

21.

We consider the wheel as it leaves the lower floor. The floor no longer exerts a force on the wheel, and the only forces acting are the force F applied horizontally at the axle, the force of gravity mg acting vertically at the center of the wheel, and the force of the step corner, shown as the two components f_h and f_v . If the minimum force is applied the wheel does not accelerate, so both the total force and the total torque acting on it are zero.

We calculate the torque around the step corner. The second diagram indicates that the distance from the line of F to the corner is $r - h$, where r is the radius of the wheel and h is the height of the step. The distance from the line of mg to the corner is $\sqrt{r^2 + (r - h)^2} = \sqrt{2rh - h^2}$. Thus $F(r - h) - mg\sqrt{2rh - h^2} = 0$. The solution for F is

$$F = \frac{\sqrt{2rh - h^2}}{r - h} mg .$$

