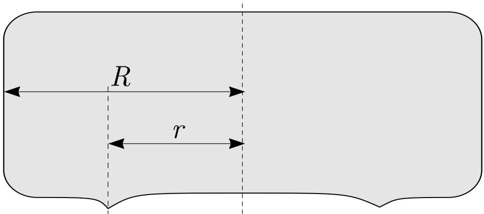
1. CURLING (8 points) — *Oskar Vallhagen.*

In the sport of curling, participants take turns sliding near-cylindrical stones across an ice court towards a target, trying to get their stones as close to the target as possible after using a set of stones. A vertical cross section of a stone is depicted below, showing that the stone is in contact with the ice on a thin ring of radius r. The full radius of the stone is R, the mass of the stone is m and the coefficient of friction with the ice is μ.



Consider the case when the stone is released at a speed v_0 with the aim of knocking out an opponent's stone at a distance s.

i) *(1 point)* Give an expression for the sliding speed v_s as a function of the time t since the stone was released until the stone hits the opponent's stone.

ii) *(1 point)* What is the sliding speed v_{hit} just before the stone hits the opponent's stone?

Now the stone is given a small rotation at the initial angular speed ω_0 (this can be done to alter the deflection angle of the stone when it hits the opponent's stone). Assume that the rotation speed ω remains small throughout the sliding motion: $\omega r \ll v_s$. Keep only the main non-vanishing terms in your calculations, i.e. among the terms with a factor $(\omega r/v_s)^n$, keep only the term with the smallest n. Depending on your approach you may use the following approximations for $x \ll 1$: $(1+x)^\alpha \approx 1+\alpha x+\frac{1}{2}\alpha(\alpha-1)x^2$, $\sin(\alpha+x) \approx \sin\alpha + x\cos\alpha$, $\cos x \approx 1-x^2/2$. You may also need the integral $\int(at+b)^{-1}dt = a^{-1}\ln|at+b|+C$.

iii) *(2 points)* By how much does the friction force on the stone change due to its rotation? Express your answer in terms of the current angular speed ω and sliding speed v_s.

iv) *(2 points)* Give an expression for the torque T exerted on the stone.

v) *(2 points)* What is the angular speed of the stone just before it hits the opponent's stone?