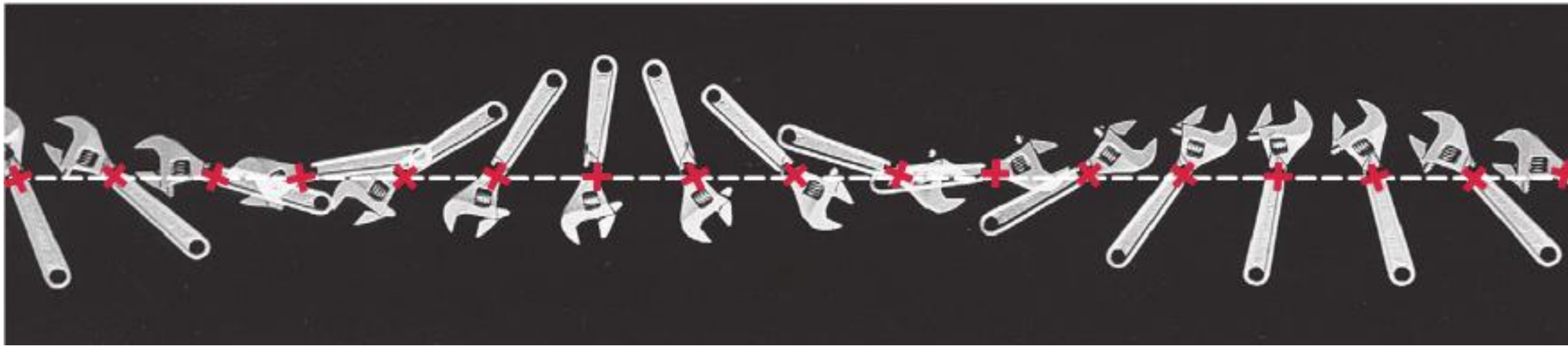
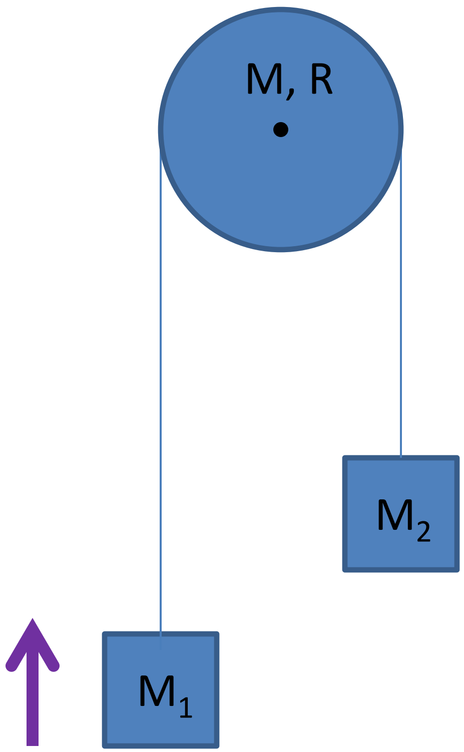


- Motion broken into
  - Motion of CM
  - Motion about CM

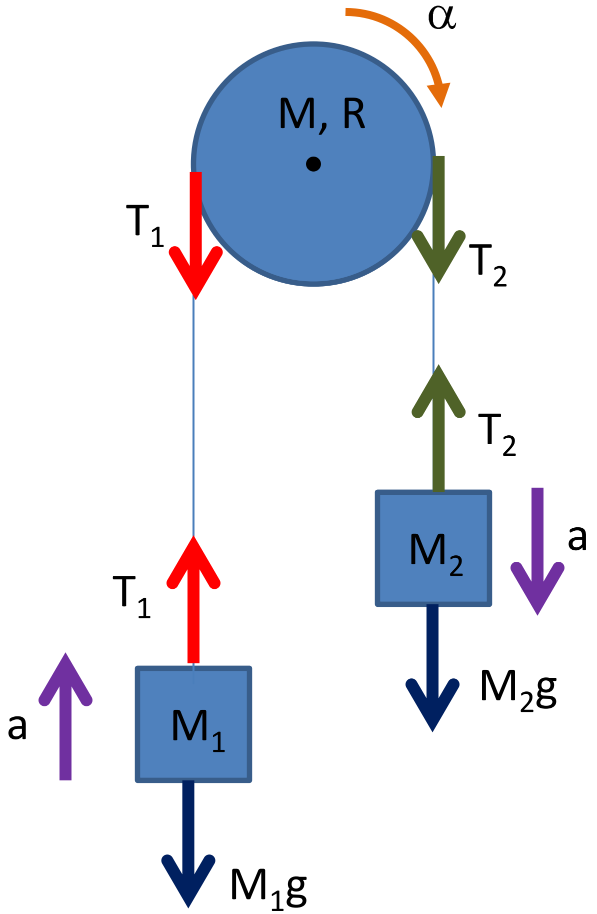
Three Problem Types

- Real Pulleys
- Rolling
- Onset of Rolling

1. Real Fixed Pulleys



- Fixed pulley, no *a*. Interested only in τ's and α. TFBD only
- Friction btw string and pulley. Tension varies over pulley.
- Treat as two different T's
- String relates a_{block} to α and R
- R is lever arm for T's ($T \perp R$ always)



$$RT_1 - RT_2 = -I\alpha$$

$$I = \tfrac{1}{2}MR^2 \quad \& \quad \alpha = a/R$$

$$T_1 - T_2 = -\tfrac{1}{2}Ma$$

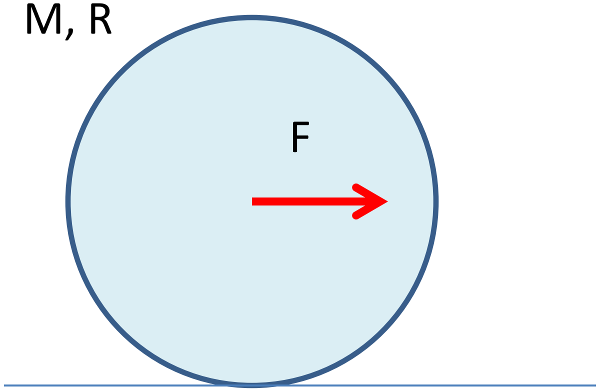
$$T_1 - M_1 g = +M_1 a$$

$$T_2 - M_2 g = -M_2 a$$

$$a = (M_2 - M_1)g/(M_1 + M_2 + \tfrac{1}{2}M)$$

2. Rolling Without Slipping

Disk
M, R

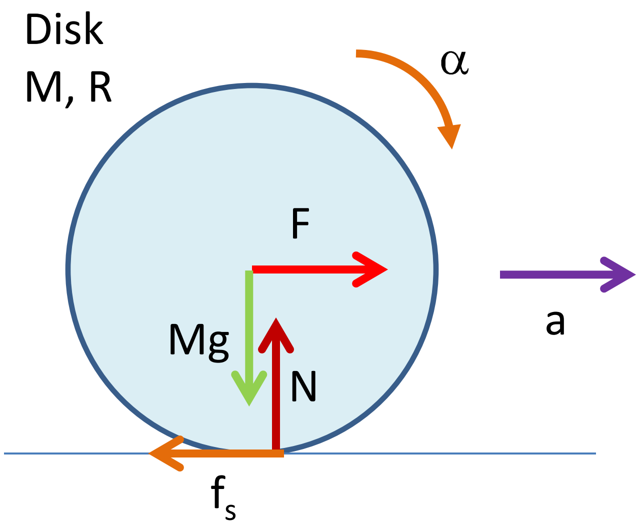


Moving right & speeding up

Given μ_s and μ_k. Find a and f_s.

If F is too big , disk will slip.
What is F_{slip}?

- a and α dir^{n}s related
- $a = R\alpha$
- f_s, not f_k , not f_s^{max}
- Must find formula for f_s
- Dir^n of f_s must be consistent with Newton's Laws
- f_s and a must be expressed in terms of given quantities



Find consistent a & α

Add all forces but f_s

F, N, & W cannot produce a torque. Some "other" force must!

$$-Rf_s = -I\alpha$$

$$I = \tfrac{1}{2}MR^2 \;\;\&\;\; \alpha = a/R \;\Rightarrow\; f_s = \tfrac{1}{2}Ma$$

$$F - f_s = Ma \quad \& \quad N - Mg = 0$$

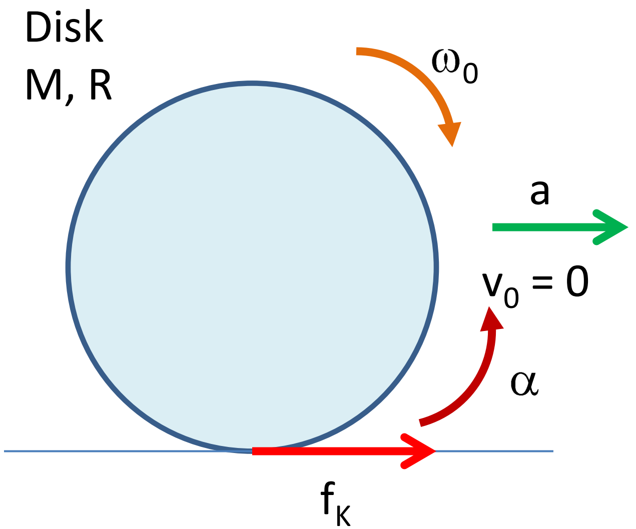
$$F - \tfrac{1}{2}Ma = Ma \;\Rightarrow\; a = 2F/3M$$

$$f_s = \tfrac{1}{2}Ma \;\Rightarrow\; f_s = F/3$$

Will start to slip …

- Note $f_s = F/3$ so $f_s \uparrow$ when $F \uparrow$
- But f_s cannot exceed f_s^{max}
- $f_s^{max} = \mu_s N = \mu_s Mg$
- So will slip when $f_s = f_s^{max}$ or
- $F/3 = \mu_s Mg$ or $F = 3\mu_s Mg$

3. Onset of Rolling



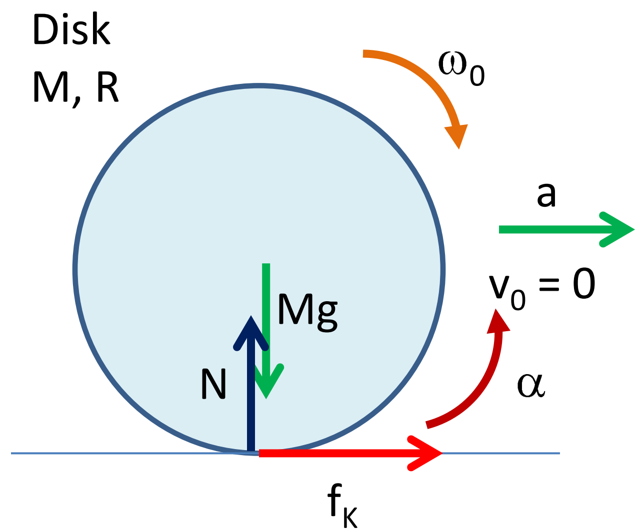
If you place a spinning wheel on a surface, it will slip (f_k acting to slow rotation)

But f_k makes CM move.

At some time t, $v_f = R\omega_f$.

Object rolls without slipping.

Note $a \neq R\alpha$. Must find equation for a and equation for α. Then $v_0 + at = R(\omega_0 + \alpha t)$. NB scalar eqn.



$$f_k = Ma \quad \& \quad N - Mg = 0 \quad \& \quad f_k = \mu_k N$$

$$\Rightarrow \quad a = \mu_k g$$

$$Rf_k = I\alpha \quad \& \quad I = \tfrac{1}{2}MR^2$$

$$\Rightarrow \quad \alpha = 2f_k/MR \quad \Rightarrow \quad \alpha = 2\mu_k g/R$$

$$v_0 + \mu g t = R(\omega_0 - 2\mu_k g t/R) \quad \Rightarrow \quad t = R\omega_0/3\mu_k g$$