Physics 101: Lecture 7-8: Newton's Laws, Frictional Forces and Circular Motion

EXAM 1

- Exam 1 will be held Wed 2/20 – Fri 2/22
- You MUST sign up for a time slot here:
  - https://cbtf.engr.illinois.edu
  - Sign-Up Opens on Thursday 7 February 2019
- Exam is computer-administered at the CBTF:
  - When you make your reservation, a room assignment (either Grainger Library or DCL) will be listed on the reservation.
  - Mark your room assignment on your calendar.
- Exam covers Lectures 1-8 (kinematics and dynamics—Newton's Laws; friction; circular motion)
- No lab the week of exam (good sign-up slot!)
- Discussion **IS** held the week of the exam
- Contact Dr. Schulte w/ Qs about sign up: eschulte@illinois.edu
- Exam is all multiple choice (3 & 5 choice Qs)
- How to study for exam?

Continuing with friction:

Last time we discussed kinetic friction:

$$F_k = \mu_k N$$

Today we discuss Static Friction
(this one can be tricky!!)

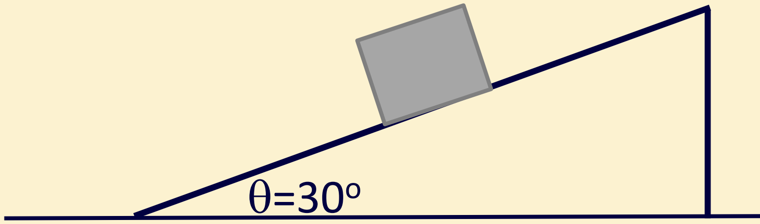
2. Static friction: Object must be stationary on a rough surface if it is going to MAYBE experience static friction. Static = not moving.

- Ex. 1: Book rests on table. Is there a frictional force?
- Ex. 2: Push book horizontally with a force of 3 N; doesn't move. Is there a frictional force?
- Ex. 3. Push book harder, 6 N, and it does not move.
- Static friction force: $F_s \leq \mu_s N$. Static friction can prevent motion, **up to a maximum force**! Once object starts to move, friction is *kinetic*.
- Bottom line: Static frictional force can have any value between 0 and a maximum of $\mu_s N$.
- Note: $\mu_k < \mu_s$ for same object on same surface
- Direction in which it points depends on the situation.

Another example involving friction

m_1=10 kg

The block is **stationary** and there is friction between the block and the incline.
The coefficients of friction are μ_s=0.7 & μ_k=0.45
What is the normal force on the block?

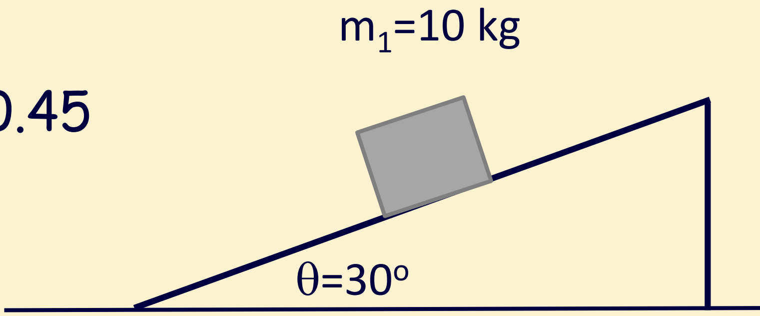


Plan:

1. Identify body, choose coordinate system, draw a FBD
2. Apply Newton's Second Law in y direction
3. Solve for N

Clicker question

The block is **stationary** and there is friction between the block and the incline.
The coefficients of friction are μ_s=0.7 & μ_k=0.45

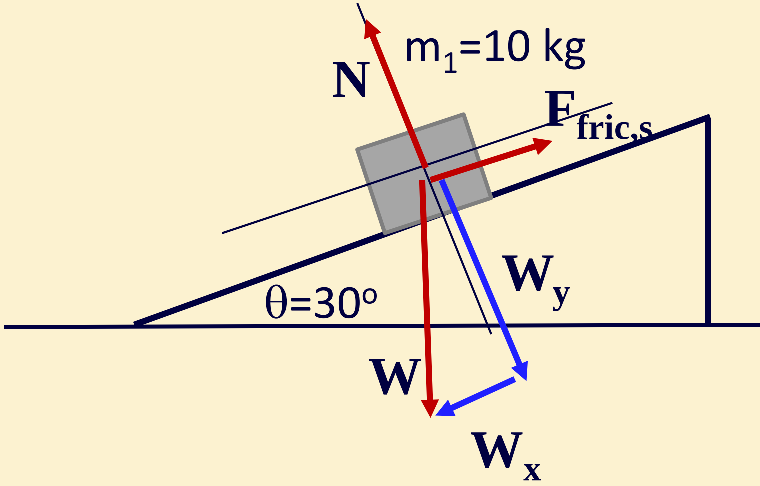


What is the static frictional force on the block?

a) 49 N   b) 59.4 N   c) 98 N   d) 84.9 N

(The normal force we found to be N=84.9 Newtons)

To find what static friction **needs to be**, apply N#2 in x-direction.



Plan:

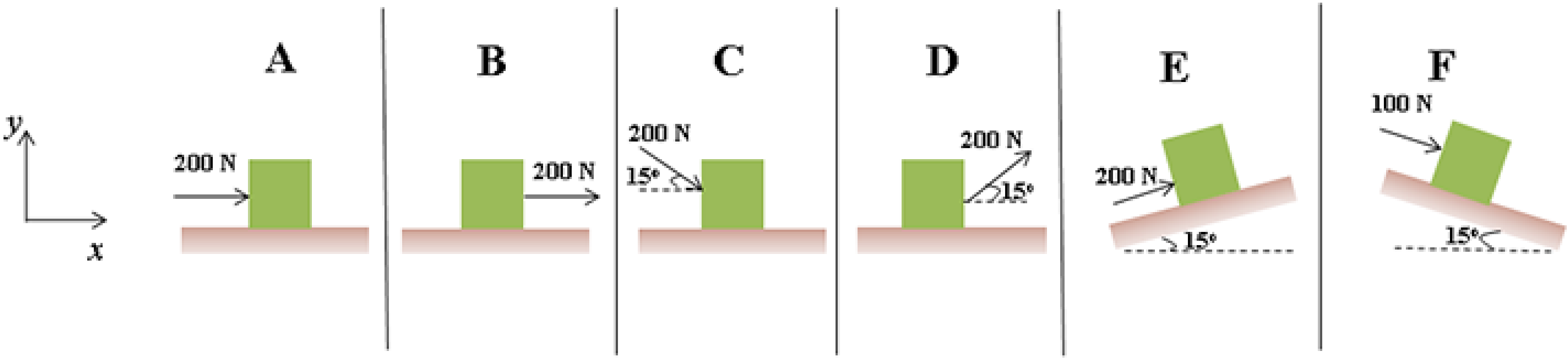
1. Use FBD and coordinate system from previous

2. Apply Newton's Second Law in x direction

3. Solve for static friction force knowing a=0

Checkpoint 1

A student is either pushing or pulling a 50-kg box along a carpeted platform. The box, however, remains at rest even though the student probes a number of setups, as shown. In all cases, the box and carpet are made of the same material.



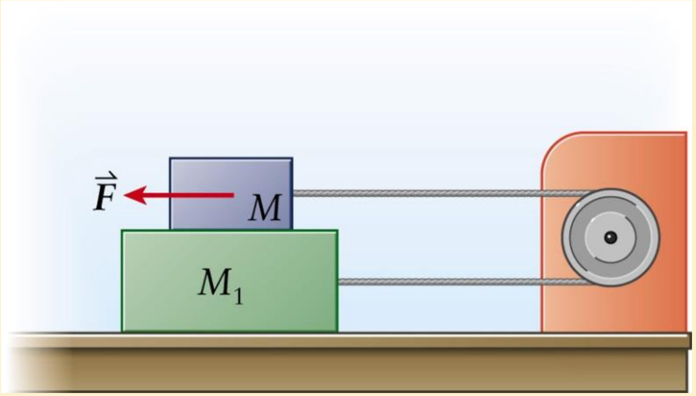
1) Which is the correct ranking of setups based on the magnitude of the friction force on the box due to the carpeted platform?

- D < E = F < A = B < C
- F < D < A = B = E < C
- E < C = D < A = B < F
- All the same because the box is at rest and therefore there is no friction between the box and the carpeted platform.

Checkpoint 2

A block of mass M rests on a block of mass M_1 which is on a tabletop. A light string passes over a frictionless peg and connects the blocks. The coefficient of kinetic friction between the blocks and between M_1 and the tabletop is the same. A force F pulls the upper block to the left and the lower block to the right. The blocks are moving at a constant speed. Which of the following statements is true?

A. There is no kinetic friction because the blocks are moving at constant speed.
B. The magnitude of the kinetic friction between the blocks and the kinetic friction between M_1 and the tabletop are the same because the coefficient of kinetic friction is the same.
C. The kinetic friction force that acts on M points to the left.
D. Block M_1 experiences the kinetic friction due to the tabletop and the kinetic friction due to M and both forces point to the left.



Force at an Angle Example

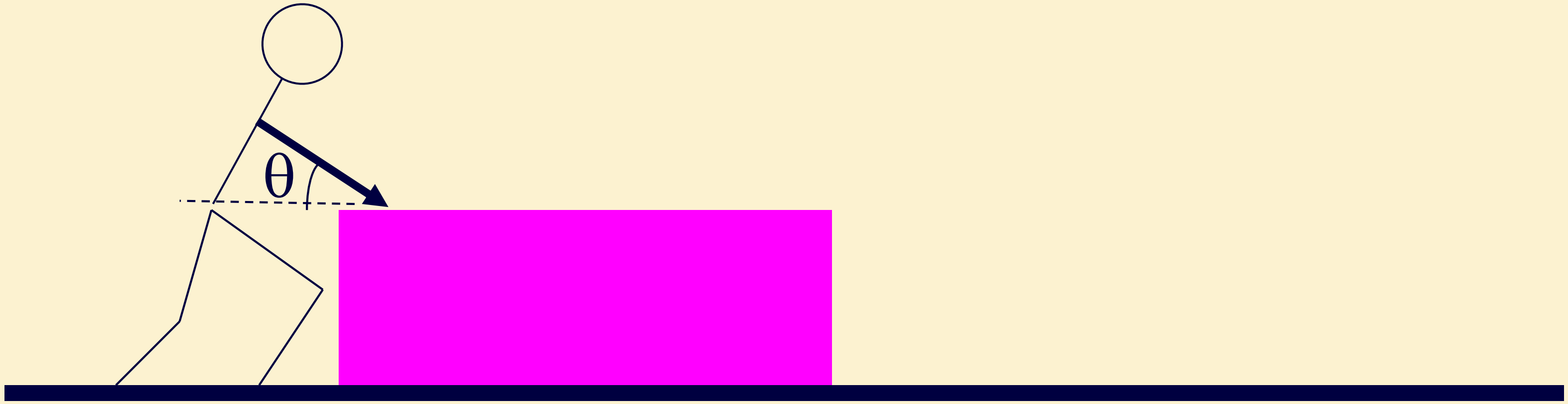
- A person is pushing a 15 kg block across a floor with μ_k= 0.4 at a constant speed. If she is pushing down at an angle of θ=25^o, what is the magnitude of her force on the block?

Clicker Question: The normal force exerted on the block by the floor is:

A) Less than the weight of the box

B) More than the weight of the box

C) Equal to the weight of the box



Force at Angle Example

A person is pushing a 15 kg block across a floor with $\mu_k = 0.4$ at a constant speed. If she is pushing down at an angle of $\theta=25^o$, what is the magnitude of her force on the block?

Plan step1: Body is the block, draw a FBD

Step 2: Apply N#2 in x-direction

$$P_x - f_k = P\cos(\theta) - f_k = 0 \quad (\text{note: } a=0)$$

$$P\cos(\theta) - \mu_k N = 0$$

$$N = P\cos(\theta) / \mu_k$$

Step 4: Use algebra to combine Equations and solve for P

$$(P\cos(\theta) / \mu_k) - mg - P\sin(\theta) = 0$$

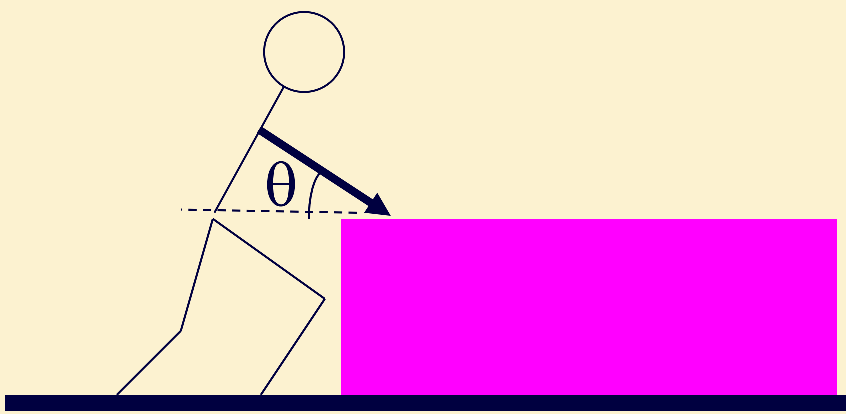
$$P\,(\cos(\theta) / \mu_k - \sin(\theta)) = mg$$

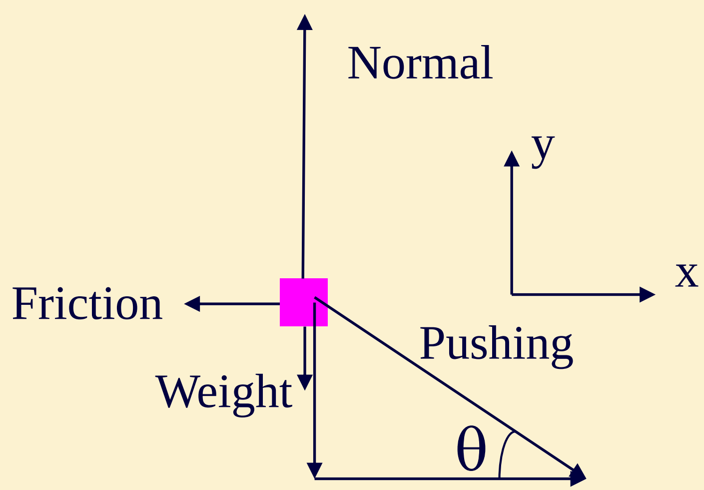
$$P = mg / (\cos(\theta)/\mu_k - \sin(\theta))$$

Step 3: Apply N#2 in y-dir

$$N - W - P_y = N - W - P\sin(\theta) = 0$$

$$N - mg - P\sin(\theta) = 0$$



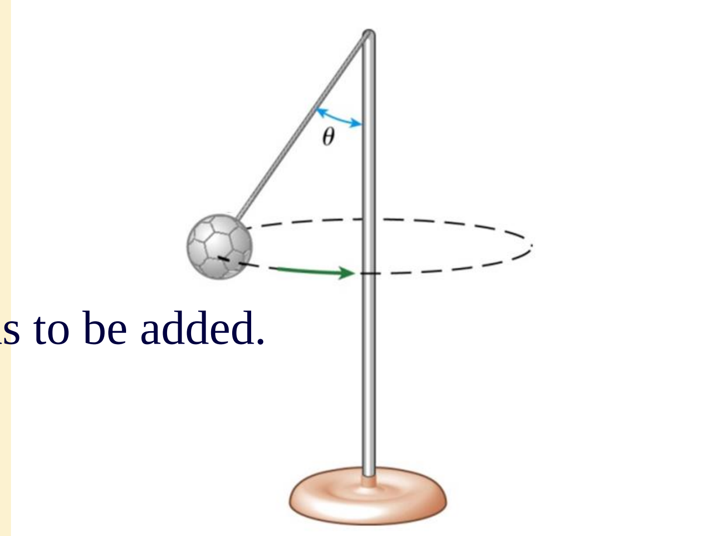


Checkpoint 4, Lecture 7

In the game of tetherball, a rope connects a ball to the top of a vertical pole as shown. In one case, a ball of mass m_1 is attached to the rope. In the second case, a ball of mass $m_2 = 2\ m_1$ is attached to the rope. In both cases the speed of the ball is the same.

What is the tension T_1 in the rope with ball m_1 compared to the tension T_2 in the rope with ball m_2?

A. $T_1 = T_2$
B. $T_1 = 2\ T_2$
C. $T_1 = 0.5\ T_2$
D. None of the above because the weight of the ball needs to be added.

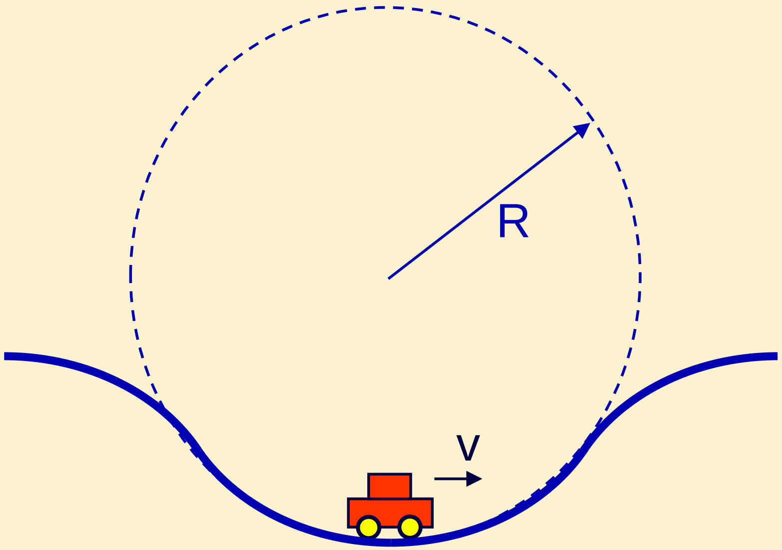


Clicker Q

Recall centripetal acceleration of an object moving in a circle: $a=v^2/R$

Suppose you are driving through a valley whose bottom has a circular shape. If your mass is m, what relationship below is valid for the normal force F_N exerted on you by the car seat as you drive past the bottom of the hill

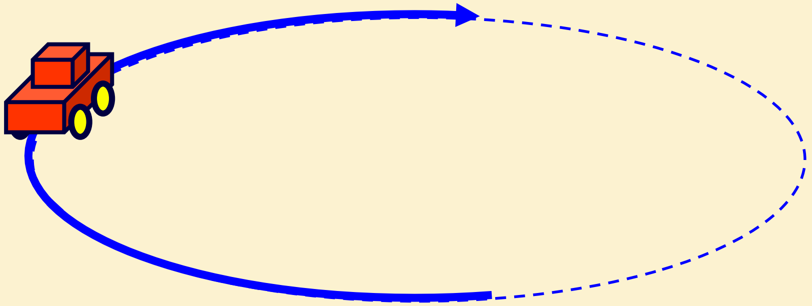
A. $F_N < mg$
B. $F_N = mg$
C. $F_N > mg$



Clicker Q

Consider the following situation: You are driving a car with constant speed around a horizontal circular track. On a piece of paper, draw a Free Body Diagram (FBD) for the car. The net force on the car is

A. Zero
B. Pointing radially inward
C. Pointing radially outward

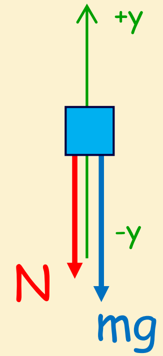


Roller Coaster Example

What is the minimum speed you must have at the top of a roller coaster loop or radius 20 m, to keep the wheels on the track?

Big Idea: N#2 applied to car at top of loop
Justification: N#2 relates forces and *a*, and *a* is related to speed for circular motion

Plan:
1. Select car as body, draw a FBD, pick coordinate system
2. Apply N#2 in y-dir., knowing *a* and *v* are related
3. Set N=0 at top so that wheels barely remain on track.
4. Solve for v.

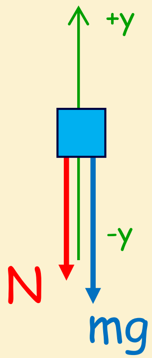


Roller Coaster Example

What is the minimum speed you must have at the top of a roller coaster loop or radius 20 m, to keep the wheels on the track?

Big Idea: N#2 applied to car at top of loop

Justification: N#2 relates forces and *a*, and *a* is related to speed for circular motion



Plan:

1. Select car to analyze, draw a FBD, pick coordinate system
2. Apply N#2 in y-dir., knowing *a* and *v* are related
3. Set N=0 at top so that wheels barely remain on track.
4. Solve for *v*

Y Direction: $F_{Net} = ma$

$-N - mg = m(-a) = -m v^2/R$

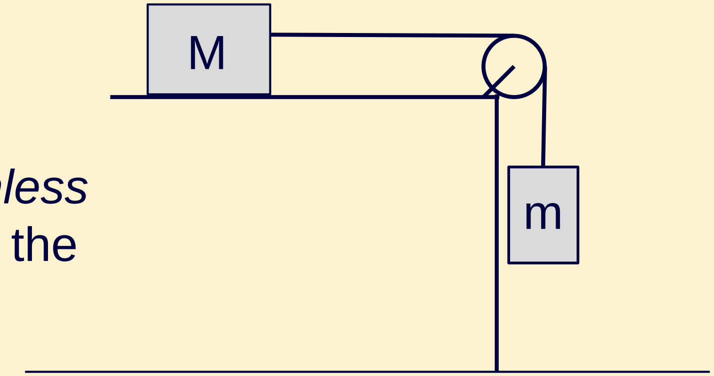
Let N = 0, just touching at top

$-mg = -m v^2/R$

$v = \text{sqrt}(g*R) = 14$ m/s

Clicker Q

The blocks of mass M and m are connected by a string that passes over a light, frictionless pulley. The system is released from rest with M on a *frictionless surface*. Which relationship is valid for the tension in the string connected to m?

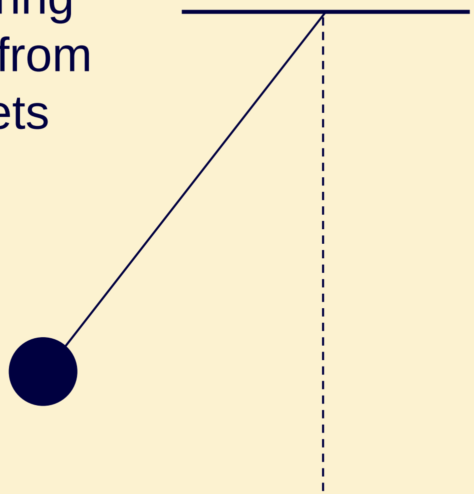


A. T = mg B. T < mg C. T > mg

Determine an expression for the tension in the string, and the acceleration of the masses, in terms of M, m and g.

Clicker Q

A pendulum is formed by attaching a mass, m, at the end of a string of length L. The mass is pulled with the string taut and released from rest, as shown in the diagram. The speed of the mass when it gets to the bottom of the swing is v. Which of the following is valid for the tension in the string at the bottom of the swing?

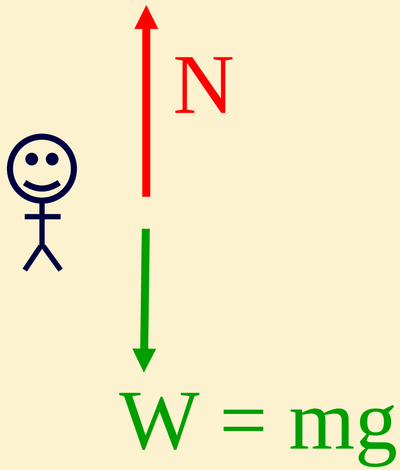


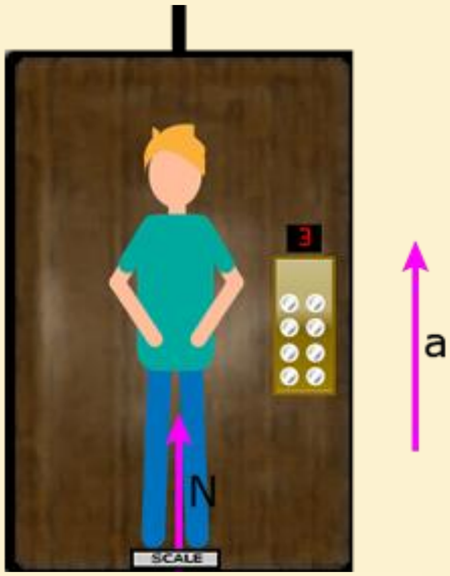
A. $T = mg$ B. $T < mg$ C. $T > mg$

Determine an expression for the tension in the string at the bottom of the swing in terms of m, L, v and g.

Apparent Weight

- Recall: $F_{Net} = m\,a$
  - ➔Consider a person accelerating up in an elevator.
  - ➔Draw FBD
  - ➔Apply Newton's 2nd!
    - » $F_{net} = ma$
    - » $N - mg = ma$
    - » Algebra: $N = m(g+a)$





- Apparent weight is ***normal force*** from scale or floor.

•Note: in free fall $a_y = -g$ so $N=0$

Apparent Weight Examples

A person's mass is 50 kg. What is the person's apparent weight when riding on an elevator

Last slide: $N = m(g+a)$

1. Going up with constant speed 5 m/s

   $a = 0$ so $N = mg = 490$ N

2. Going down with constant speed 4 m/s

   $a = 0$ so $N = mg = 490$ N

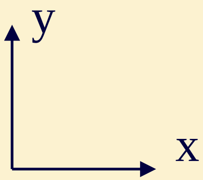
3. Accelerating up at a rate of 9.8 m/s^2

   $a = +9.8$ m/s so $N = 2\ mg = 980$ N

4. Accelerating down at a rate of 4.9 m/s^2

   $a = -4.9$ m/s so $N = (1/2)\ mg = 245$ N

Apparent Weight Clicker Qs



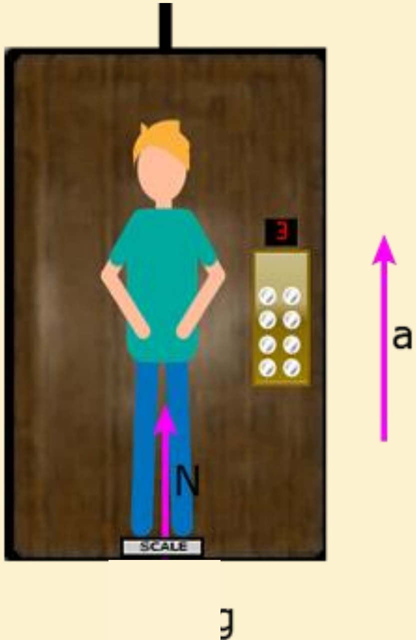
- You are standing on a scale inside an elevator. You weigh 125 pounds, but the scale reads 140 pounds.

The elevator is going (up down can't tell)

A B C

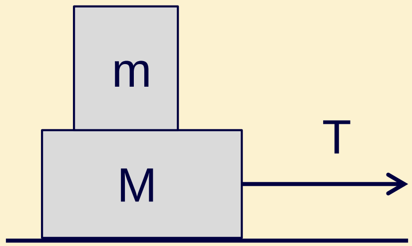
The elevator is accelerating (up down can't tell)

A B C



Example that puts it all together:
See if you can carry out the plan on your own

Two blocks are stacked one on top of the other on a table as shown. There is no friction between M and the table but there is friction between M and m. A string is used to pull M as shown and the blocks accelerate together along the surface. If the coefficient of static friction is μ_s=0.6, with what maximum tension can you pull on M before m starts to slide on top of M? Use M=0.4 kg and m=0.22 kg.



Big Idea: 2 Step problem: First apply N#2 to m to determine maximum acceleration.

Then apply N#2 to BOTH blocks together to relate T to maximum acceleration

Justification: N#2 will relate forces and a, and max. a will be related to max. T

Plan: 1) Draw a FBD for m with usual coordinate system

2) Apply N#2 to m and set friction to max. to determine max. a.

3) Solve for max. *a*.

From last slide: $a_{max} = \mu_s g$

Next analyze m+M together.

Plan: 1) Draw FBD for m & M together as one body with usual coordinate system

2) Apply N#2 to both blocks to relate T to a_{max}.

3) Substitute for a_{max} what you got from previous part to obtain a final expression for T