
Try opening a door. How easy it is to open depends on 1) *How hard* you push and 2) *where* you push.



Mathematically:

$$\text{torque} = \mathbf{r} \times \mathbf{F}$$

What about our gear train?

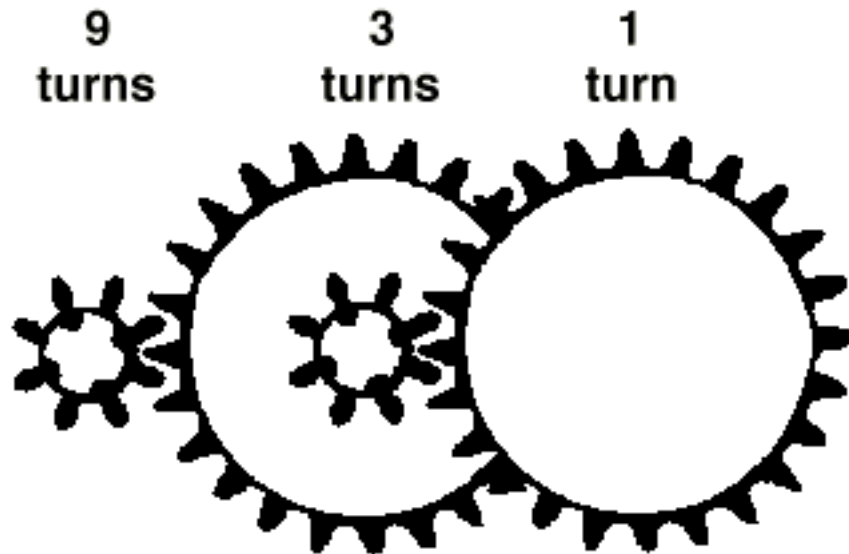


Since torque = $r \times F$, the torque about axle #2 is three times greater than the torque about axle #1; the gear train acts as a **“torque amplifier”**.

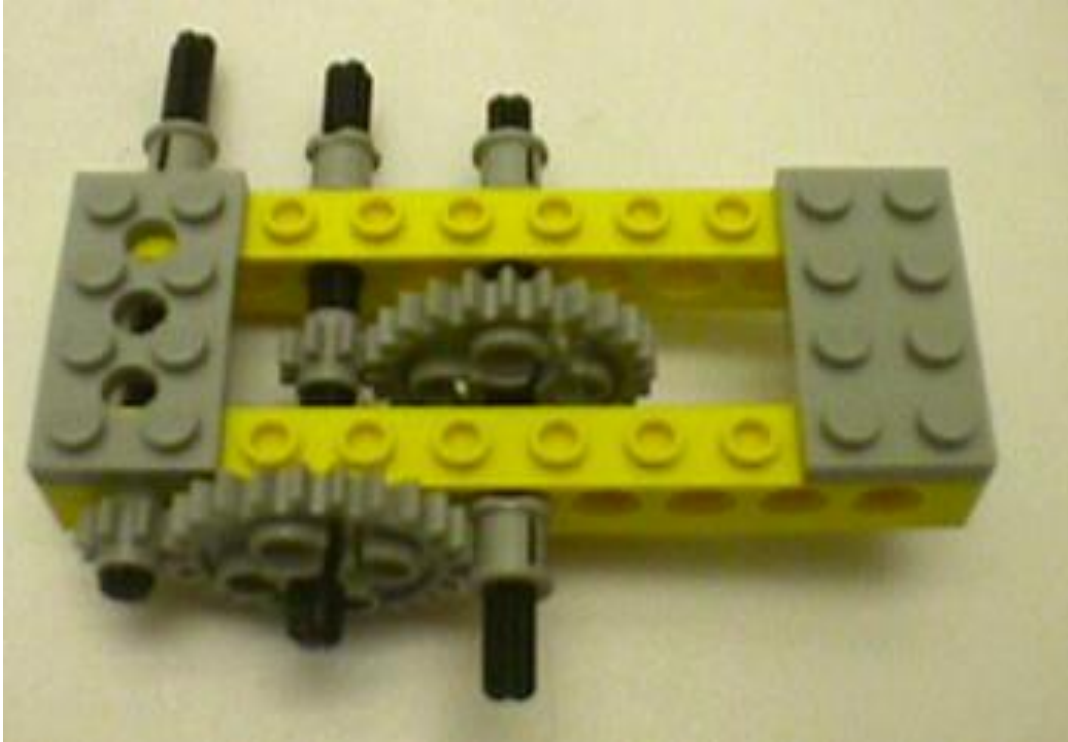
Going from small gears to big gears increases the torque by a factor equal to the gear ratio.

Gear Trains: Ganging Gears

Here's an absolutely brilliant trick:



By “ganging together” – or multiplying – two 3-to-1 gear reductions, a 9-to-1 output reduction can be achieved. The key is to use intermediary shafts that hold both a large input gear (e.g. a 24-tooth) and a small output gear (e.g. an 8-tooth).



So now the torque at the “output shaft” is 9 times the torque provided on the left (“input”) axle. The output shaft will of course spin 9 times slower than the input shaft, but it will be much harder to stall!

Gear Train Building Tips

- **adjust the “bushings”** so they’re not too tight, not too loose.
- build a **square and rigid frame** so that the holes in the beams remain lined up.
- **support the axles** in at least two places so that they don’t bend.
- The LEGO gears are sized so that they mesh nicely in “horizontally” aligned holes as shown above. (Note: This works because an 8-tooth gear has a radius of 0.5 FLU and a 24-tooth gear has a radius of 1.5 FLU.)

Getting Geared Up

Radii of gears:

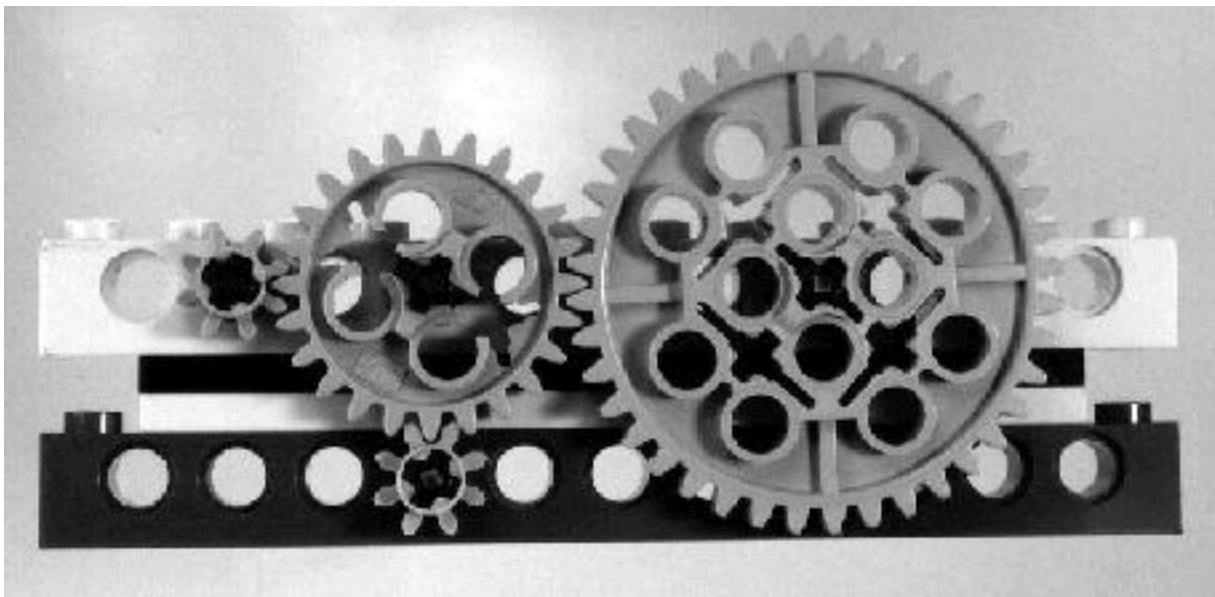
8 tooth = 0.5 FLU

16 tooth = 1.0 FLU

24 tooth = 1.5 FLU

40 tooth gears = 2.5 FLU

By use of plates, it is also possible to mesh gears in the vertical direction:



LEGO Motor Varieties

Red “micromotors” – relatively low power but high torque, since they have internal gearing inside the red box (amazing!)

Old Gray Motors - Much higher power than the micromotors but output shaft is high speed / low torque. You need to build gear trains to use them!

New Gray Motors (Gear Reduction Motors) - The best of both worlds! Similar in power to the old gray motors, but with internal gearing so that the output shaft speeds at a decent rate with lots of torque. You’ll need less in the way of gear trains when you use them!

Newest Clear Motors - Similar to the new gray motors in performance; the transparent case lets you see the internal gear train. They lack the awkward “hump” found on the new gray motors, and hence a bit easier to build with.