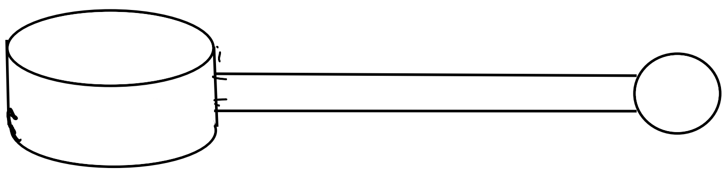
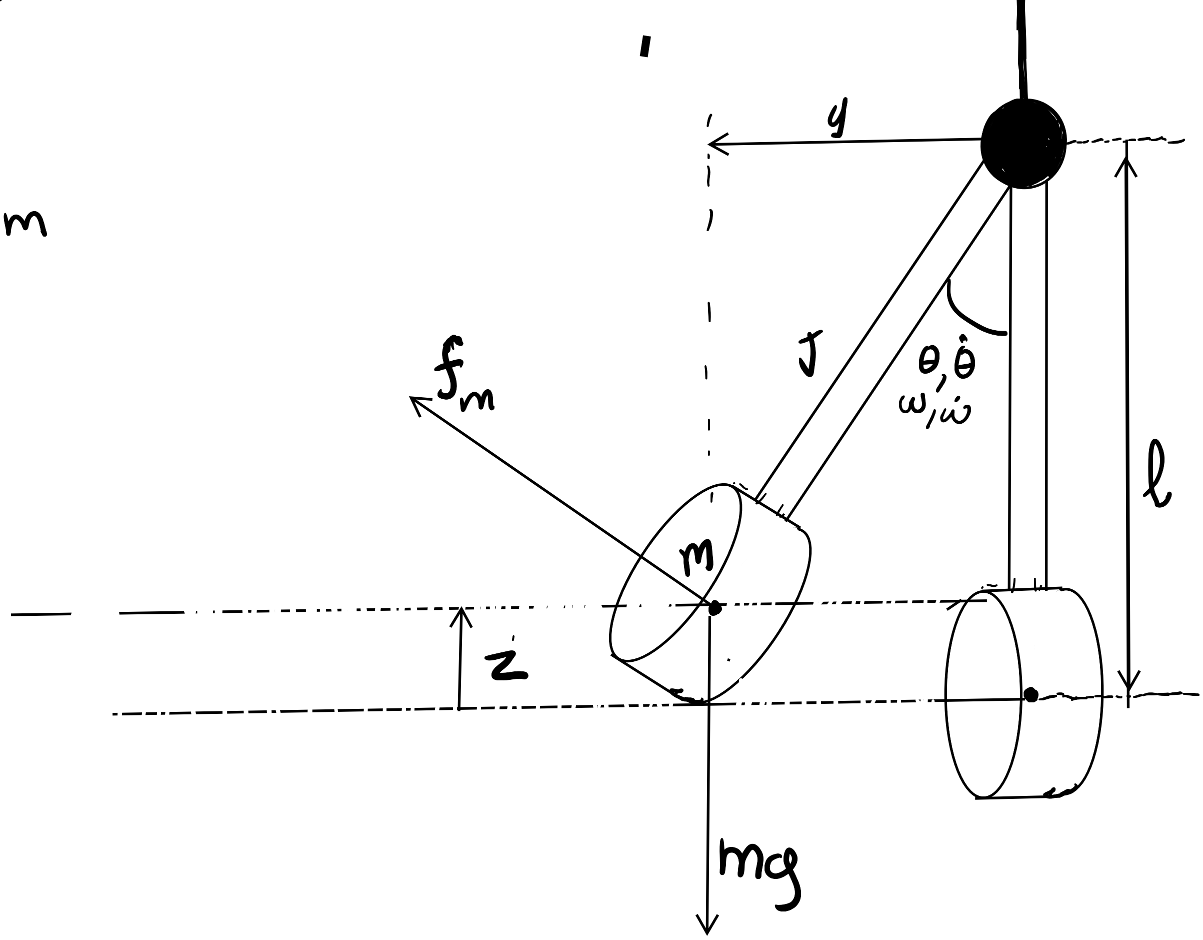


$l = 28\,cm$



$T = \frac{1}{2}m(\dot{z}^2 + \dot{y}^2)$ $\quad y = l\sin\theta \quad \dot{y} = l\dot{\theta}\cos\theta$

$V = mgz \quad z = l\cos\theta \quad \dot{z} = -l\dot{\theta}\sin\theta$

$L = T - V = \frac{1}{2}m(\dot{z}^2 + \dot{y}^2) - mgz$

$L = \frac{1}{2}m\left((-l\dot{\theta}\sin\theta)^2 + (l\dot{\theta}\cos\theta)^2\right) - mgl\cos\theta$

$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{y}}\right) - \frac{\partial L}{\partial y} = f \quad \frac{\partial L}{\partial \dot{y}} = ml\dot{\theta}\cos\theta \quad \frac{\partial L}{\partial \dot{\theta}} = m\dot{\theta}l^2$

$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{\theta}}\right) - \frac{\partial L}{\partial \theta} = 0 \quad \frac{\partial L}{\partial y} = 0 \quad \frac{\partial L}{\partial \theta} = mgl\sin\theta$

$$ml(\ddot{\theta}\cos\theta - \dot{\theta}^2\sin\theta) = f$$
$$m\ddot{\theta}l^2 - mgl\sin\theta = 0$$

Using small θ approximation

$$ml\ddot{\theta}\theta = f$$
$$m\ddot{\theta}l^2 - mgl\theta = 0 \qquad m\ddot{\theta}l = mg\sin\theta$$

$$\dot{\omega} = \frac{g\theta}{l} \qquad J\ddot{\theta} = (f - mg\sin\theta)l$$

$$\dot{\omega} = \frac{f}{ml\theta} \qquad \dot{\omega} = \frac{fl}{J} - \frac{mgl\theta}{J}$$

$$f_m' = f_m - mg\theta$$

$$\begin{bmatrix} \dot{\theta} \\ \dot{\omega} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} \theta \\ \omega \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{l}{J} \end{bmatrix} f_m'$$

$f =$

$$\tau = rf = -\frac{k^2}{R}\omega + \frac{K}{R}e \qquad m\ddot{y} = f - mg\theta$$
$$f = -\frac{k^2}{Rr}\omega + \frac{K}{Rr}e$$