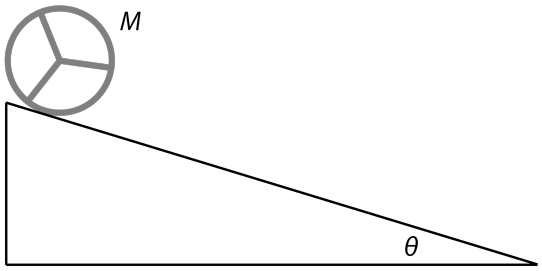
Flipping Physics Lecture Notes:

2016 #1 Free Response Question - AP Physics 1 - Exam Solution
http://www.flippingphysics.com/ap1-2016-frq1.html

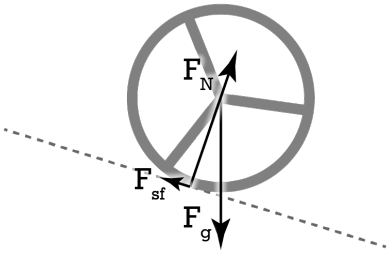
This Short Answer question also works as a part of the AP Physics C: Mechanics curriculum.



A wooden wheel of mass M, consisting of a rim with spokes, rolls down a ramp that makes an angle θ with the horizontal, as shown above. The ramp exerts a force of static friction on the wheel so that the wheel rolls without slipping.

(a)

i. On the diagram below, draw and label the forces (not components) that act on the wheel as it rolls down the ramp, which is indicated by the dashed line. To clearly indicate at which point on the wheel each force is exerted, draw each force as a distinct arrow starting on, and pointing away from, the point at which the force is exerted. The lengths of the arrows need not indicate the relative magnitudes of the forces.



- *Force of gravity, F_g, acts straight down from the center of mass of the wheel.*
- *Force Normal, F_N, acts perpendicular to the incline and up from the point of contact between the wheel and the incline.*
- *Force of Static Friction, F_{sf}, acts parallel to the incline and up from the point of contact between the wheel and the incline.*

Notes about grading:

- *This problem, problem #1, is worth 7 points. 2 of those points are just for getting this free body diagram correct. Yes, roughly 30% of the points from this problem come from this free body diagram. Hopefully this helps you to understand how important free body diagrams are.*
- *All forces need a clear indication of where they start and their direction. If you are terrible at drawing, you can always clarify force start locations and directions using words.*

ii. As the wheel rolls down the ramp, which force causes a change in the angular velocity of the wheel with respect to its center of mass? Briefly explain your reasoning.

Change in angular velocity is caused by angular acceleration: $\vec{\alpha} = \frac{\Delta\vec{\omega}}{\Delta t}$

Angular acceleration is caused by net torque: $\sum \vec{\tau} = I\vec{\alpha}$

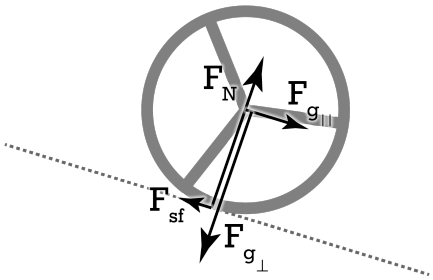
The only force causing a torque on the wheel about its center of mass is the ***force of static friction*** *because:* $\tau = rF\sin\theta$

- *r for the force of gravity is zero.*
- *θ for the force normal is 180° and sin(180°) = 0.*

(b) For this ramp angle, the force of friction exerted on the wheel is less than the maximum possible static friction force. Instead, the magnitude of the force of static friction exerted on the wheel is 40 percent of the magnitude of the force or force component directed opposite to the force of friction. Derive an expression for the linear acceleration of the wheel's center of mass in terms of M, θ, and physical constants, as appropriate.

The "force component directed opposite to the force of friction" is the component of the force of gravity which acts parallel to and down the incline, $F_{g_\parallel}$.
Therefore, from the problem statement:

$$F_{sf} = 0.4F_{g_\parallel} = 0.4mg\sin\theta$$



And we can sum the forces in the parallel direction to solve for the acceleration of the center of mass of the wheel in the parallel direction. Defining down the incline as positive, we get:

$$\sum F_\parallel = F_{g_\parallel} - F_{sf} = ma_\parallel \Rightarrow mg\sin\theta - 0.4mg\sin\theta = ma_\parallel$$

$$\Rightarrow a_\parallel = g\sin\theta - 0.4g\sin\theta = 0.6g\sin\theta$$

Notes about grading:

- *Understand what this line means in the scoring guideline: "The expression need not be correct or consistent with the force diagram in part (a)."*
  - *This means you did not have to get part (a) correct to get points for part (b). So please, always answer every question, regardless of whether you think the rest of your solution is correct or not.*
- *Also, please make sure your answer is in terms of the variables provided.*

(c) In a second experiment on the same ramp, a block of ice, also with mass M, is released from rest at the same instant the wheel is released from rest, and from the same height. The block slides down the ramp with negligible friction.

i. Which object, if either, reaches the bottom of the ramp with the greatest speed?

____ Wheel __X__ Block ____ Neither; both reach the bottom with the same speed.

Briefly explain your answer, reasoning in terms of forces.

*The block has no force of friction acting on it, therefore, the net force in the parallel direction on the block has a larger magnitude and therefore has a larger acceleration down the incline. A larger acceleration on the block will result in a larger speed on the **block** at the bottom of the incline.*

ii. Briefly explain your answer again, now reasoning in terms of energy.

*Both the block and the wheel start with the same amount of mechanical energy and it is all gravitational potential energy. Gravitational potential energy is converted to kinetic energy as the objects go down the ramp. The block is not rotating; therefore, the block will not have any rotational kinetic energy as it slides down the incline, therefore the block will have more translational kinetic energy than the wheel and the **block** will have a larger speed at the base of the ramp.*

*Note about grading: Both (ci) and (cii) are worth one point and state "*No credit for answer without explanation*". In other words, anytime a question asks you to "*explain your answer*" you absolutely must do so! Not doing so will most likely get you zero points.*