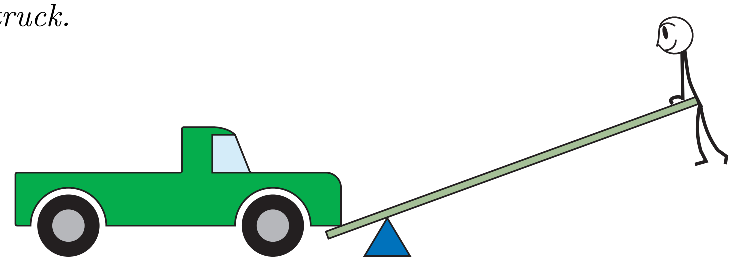
Physics 106 - How Things Work II - Spring 2008
Problem Set #2

A person needs to lift the end of their truck and decides to use a lever. They find that if there is 1 m between the pivot and the truck, and 5.5 m between the pivot and where the person hangs off the end of the lever, they have just enough mechanical advantage to lift the end of the truck.



1. Consider the truck, person and lever in the figure above.
   a. If the force on the truck is 11,000 Newtons, how much does the person weigh?

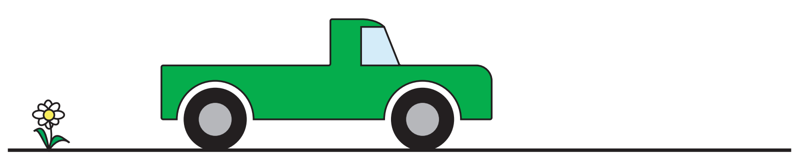
   When the person is exerting just enough force to lift the end of the truck the torque on the lever from the truck is exactly equal in magnitude to the torque on the lever from the person. In this case:

$$(Force\ on\ truck) \cdot (lever\ arm)_{truck} = (Force\ from\ person) \cdot (lever\ arm)_{person}$$
$$(11,000\,\mathrm{N}) \cdot (1\,\mathrm{m}) = (person's\ weight) \cdot (5.5\,\mathrm{m})$$

   So the $person's\ weight = (11,000\,\mathrm{N})(1\,\mathrm{m})/(5.5\,\mathrm{m}) = 2000\,\mathrm{N}$.

   b. When the person is just balancing the end of the truck, what can you say about the net torque on the lever?

   When the person is just balancing the end of the truck, the lever is stationary, and hence not undergoing angular acceleration. From Newton's 2nd law of rotational motion, we can thus say that the net torque is zero. This is implicit in the solution to part "a" during which we set the torque due to the truck equal to the torque due to the person.



2. Consider the truck in the figure above.
   a. When the truck is entirely stationary, what are the forces on the truck?

   There are no forces in the horizontal direction. In the vertical direction there is the force of gravity (the truck's weight) pulling it downward and the support or normal force pushing it upward.

2. Solutions to problem #2 continued.
   b. A person inside the truck steps on the accelerator and the truck begins to move. Describe the force that causes the truck to begin moving forward.

   The forces in the vertical direction are unchanged and do not contribute to the truck's forward motion. In the horizontal direction, the only force on the truck is that due to the road, which causes it to move forward. If the truck's tires do not skid, the force due to the road is a static frictional force.
   Further explanation: (This is for your benefit. I would not necessarily expect you to include all of this in your answer.) *When the person steps on the accelerator, the tire, in trying to rotate, exerts a static frictional force on the road. By Newton's 3rd law, the road then exerts an equal and opposite force on the tire, and hence the truck.*

3. Bob is sliding a heavy crate across the floor at a constant speed. Helen is also moving a crate but it is on rollers. Both people exert the same force over the same distance, and thus do the same work on their crates.
   a. What happens to the energy represented by the work performed by Bob?

   Most of the energy represented by Bob's work goes into thermal energy because of the frictional force against which he is fighting. A small amount of Bob's energy also goes into the kinetic energy of the crate as he first gets it moving.

   b. What happens to the energy represented by the work performed by Helen?

   Since Helen's crate is on rollers, there is fairly little friction. If she exerts the same force as Bob over the same distance, her crate will accelerate and go faster and faster. Thus, most of the energy represented by the work she performs will go into kinetic energy. Some of her energy, however, will inevitably go into thermal energy because of residual frictional forces that are present despite using rollers.

4. When an airplane starts its propellors, they spin slowly at first and gradually pick up speed. Why does it take so long for them to reach their full rotational speed?

   The airplane's engine applies a torque, and if the torque is constant, the angular acceleration will be given by the torque divided by the rotational mass. If the rotational mass is large (as is probably the case with the propellors), even with a significant torque, the angular acceleration may still be relatively small. Even so, with constant torque the angular velocity of the propellors will go up linearly with time, and eventually they will be going quite fast.

5. A person sits on a rotatable stool with their arms extended and a weight in each hand just as we did during the demo in class. They then use their feet to get themselves rotating. With their feet no longer touching the floor, they pull their arms in and begin spinning faster. Explain why this happens.

   Angular momentum is equal to the product of rotational mass and angular velocity. If the person pulls in their arms, their rotational mass gets smaller. In order for angular momentum to be conserved (which must be the case since there are no external torques) they must begin to spin faster. That way the product of rotational mass and angular velocity will remain constant.

6. A blue billiard ball smacks into a red billiard ball on a pool table. Following the collision the blue billiard ball stops and the red billiard ball goes flying off.
   a. What conservation principle can you use to explain this.

   Conservation of linear momentum. It is tempting to use conservation of energy here, but in fact, without knowing more details of the problem you cannot be sure that at least some energy is not lost to thermal energy. Linear momentum, however, is always conserved in a collision.

   b. During the collision the blue billiard ball gives an impulse to the red billiard ball. If the balls had been squishy like tennis balls but had the same initial velocities and weighed the same amount, what would that imply about the force that each ball exerted on the other during the collision. Explain your answer using the idea of an impulse.

   If the squishy ball that is moving initially had the same velocity and weighed the same amount as its billiard-ball counterpart, it would also have had the same momentum. Thus, when it hits the second ball, it would necessarily need to give the second ball the same impulse as occurred during the collision involving the billiard balls. Since the second set of balls are squishy, however, the time over which they are in contact is longer. Impulse is the product of force and the time over which the force is applied. If the time is longer and the impulse is the same, the force would necessarily need to be smaller.