# Lab 2

## Using Extended Free Body Diagrams to apply Newton's laws

**Due 01/26/2020**

This lab is a take-home lab. 5 questions will be graded out of 3 just like lab questions. Feel free to work in groups, but you must turn in your own unique work. I will be in the lab room during lab hours this week if you want to attend for any help (highly recommended).

**Purpose of the lab:** To learn to analyze an object by isolating it and showing all the forces acting on it at their respective locations.

**Note:** This is an extensive take-home exercise - be sure to make plenty of time to complete it. Turn it into my office (under the door) by 8pm on the due date.

**Directions:** For each situation,

1. Use the given sketch (or create your own, as necessary), identify the type and direction of all forces acting on the object of interest. If you don't know a direction, make your best guess.

2. Choose and indicate a "coordinate system" for each situation.

3. Draw an extended free body diagram (e-FBD) showing all forces acting on the object of interest. Lab all forces with variables, not numbers. Draw all force vectors with their tails beginning at the location of the force on the object of interest. Also draw and label any moment arms that are not zero. Use the provided reference axis "o" labeled on each figure. Indicate any reference angles and lengths that will be used in the rotational version of Newton's 2nd law.

4. Use the rotational version of Newton's 2nd law to write an equation for the situation given. You do not need to solve these equations. In writing each equation, don't plug in any numbers except zero. Just sum the torques on the left-hand side and use any expressions you know for forces whenever applicable (e.g. the magnitude of the force of gravity is $mg$, and friction (if kinetic or max static) is $|$. Do not plug in the moment of inertia for any object, but do think about about what it would be for each scenario.

**Example:** A bicycle is slowing down by using brakes that squeeze two rubber pads against the rim of the wheels with equal force. Analyze all the torques on the front wheel ($m_1$) and radius r. The coefficient of static friction and kinetic friction between the rubber brake pads and the rim are $\mu_{s,p}$ and $\mu_{k,p}$ respectively. Ignore the rolling friction between the tire and the surface, and assume the normal force acts radially.

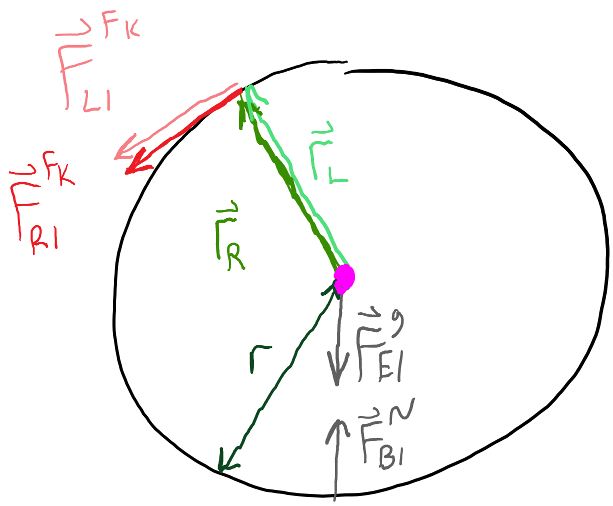
Sketch


Coordinate system

CCW (+)

CW (−)

e-FBD of $m_1$




Newton's 2nd law analysis

$$\sum \tau_o = I_o \alpha$$

$$\tau^R + \tau^L + \tau^g + \tau^N = I_o\alpha$$

$$|\vec{r}_R||\vec{F}^{F_K}_{R1}|\sin\theta_R + |\vec{r}_L||\vec{F}^{F_K}_{L1}|\sin\theta_L + |\vec{r}_g||\vec{F}^{g}_{E1}|\sin\theta_g + |\vec{r}_N||\vec{F}^{N}_{B1}|\sin\theta_B = I_o\alpha$$

($\sin\theta_R \to 1$, $\sin\theta_L \to 1$, $|\vec{r}_g| \to 0$, $\sin\theta_B \to 0$)

$$r\mu_K|\vec{F}^{N}_{R1}| + r\mu_K|\vec{F}^{N}_{L1}| = I_o\alpha \qquad |\vec{F}^{N}_{R1}| = |\vec{F}^{N}_{L1}|$$

$$2\mu_K r|\vec{F}^{N}_{R1}| = I_o\alpha$$

$$2\mu_K r|\vec{F}^{N}_{R1}| = \tfrac{1}{2}m_1 r^2\alpha$$

$$4\mu_K|\vec{F}^{N}_{R1}| = m_1 r\alpha$$

**Exercise 1:** A plank with length L and mass $m_1$, which is uniformly distributed, is balanced horizontally on a pivot located halfway from one end of the plank. A person of mass $m_2$ then sits on one of the ends of the plank. Analyze the torques on the plank about the pivot point the moment the person sits on the end.

Sketch

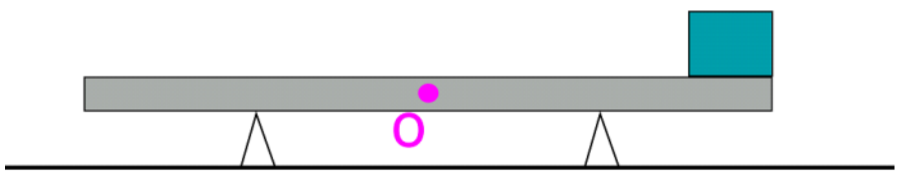
Coordinate system

e-FBD of $m_1$

Newton's $2^{nd}$ law analysis

**Exercise 2:** A plank with length L and mass $m_1$, which is uniformly distributed, rests horizontally on two pivots, each located a distance of 1/3 L from the ends. A box of width W and mass $m_2$, which is uniformly distributed, is placed at the end of the plank and is just the right weight that the plank L is about to tip over. Analyze the torques on the plank, the reference axis is halfway between the ends of the plank.

Sketch



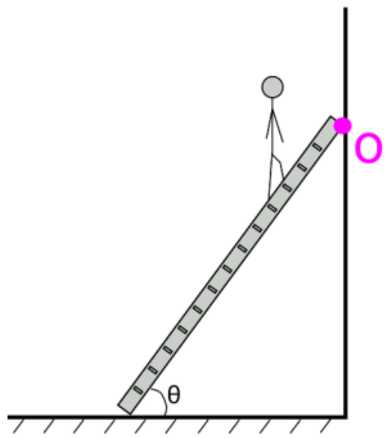

Coordinate system

e-FBD of $m_1$

Newton's $2^{nd}$ law analysis

**Exercise 3:** A ladder with length L and mass $m_1$, which is uniformly distributed, is leaning against a wall at an angle θ relative to the horizontal as shown in the figure below. A person of mass $m_2$ climbs the ladder some distance d along the length of the ladder, as measured from the bottom, such that the bottom of the ladder almost begins to slide relative to the horizontal surface. The coefficient of static friction between the horizontal surface and the ladder of $\mu_s$. Analyze the torques on the plank.

Sketch




Coordinate system

e-FBD of $m_1$

Newton's $2^{nd}$ law analysis

**Exercise 4:** A small ball of mass $m_1$ is attached to the end of string of length L and negligible mass. The other end of string is attached to a pivot located on a ceiling. The system forms a simple pendulum. Analyze the torques on the ball about the pivot on the ceiling when the ball makes an angle θ with respect to the vertical.

Sketch

Coordinate system

e-FBD of $m_1$

Newton's $2^{nd}$ law analysis

**Exercise 5:** A thin rod of length L and mass $m_1$, which is uniformly distributed, is attached to a ceiling at one end via a frictionless hinge. The system forms a physical pendulum. Analyze the torques on the rod about the hinge on the ceiling when the rod makes an angle θ with respect to the vertical.

Sketch

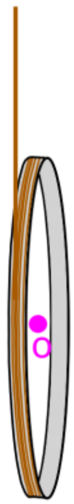
Coordinate system

e-FBD of $m_1$

Newton's $2^{nd}$ law analysis

**Exercise 6:** A thin circular ring with radius R and mass $m_1$ has string of negligible mass wrapped around it. A person holds one end of the string vertically and lets the ring fall, unraveling string as it descends. Analyze the torques on the ring about the center of the ring. (Hint: draw your e-FBD from a different perspective than the sketch.)

Sketch



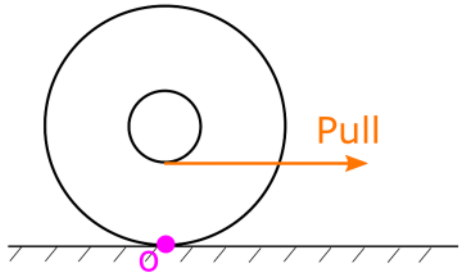

Coordinate system

e-FBD of $m_1$

Newton's $2^{nd}$ law analysis

**Exercise 7:** A yo-yo is made by securing two large radii, R, disks to each other via a smaller radii, r, cylinder with bearings so that the two larger disks can spin freely together. The yo-yo shown below is placed on a table with large enough friction such that the yo-yo doesn't slide relative to the table when you pull on the rope. A cross section of how the rope is wrapped around the center is also shown. Analyze all the torques on the yo-yo ($m_1$). The coefficient of static friction between the yo-yo and the table is $\mu_s$ . The yo-yo initially starts from rest and begins to rotate when you apply the force tension shown below.

Sketch



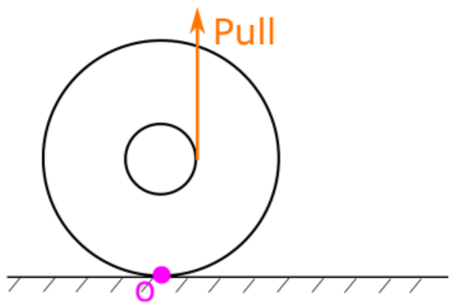

Coordinate system

e-FBD of $m_1$

Newton's $2^{nd}$ law analysis

**Exercise 8:** A yo-yo is made by securing two large radii, R, disks to each other via a smaller radii, r, cylinder with bearings so that the two larger disks can spin freely together. The yo-yo shown below is placed on a table with large enough friction such that the yo-yo doesn't slide relative to the table when you pull on the rope. A cross section of how the rope is wrapped around the center is also shown. Analyze all the torques on the yo-yo ($m_1$). The coefficient of static friction between the yo-yo and the table is $\mu_s$ . The yo-yo initially starts from rest and begins to rotate when you apply the force tension shown below.

Sketch



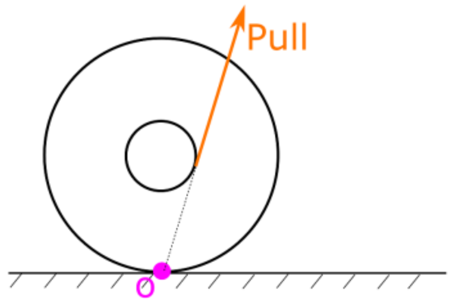

Coordinate system

e-FBD of $m_1$

Newton's $2^{nd}$ law analysis

**Exercise 9:** A yo-yo is made by securing two large radii, R, disks to each other via a smaller radii, r, cylinder with bearings so that the two larger disks can spin freely together. The yo-yo shown below is placed on a table with large enough friction such that the yo-yo doesn't slide relative to the table when you pull on the rope. A cross section of how the rope is wrapped around the center is also shown. Analyze all the torques on the yo-yo ($m_1$). The coefficient of static friction between the yo-yo and the table is $\mu_s$ . The yo-yo initially starts from rest and begins to rotate when you apply the force tension shown below.

Sketch



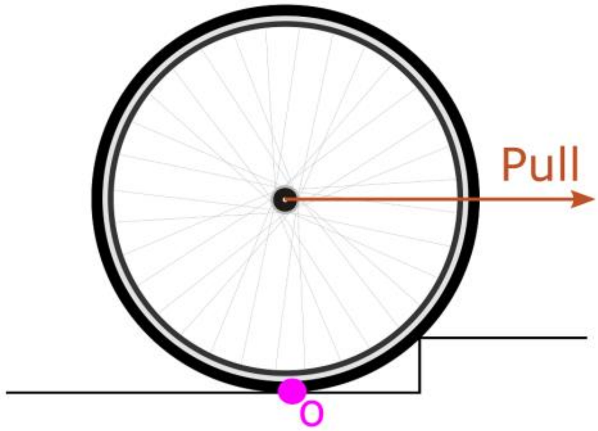

Coordinate system

e-FBD of $m_1$

Newton's $2^{nd}$ law analysis

**Exercise 10:** A bicycle wheel of radius R and mass $m_1$ encounters a step of height 1/4 R. A horizontal force is applied to the center of the wheel as shown in the figure below, the force is not enough pull the wheel over the step. Analyze the torques on the wheel.

Sketch




Coordinate system

e-FBD of $m_1$

Newton's $2^{nd}$ law analysis