1) Paul pushes a cart and block across the floor at constant speed. The cart has twice the mass as the block and the cart's wheels are "frictionless," meaning there is no friction force on the cart. The floor does cause friction on the block.

![Diagram of cart and block with person pushing]

\[ \vec{v} = 0.1 \text{ m/s to the right constant speed} \]

**Free-Body Diagrams**

**Group Problem 03**

**Name**

---

a) Draw a free body diagram for the **system of the cart and block together**, labeling all forces by type and with the object causing the force. Draw your arrows carefully to scale, consistent with \( \vec{F}_{net} = m\vec{a} \). Explain briefly.

\[
\begin{align*}
\vec{F}_{net} &= 0 \\
\vec{a} &= 0
\end{align*}
\]

Tell students before they start that Explain Briefly means to state why their FBD is consistent with the 2nd law. Here the net force and acceleration both equal 0 so \( N_{F, Sys} = W_{E, Sys} \) and \( f_{F, Sys} = N_{F, Sys} \).

b) Now draw a free body diagram for the **block only** labeling all forces by type and with the object causing the force. Draw your arrows carefully to scale, consistent with \( \vec{F}_{net} = m\vec{a} \). Explain briefly.

Friction is the same size as above as it's only on the block. Weight force 1/3 because the block has 1/3 the mass. Note that Paul does not push on the block, the cart does. All forces balanced in x and y because \( a = F_{net} = 0 \).

\[
\begin{align*}
\vec{F}_{net} &= 0 \\
\vec{a} &= 0
\end{align*}
\]

c) Now draw a free body diagram for the **cart only** labeling all forces by type and with the object causing the force. Draw your arrows carefully to scale, consistent with \( \vec{F}_{net} = m\vec{a} \). Explain briefly.

Friction is 0 now, the back arrow is the normal force of box on the cart. Weight force 2/3 the system total because the cart has 2/3 the mass. Paul does push on the cart. All forces balanced in x and y because \( a = F_{net} = 0 \). The normal of Paul on the cart = normal of Paul on the system above.

\[
\begin{align*}
\vec{F}_{net} &= 0 \\
\vec{a} &= 0
\end{align*}
\]
2) As Paul pushes a cart and block across the floor he tires and the cart and block begin to slow down. (The cart still has twice the mass as the block and the cart’s wheels are still "frictionless," meaning there is no friction force on the cart. The floor still causes friction on the block.)

\( \vec{v} = 0.1 \text{m/s to the right} \) slowing down

(a) Draw a free body diagram for the system of cart and block together labeling all forces by type and with the object causing the force. Draw your arrows carefully to scale, consistent with \( \vec{F}_{\text{net}} = m\vec{a} \). Explain briefly.

Friction is the same size as above as it’s only on the block (the students will not know that it doesn’t depend on distance). Weight force 1/3 because the block has 1/3 the mass. Note that Paul does not push on the block, the cart does. All forces balanced y because a = Fnet = 0 in the y direction. Normal of the cart on block is shorter because Fnet points left. Also note that as all accelerations are the same and the mass is 1/3, Fnet is also 1/3 as large as that on the system. This means that \( N_{c,b} \) is bigger than \( N_{p,sy} \) above!!!

(b) Now draw a free body diagram for the block only labeling all forces by type and with the object causing the force. Draw your arrows carefully to scale, consistent with \( \vec{F}_{\text{net}} = m\vec{a} \). Explain briefly.

(c) Now draw a free body diagram for the cart only labeling all forces by type and with the object causing the force. Draw your arrows carefully to scale, consistent with \( \vec{F}_{\text{net}} = m\vec{a} \). Explain briefly.
3) Paul pushes parallel to the handle of a lawnmower with a force directed at a $\theta$ angle 30° above horizontal. The lawnmower moves across the lawn at a constant speed as shown. The lawnmower has a 20 kg mass M. The grass impedes motion of the lawnmower and can be considered to have a coefficient of sliding friction $\mu_s$ of 0.2.

$\vec{v} = 0.1 \text{ m/s to the right constant speed}$

a) Draw a free body diagram for the system, the lawnmower, labeling all forces by type and with the object causing the force. Draw your arrows carefully to scale, consistent with $\vec{F}_{\text{net}} = m\vec{a}$ . What is the magnitude of the acceleration? Explain briefly.

$\vec{F}_{\text{net}} = 0$
$\vec{a} = 0$

b) Are there components of Paul's force parallel and perpendicular to the ground? What are they?

Parallel (along the x-axis): $F_{\text{P,sys}} \cos \theta$

Perpendicular (along the y-axis): $-F_{\text{P,sys}} \sin \theta$

c) Now redraw your free body diagram for the lawnmower replacing Paul's original force vector with the two from part b. Label all forces by type and with the object causing the force.

d) In terms of the normal force $N_{\text{G,sys}}$ and any knowns ($\theta$, M, $\mu_s$ & g) what is the frictional force $f_{\text{G,sys}}$?

$f_{\text{G,sys}} = \mu_s N_{\text{G,sys}}$
e) Write down expressions for Newton's 2\textsuperscript{nd} Law in the x and y directions.

\[ F_x = M \ a_x = 0 = -f_{G, Sys} + F_{x, P, Sys} = -f_{G, Sys} + F_{P, Sys} \cos \theta = - \mu_s N_{G, Sys} + F_{P, Sys} \cos \theta \]

\[ F_y = M \ a_y = 0 = N_{G, Sys} - W_{E, Sys} - F_{y, P, Sys} = 0 = N_{G, Sys} - mg - F_{P, Sys} \sin \theta \]

f) How does the magnitude of the normal force compare to the weight of the lawnmower?

The normal force is greater than the weight.

g) How much force does Paul apply?

h) What would happen if Paul increased his force? Would you expect the lawnmower to speed up or slow down. Explain your reasoning.
4) Tension at Work: You have been hired to design the interior of a special executive express elevator for a new office building. This elevator has all the latest safety features and will stop with an acceleration of g/3 in case of any emergency. The management would like a decorative lamp hanging from the unusually high ceiling of the elevator. You design a lamp which has three sections which hang one directly below the other. Each section is attached to the previous one by a single thin wire which also carries the electric current. The lamp is also attached to the ceiling by a single wire. Each section of the lamp weighs 7.0 N. Because the idea is to make each section appear that it is floating on air without support, you want to use the thinnest wire possible. Unfortunately the thinner the wire, the weaker it is. To determine the thinnest wire that can be used for each stage of the lamp, calculate the force on each wire in case of an emergency stop. (Do not consider the weight of the wire.)

\[ T_1 = \frac{7.0 \text{ N} + \frac{7.0 \text{ N}}{3}}{3} = 9 \frac{1}{3} \text{ N} \]

\[ T_2 = T_1 + \frac{7.0 \text{ N}}{3} + \frac{7.0 \text{ N}}{3} = 18 \frac{2}{3} \text{ N} \]

\[ T_3 = 28 \text{ N} \]
5) Worker’s Comp Scenario: Larry and Curly are trying to push a 100. kg box located 5.0 m meters from the end of a horizontal plank 10.0 m long but it just won’t budge. The plank is angled with one end on the ground and the other at the back of a truck bed 1.5 m above the ground. At the other end (i.e. one the ground) Moe is impatiently waiting for them to deliver it to him. He suggests that they go to the far end and start lifting the plank up. They do so and stop lifting just when the block starts sliding.

If the kinetic and static coefficients of friction are 0.19 and 0.30 respectively, how much higher must they lift the end of the plank before it starts to slide?

How fast is the block going when it encounters Moe (who has now turned around and is not paying attention)?