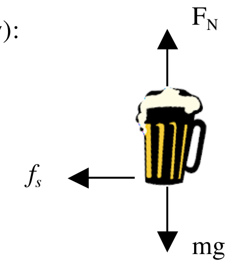
1. a)

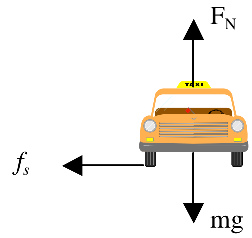
(towards center of turntable)

FBDs (side view):



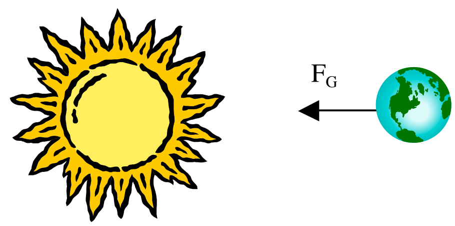
b)

(towards center of curvature of road)

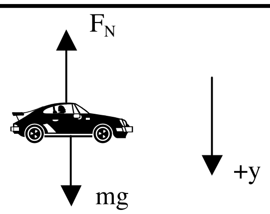


c)

(towards sun)



2. a) FBD:



Note that I chose the positive direction to be down. I did this because down is towards the center of the car's circular motion, and I want the centripetal acceleration to come out positive when I apply Newton's 2nd Law below. I could otherwise easily forget the negative sign.

b)

$$\Sigma F_y = ma_y :$$

$$mg - F_N = m\frac{v^2}{r}$$

$$\Rightarrow F_N = mg - m\frac{v^2}{r}$$

$$= (1000\text{ kg})\left(10\text{ m/s}^2 - (30\text{ m/s})^2/90\text{ m}\right)$$

$$= 0$$

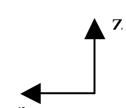
Physical interpretation: you feel "weightless" at the top of the hill (no normal force). This car has left the road and was in the air as it went over the top.

c) Obviously the normal force on an object is **not** always equal to the object's weight, since here we have an example where the normal force becomes zero. The only way to accurately determine the normal force is to write out Newton's 2nd Law, as we've been doing.

d) You should arrive at an equation that looks something like this: $F_N = mg\cos\theta - m\frac{v^2}{r}$

where θ is the angle between the car's direction of motion and the vertical. This shows that the normal force is actually smaller at larger angles, so that the car is in fact most likely to leave the road as soon as it encounters a concave-down section. This can be understood physically by noticing that when the car is at an angle, it still needs the same centripetal force to provide its centripetal acceleration, but only a component of the weight is available to do the job.

3. a) Refer to 1(b) for the FBD. I'm going to use a coordinate system where r



points towards the center of the circular motion and z points perpendicular to the plane of the motion:

$$\Sigma F_r = ma_r : \quad f_s = m\frac{v^2}{r}$$

$$\Sigma F_z = ma_z : \quad F_N - mg = 0 \quad \Rightarrow F_N = mg$$

b) I actually already did this above; the answer was simply $\mathbf{F_N = mg}$.

c) Recall that the force of static friction is given by $f_s \le \mu_s F_N$, so in this case we have $f_s \le \mu_s mg$. Therefore:

$$m\frac{v^2}{r} = f_s \le \mu_s mg$$

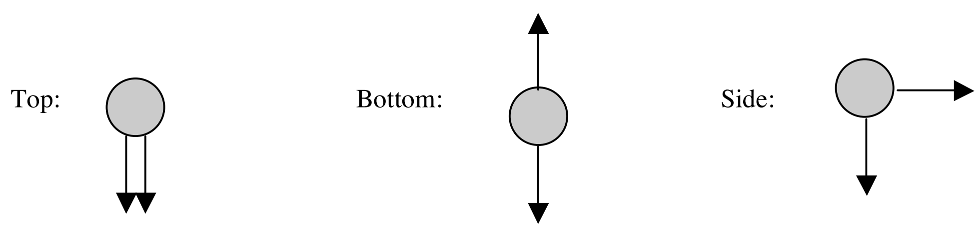
$$\Rightarrow v = \sqrt{\frac{f_s r}{m}} \le \sqrt{\mu g r}$$

Taking $\mu_s = 1.0$, this gives $v \le 20$ m/s.

d) Same as above, but now $\mu_s = 0.7$, which leads to $v \le 17$ m/s.

4. a) This is really just a guess based on intuition, but if you try it as an experiment, you'll see that the tension is greatest when the ball is at the bottom of its swing.

b) Here are the FBDs for the ball at the 3 places. In the equations below, "r" means the direction towards the center of the circle in each case.



Top:

$$\Sigma F_r = ma_r :$$

$$mg + F_T = m\frac{v^2}{R}$$

$$\Rightarrow F_T = m\left(\frac{v^2}{R} - g\right)$$

Bottom:

$$\Sigma F_r = ma_r :$$

$$F_T - mg = m\frac{v^2}{R}$$

$$\Rightarrow F_T = m\left(\frac{v^2}{R} + g\right)$$

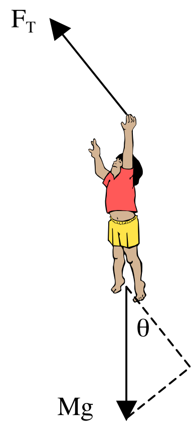
Side:

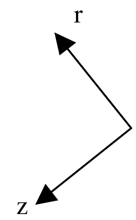
$$\Sigma F_r = ma_r :$$

$$F_T = m\frac{v^2}{R}$$

c) Using the numbers supplied, you should find the tension to be 13 N, 23 N and 18 N at the top, bottom and side of the circular motion, respectively.

5. a)





Note that the coordinate system has been chosen so that the r-direction points towards the center of the boy's circular motion.

b) Applying Newton's 2nd Law in the r-direction:

$$\Sigma F_r = ma_r :$$

$$F_T - mg\cos\theta = m\frac{v^2}{R}$$

$$\Rightarrow F_T = m\left(\frac{v^2}{R} + g\cos\theta\right)$$

c) Looking at the above expression, we see that it has two terms. The first term will be greatest when the boy's speed is greatest, which is right when he grabs the rope (since he'll slow down as he swings up). The second term will be greatest when θ = 0 (since cos 0 = 1), which also occurs right when the boy grabs the rope. So the tension in the rope will clearly be greatest at the bottom of the swing, and will go down from there.

Additional Questions

1) Your inertia wants you to keep moving in a straight line (Newton's 1st Law), but the car is turning underneath you and preventing you from doing so. In other words, the car has to exert a force on you to provide you with the centripetal acceleration needed to go around the curve.

2) Once it gets moving, the water in your clothes wants to continue in a straight line (Newton's 1st Law again). In this case, when the washer starts to spin, the holes in the side allow the water to pass through because of its own inertia, and so the water escapes out the holes. Your clothes would do the same thing, except the holes are too small!

3) It's actually not possible. The ball on the string feels only two forces: the tension in the string and its own weight. If the string were horizontal, then there would be nothing to balance the downward force of weight, and the ball would descend. There must be some vertical component of tension to balance the weight, so the string must be at some angle to the horizontal: