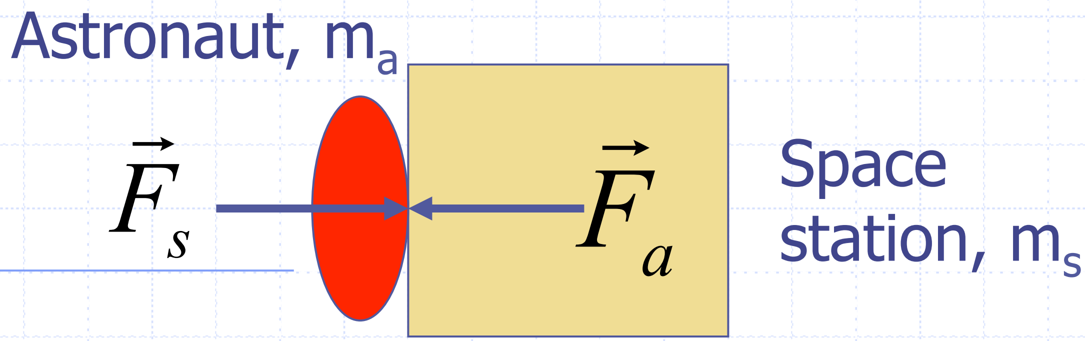
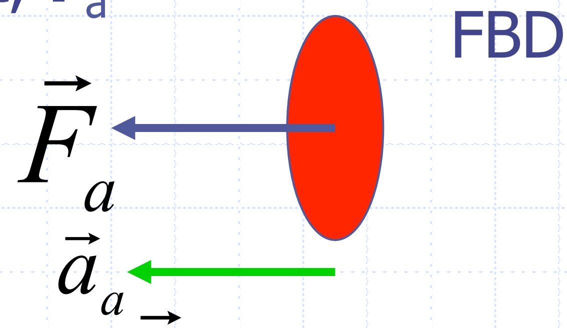
Chapter 7: Newton's Third Law of Motion

- The first two laws deal with a single object and the net forces applied to it
  - but not what is applying the force(s)
- *The third law* deals with how two objects interact with each other
- Whenever one object exerts a force on a second object, the second object exerts a force of the same magnitude, but opposite direction, on the first object



Third law says: force astronaut applies to space station, **F**$_{s,}$ must be equal, but opposite to force the space station applies to astronaut, **F**$_a$

$$\vec{F}_s = -\vec{F}_a = \vec{F}$$

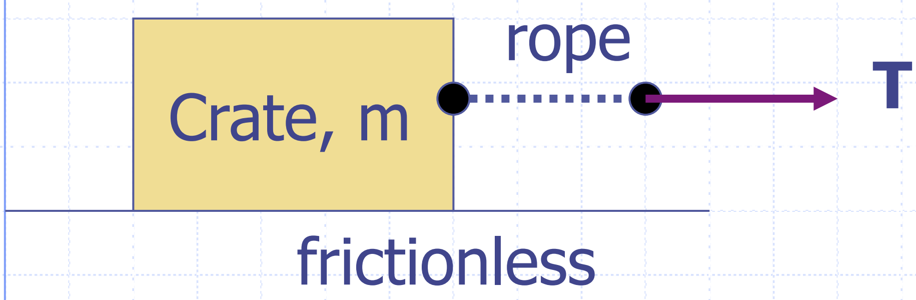


$$\vec{F}_a = m_a \vec{a}_a \Rightarrow \vec{a}_a = \vec{F}_a / m_a = -\vec{F} / m_a$$

$$\vec{F}_s = m_s \vec{a}_s \Rightarrow \vec{a}_s = \vec{F}_s / m_s = \vec{F} / m_s$$

Since $m_a << m_s \Rightarrow a_a >> a_s$

The Tension Force

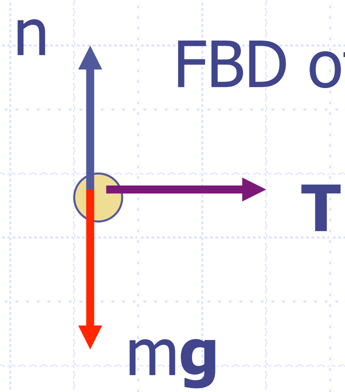


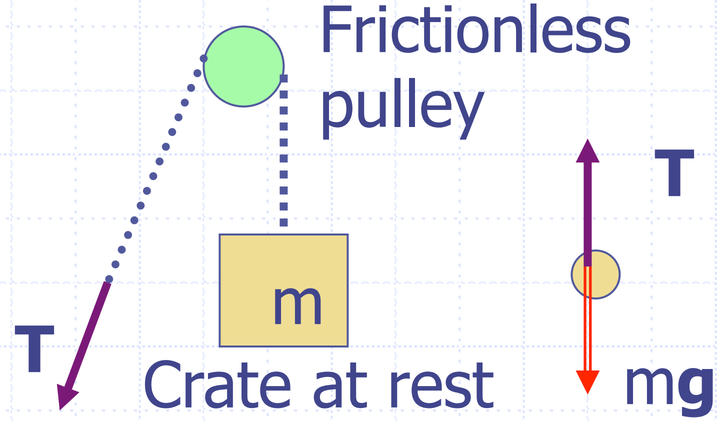
- Assume rope is massless and taut

FBD of rope

$$\sum F_x = T - T = 0$$

FBD of crate





Crate at rest

$$\sum F_y = T - mg = 0$$

$$T = mg$$

- Like the normal force, the friction and tension forces are all manifestations of the electromagnetic force

- They all are the result of attractive (and repulsive) forces of atoms and molecules within an object (normal and tension) or at the interface of two objects

Applications of Newton's 2nd Law

- Equilibrium – an object which has zero acceleration, can be at rest or moving with constant velocity

$$\sum \vec{F} = 0 \Rightarrow \sum F_x = 0, \sum F_y = 0$$

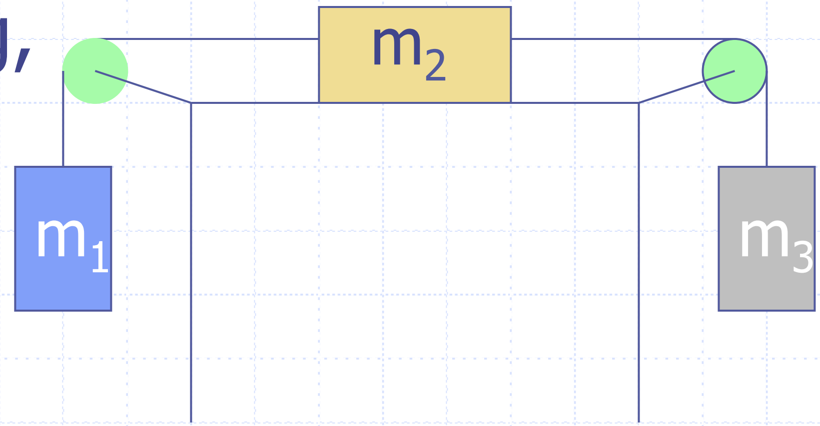
- Example: book at rest on an incline with friction
- Non-equilibrium – the acceleration of the object(s) is non-zero

$$\sum \vec{F} = m\vec{a} \Rightarrow \sum F_x = ma_x, \sum F_y = ma_y$$

Example Problem

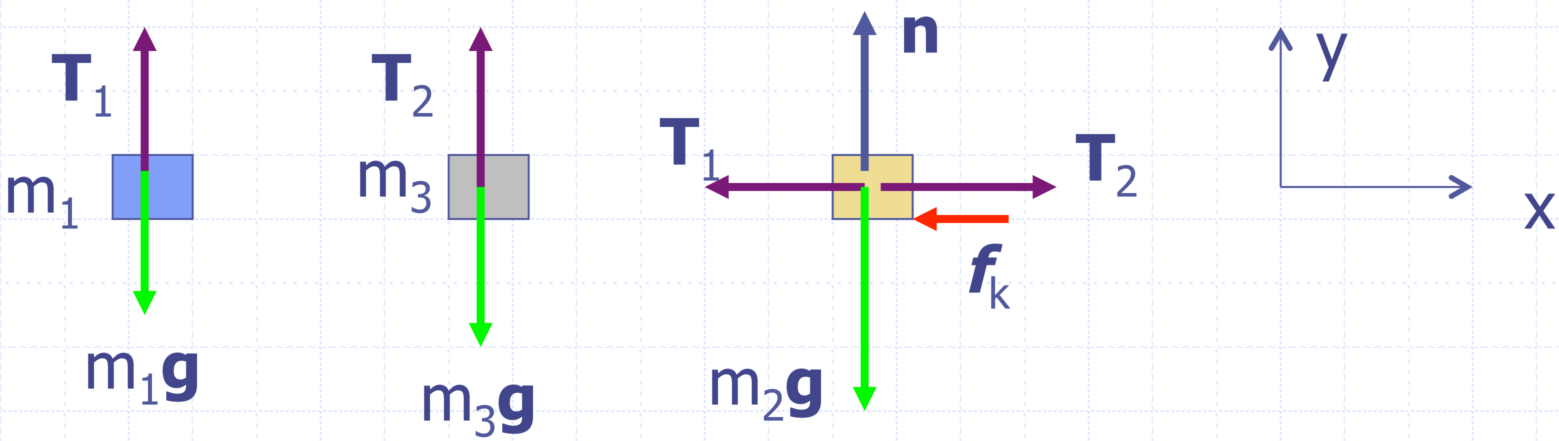
Three objects are connected by strings that pass over massless and frictionless pulleys. The objects move and the coefficient of kinetic friction between the middle object and the surface of the table is 0.100 (the other two being suspended by strings). (a) What is the acceleration of the three objects? (b) What is the tension in each of the two strings?

- Given: m_1 = 10.0 kg, m_2=80.0 kg, m_3=25.0 kg, μ_k=0.100



- Find: a_1, a_2, a_3, T_1, and T_2

<u>Solution</u>: 1) Draw free-body *diagrams*



2) Apply Newton's 2nd Law to each *object*

$$\sum F_{y1} = m_1 a_{y1}$$

$$T_1 - m_1 g = m_1 a_{y1}$$

$$\boxed{T_1 = m_1(a_{y1} + g)}$$

$$\sum F_{y3} = m_3 a_{y3}$$

$$T_2 - m_3 g = m_3 a_{y3}$$

$$\boxed{T_2 = m_3(a_{y3} + g)}$$

$$\sum F_{x2} = m_2 a_{x2}$$

$$\boxed{T_2 - T_1 - f_k = m_2 a_{x2}}$$

$$\sum F_{y2} = 0$$

$$n - m_2 g = 0$$

$$\boxed{n = m_2 g}$$

$$f_k = \mu_k n = \mu_k m_2 g$$

Also, $a_{x1}=0$, $a_{x3}=0$, $a_{y2}=0$

$$T_2 - T_1 - \mu_k m_2 g = m_2 a_{x2}$$

$$T_1 = m_1(a_{y1} + g)$$

$$T_2 = m_3(a_{y3} + g)$$

- Three equations, but five unknowns: a_{y1}, a_{y3}, a_{x2}, T_1, and T_2

- But, $a_{y1} = a_{x2} = -a_{y3} = a$
- Substitute 2nd and 3rd equations into the 1st equation

$$m_3(-a + g) - m_1(a + g) - \mu_k m_2 g = m_2 a$$

$$-m_3 a + m_3 g - m_1 a - m_1 g - \mu_k m_2 g - m_2 a = 0$$

$$a(-m_3 - m_1 - m_2) + g(m_3 - m_1 - \mu_k m_2) = 0$$

$$a(m_1 + m_2 + m_3) = g(m_3 - m_1 - \mu_k m_2)$$

$$a = g\frac{(m_3 - m_1 - \mu_k m_2)}{(m_1 + m_2 + m_3)}$$

$$= 9.80\left[\frac{25.0 - 10.0 - 80.0(0.100)}{10.0 + 80.0 + 25.0}\right]$$

$$= \boxed{0.60\,\tfrac{\mathrm{m}}{\mathrm{s}^2} = a_{y1} = a_{x2} = -a_{y3}}$$

$$T_1 = m_1(a+g) = 10.0(0.60+9.80)$$

$$= \boxed{104\ \text{N}}$$

$$T_2 = m_3(g-a) = 25.0(9.80-0.60)$$

$$= \boxed{230\ \text{N}}$$

Example (simple)

- Pulling up on a rope, you lift a 4.35-kg bucket of water from a well with an acceleration of 1.78 m/s^2. What is the tension in the rope?