Chapter 4 of Tipler & Mosca, section 8 and Ch 5, section 1
Two or more objects and Friction

0. Newton's Laws (reminder):

a.) 2nd: $\vec{F}_{net} = m\vec{a}$ (in inertial frame)

1st is special case. $\vec{F}_{net} = 0$

b.) 3rd: $\vec{F}_{AB} = -\vec{F}_{BA}$

8. Two or more objects

a.) When connected by a rope we can usually ignore the mass of the rope. Then the tension has the same magnitude all along the rope.

b.) And if the rope goes over a pulley, we can usually ignore friction and the mass of the pulley. Then the pulley only exerts a normal force on the rope, and the tension has the same magnitude all along the rope.

c.) When "connected" by contact forces, we need to consider the normal and tangential (friction) forces.

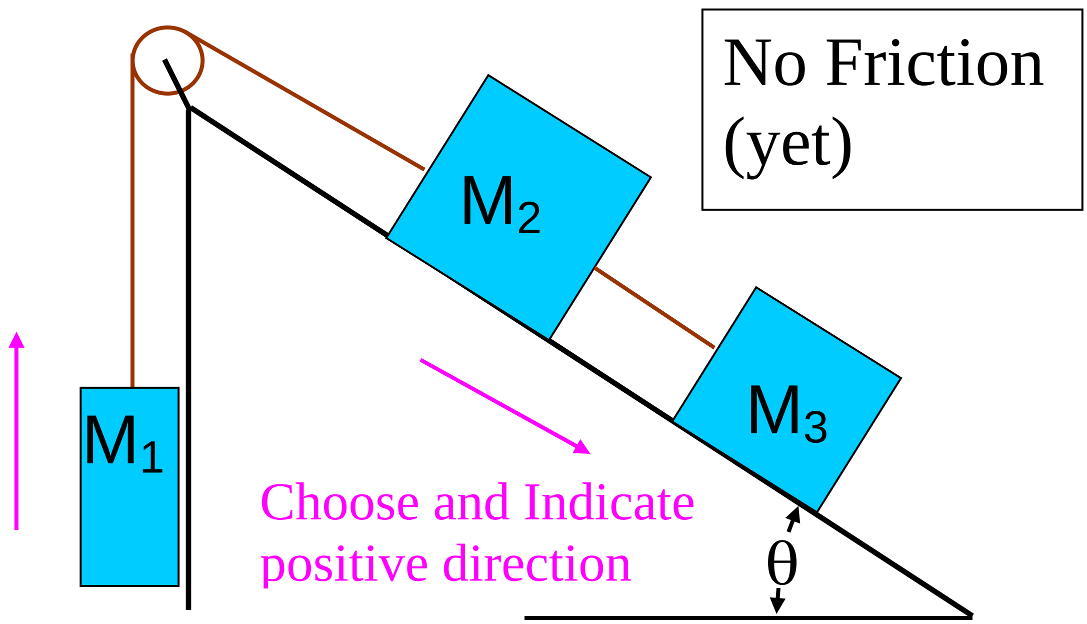
d.) **Strategy** –

i) **Draw free-body diagrams for each object.**

ii) **Apply Newton's 2nd to each. (May need 3rd too).**

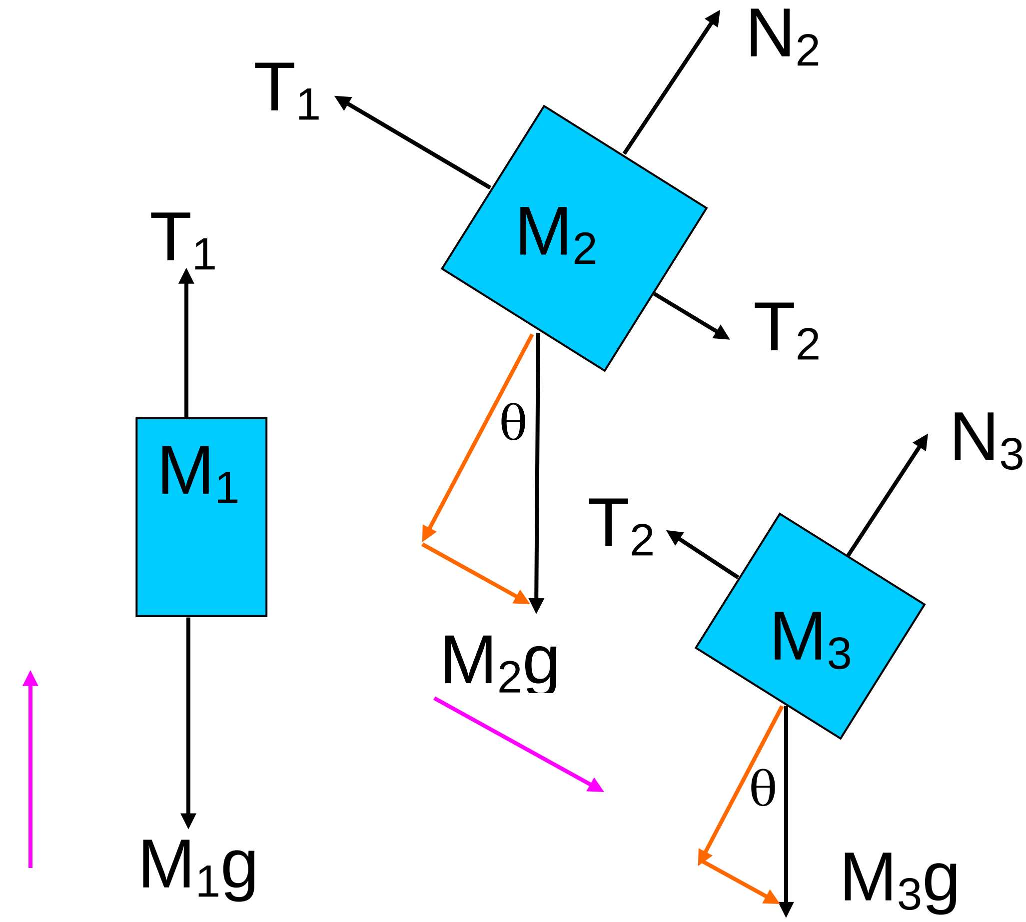
iii) **Then apply constraints**

e.) **Examples**



Mass-less rope and pulley, as usual.
If "up" is positive for M1, then "down the ramp" is positive on the ramp.
Could pick the opposite, but they must go together.

Three free body Diagrams



Equations (for components in direction of motion. Normal components not needed):

1. $F_{1,net} = T_1 - M_1 g = M_1 a$
   (we choose up positive)

2. $F_{2,net} = T_2 - T_1 + M_2 g \sin(\theta) = M_2 a$
   (down incline is positive)

3. $F_{3,net} = - T_2 + M_3 g \sin(\theta) = M_3 a$

Three equations, three unknowns.

These three are not hard to solve. Just add them together and the *T*'s cancel out.

$$-M_1 g + M_2 g \sin(\theta) + M_3 g \sin(\theta) = (M_1 + M_2 + M_3)\, a$$

Solve for *a*:

$$a = \frac{-M_1 + M_2 \sin(\theta) + M_3 \sin(\theta)}{M_1 + M_2 + M_3} g$$

check units
check plausibility

Put *a* in #1 to get T_1 or in #3 to get T_2

$$T_1 = M_1(a + g)$$

$$T_2 = M_3(g \sin(\theta) - a)$$

DO NOT TRY TO MEMORIZE these equations. But DO learn how to derive them.

Chapter 5, section 1. Friction depends on normal force:

A. Kinetic (sliding)
force is opposite direction of sliding

$$f_k = \mu_k F_n$$

coefficient is independent of speed or F_n (more or less).

B. Static
Friction force cancels the applied force. Object does not move.

$$f_s \leq \mu_s F_n$$

C. Static friction is larger than kinetic

D. Rolling – like kinetic, but involves wheels, etc.

Modifications to 3 blocks sliding problem if friction is included.

A. Need to figure out which way they go without friction, so you know which way friction force points.

B. Then include friction for M_2 and M_3