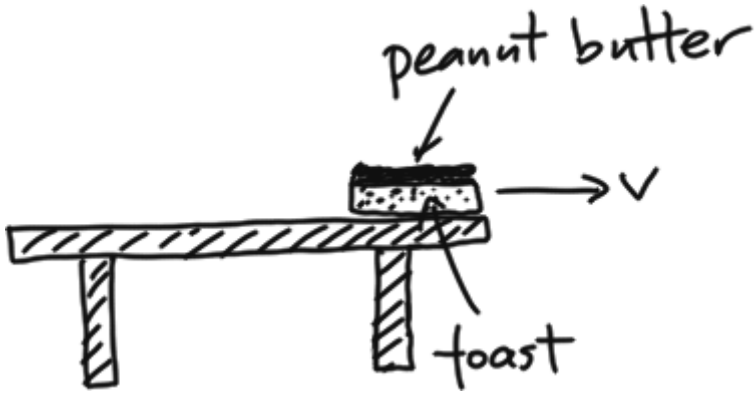
Physics tutorial: rotational motion

You have just prepared a toast with peanut butter for you breakfast.[1] As you sit down to eat it, you clumsily bump the toast, sending it flying off the table as shown.



a) Guess which side the toast will land on.

b) Draw a picture of the toast when it is 1/4 on and 3/4 off the table (assume the toast is still horizontal). Show the forces on the toast.

c) Estimate the net torque on the toast (about the toast's center of mass) at this time in terms of the mass M, the length L, and the gravitational constant g.

[1] Note for people allergic to peanuts: it's actually Sun-Butter brand sunflower seed butter. Please ignore this footnote if you are not allergic to peanuts.

d) Using your answer to c, estimate the angular acceleration of the toast at this time, in terms of M, L, and g.

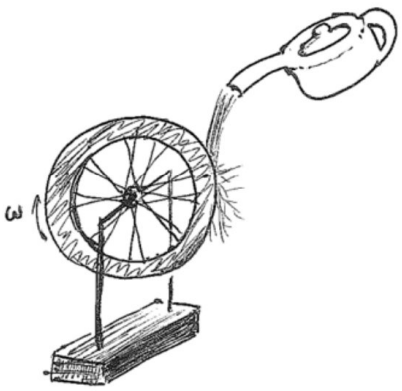
e) In terms of L and the toast speed v, estimate how long it takes for the toast to slide of the table (starting from when it is halfway off). Don't worry about the rotational motion for this part.

f) Estimate the angular velocity of the toast just as it leaves the table, assuming that your value from part d) represents the average angular acceleration for the entire time period of part e).

g) If the table has height H, by what angle does the toast rotate during its fall to the floor (your answer should be in terms of g, H, and v)?

h) Plug in some typical numbers to find a numerical answer. On which side does the toast land for your chosen numbers?

Question 2: I'm a little teapot…



An invisible man pours tea from a large teapot onto a bicycle wheel, causing it to spin. If the wheel's mass is 0.5 kg, and its radius is 20 cm, and if the torque produced by the tea is an increasing function of time,

$$\tau = \left(0.2\ \frac{\mathrm{Nm}}{\mathrm{s}}\right) t$$

How long does it take for the wheel to make one full rotation?

Question 3:

James Bond (formerly Charbonneau), fleeing some bad guys, jumps of a building but grabs a rope wound around a heavy metal cylinder attached to an axle. In terms of the mass M and radius R of the cylinder, and the mass m of James, what is James's downward acceleration compared with g?

Hints:

a) Draw force diagrams for both James and for the cylinder.

b) In terms of the tension T in the rope, what is James's acceleration?

c) In terms of the tension T in the rope, what is the cylinder's angular acceleration?

d) If the cylinder rotates one time, how much does James fall?

e) Using d, what is the relation between James's displacement and the angular displacement of the cylinder?

f) Using e), what is the relation between James's velocity and the angular velocity of the cylinder?

g) Using f), what is the relation between James's acceleration and the angular acceleration of the cylinder?

h) Using your answers to b, c, and g, eliminate the tension T and the angular acceleration α to find an expression for the acceleration a in terms of m, M, g, and R.

g) If James weighs 85kg, and the cylinder has radius 1m, how heavy does it need to be to reduce the acceleration to 1/10 g (so that James survives)?