Physics 101 Lecture 6-7: Newton's Third Law
Two Dimensional Dynamics, & Kinetic Friction

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?

Procedure for applying Newton's Second Law:

A "plan" for solving any N#2 problem

- Identify/isolate *body* or *object* of interest.
- Draw a FBD (to identify all forces acting on body)
- Apply Newton's Law #2 (find F_{net} & do: $\mathbf{F}_{net}=m\boldsymbol{a}$)
- To apply Newton's 2nd Law:
  - ➔draw a coordinate system
  - ➔apply Newton's 2nd Law in the x and y directions.
- $\mathbf{F}_{Net}= m\boldsymbol{a}$ is a vector equation.
  - ➔ It must be satisfied independently in the x and y directions.
- Use algebra to solve for the unknown quantity.

Newton's 3rd Law

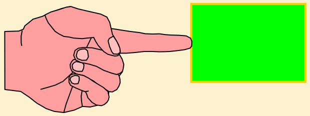
3. NEWTON'S THIRD LAW

The forces that two interacting objects (bodies) exert on each other are equal in magnitude and opposite in direction.
(Push demo; Fire extinguisher + cart)

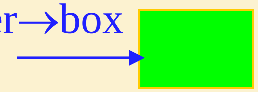
The two forces, which act on the two interacting bodies, are "action-reaction pairs."
Note: action-reaction force pairs act on different bodies.

Newton's Third Law

- For every action, there is an equal and opposite reaction.



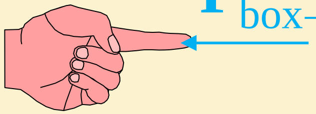
$\mathbf{F}_{finger\rightarrow box}$



Finger pushes on box

$\mathbf{F}_{finger\rightarrow box}$ = force exerted by finger on box

$\mathbf{F}_{box\rightarrow finger}$



Box pushes on finger

$\mathbf{F}_{box\rightarrow finger}$ = force exerted by box on finger

Third Law:

$\mathbf{F}_{box\rightarrow finger} = - \mathbf{F}_{finger\rightarrow box}$ (Action-reaction pair)

Newton's 3rd Law Clicker Qs

Suppose you are an astronaut in outer space giving a brief push to a spacecraft whose mass is bigger than your own.

1) Compare the **magnitude** of the force you exert on the spacecraft, F_S, to the **magnitude** of the force exerted by the spacecraft on you, F_A, while you are pushing:

1. $F_A = F_S$
2. $F_A > F_S$
3. $F_A < F_S$

Another Newton's 3rd Law Clicker Q

A person stands still on the ground outside on a windy day. What is the reaction force to the person's weight?

A. The equal and opposite normal force exerted on the person by the ground

B. The force that the wind exerts on the person

C. The upward force that the man exerts on the earth

How to identify action-reaction force pairs?

Given a force on body 1, ask: What body 2 exerts that force? The reaction force is the equal and opposite force that body 1 exerts on body 2.

The equal and opposite forces appear on *different* free body diagrams because they act on different bodies.

Newton's Laws review through problems

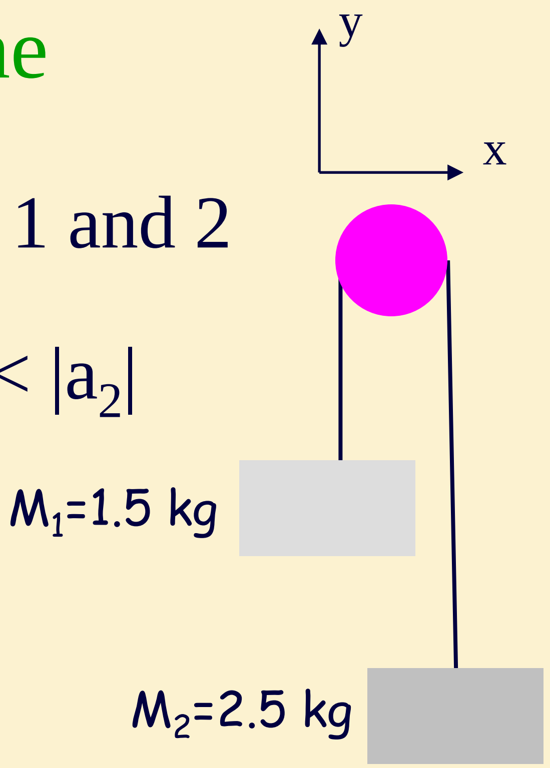
Pulley Example

- Two boxes are connected by a string over a frictionless pulley. Box 1 has mass M_1=1.5 kg, box 2 has a mass of M_2=2.5 kg. Box 2 starts from rest 0.8 meters above the table, how long does it take to hit the table?

Step 1: Need acceleration to find time

Clicker: Compare the acceleration of boxes 1 and 2

A) $|a_1| > |a_2|$ B) $|a_1| = |a_2|$ C) $|a_1| < |a_2|$



Big Idea: Apply N#2 to each block to first find acceleration, then use kinematics to find t.

Justification: The two blocks experience forces and application of N#2 will let you find *a*

Plan: 1. Identify body(bodies) to be analyzed: In this case, both M_1 and M_2.

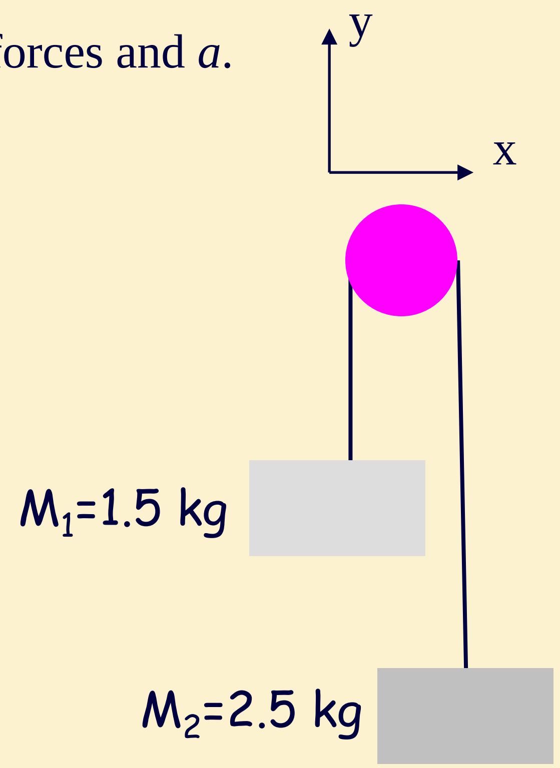
2. Pick usual coordinate system with origin on the ground and draw FBD

3. Apply N#2 to both masses, and be consistent with signs of forces and *a*.

4. Solve resulting equations for *a*.

5. Use kinematics for find time for to drop 0.8 m to table

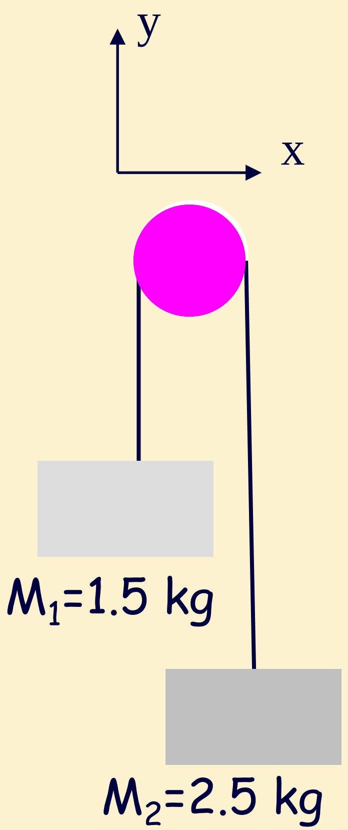
Let's carry out the plan



Pulley Example

- Two boxes are connected by a string over a frictionless pulley. Box 1 has mass M_1=1.5 kg, box 2 has a mass of M_2=2.5 kg. Box 2 starts from rest 0.8 meters above the table, $\boxed{\text{how long does it take to hit the table?}}$

5. Use kinematics to find time to drop 0.8 m to table



$a = (M_2 - M_1)g / (M_1+M_2)$

$a = 2.45 \text{ m/s}^2$

$y = y_0 + v_0 t + ½ a t^2$

$y = ½ a t^2$

$t = \text{sqrt}(2y/a)$

$t = 0.81$ seconds

Forces in 2 Dimensions: Ramp

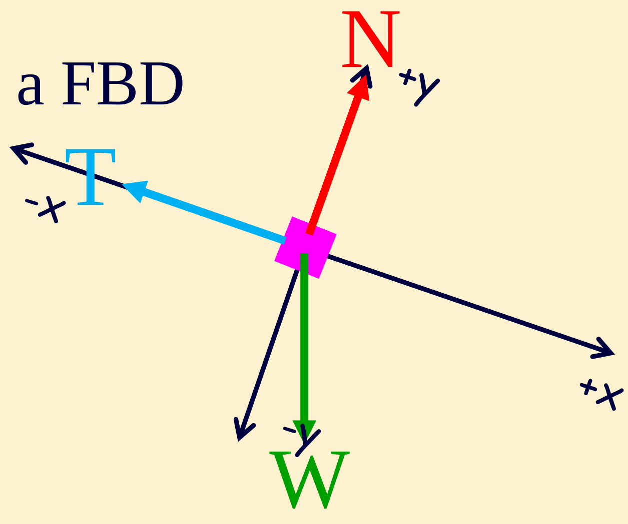
Calculate tension, T, in the rope necessary to keep the 5 kg block from sliding down a **frictionless** incline of 20 degrees.

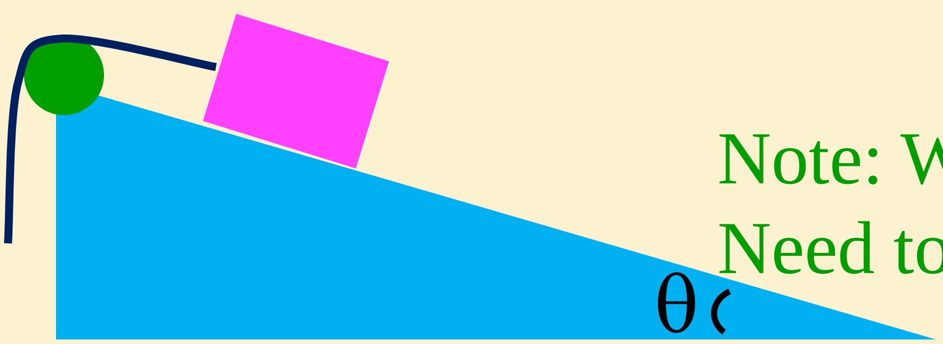
- **Big Idea**: Apply N#2 to the block.
- **Justification**: The block experiences forces and application of N#2 will let you find *T*.
- **Plan**: 1. Body is the block

  2. Pick coordinate system and draw a FBD

  3. Apply N#2 in x and y directions

  4. Solve for *T*.

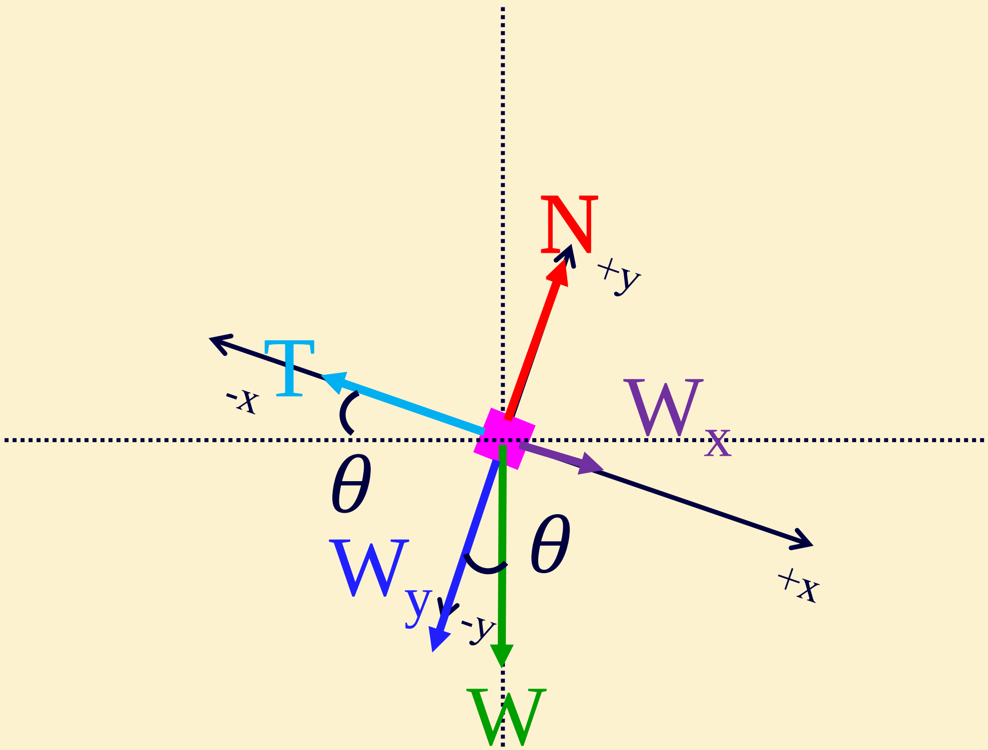




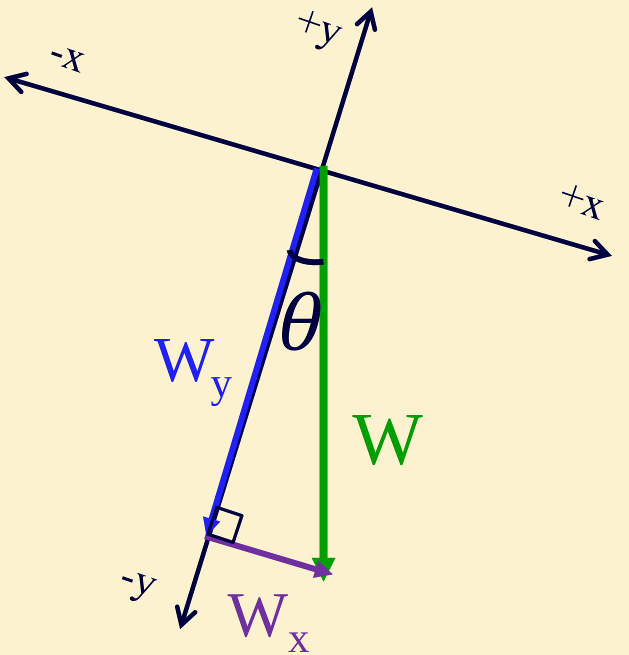
Note: Weight is not in x or y direction!

Need to DECOMPOSE it!

Vector Decomposition



Let's now do Step 3 –
Newton's 2nd!



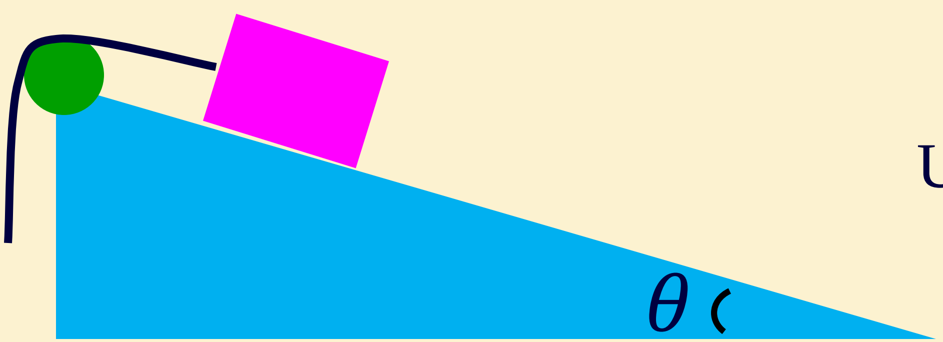
Split W into COMPONENTS parallel to axes

Note that

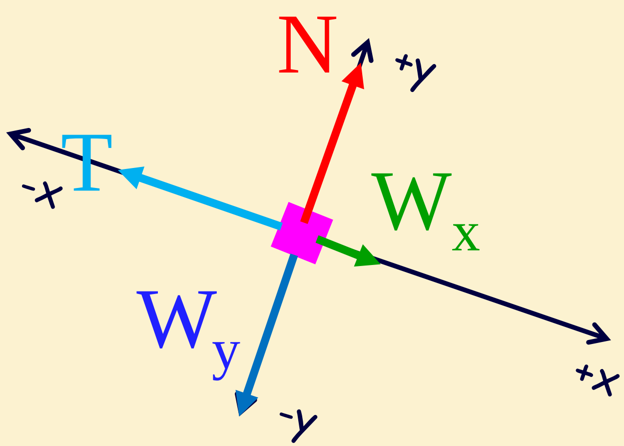
$$\overrightarrow{W} = \overrightarrow{W_y} + \overrightarrow{W_x}$$

Using Trig: $W_x = W \sin\theta$

$W_y = W \cos\theta$

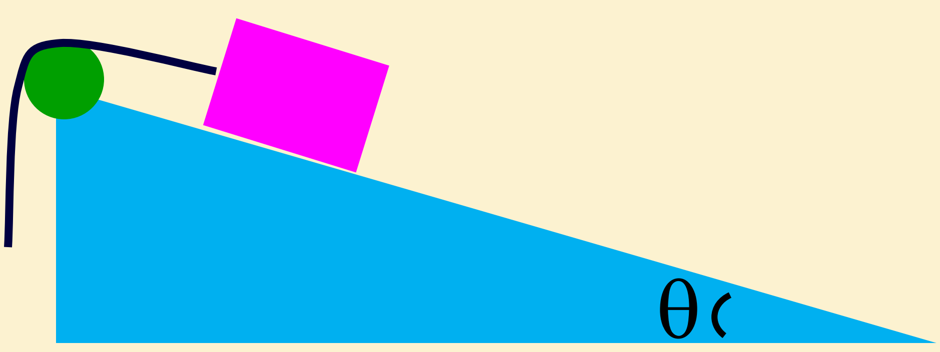


Calculate tension necessary to keep the 5 kg block from sliding down a frictionless incline of 20 degrees.



$W_x = W \sin\theta$

$W_y = W \cos\theta$



Step 3 – Newton's 2nd!

x direction: $F_{net,\,x} = ma_x$

System is in equilibrium (a = 0)!

$$F_{net,\,x} = 0$$

$$W_x - T = 0$$

Step 4: Solve for T

$$T = W_x = W \sin\theta$$

$$= mg \sin\theta$$

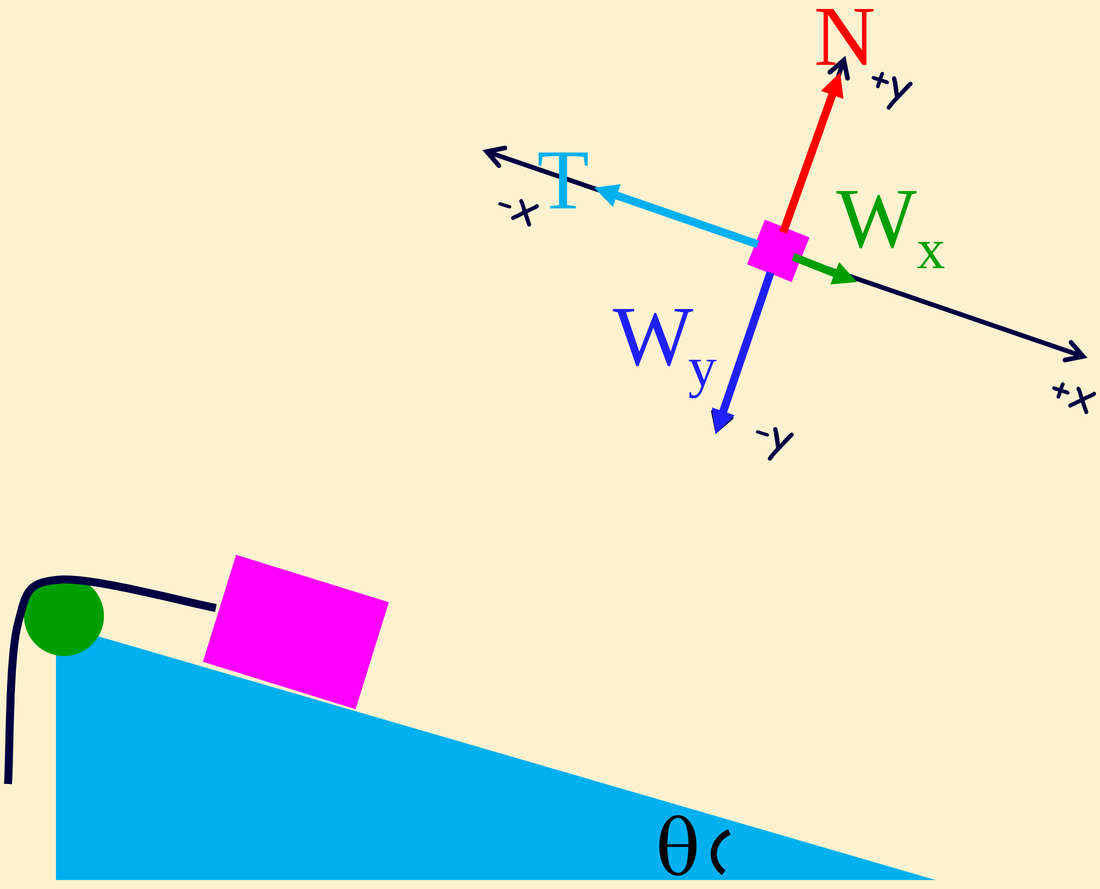
$$= (5\text{kg})(9.8\text{m/s}^2)\sin(20^o)$$

$$\boxed{T = 16.8\text{ N}}$$

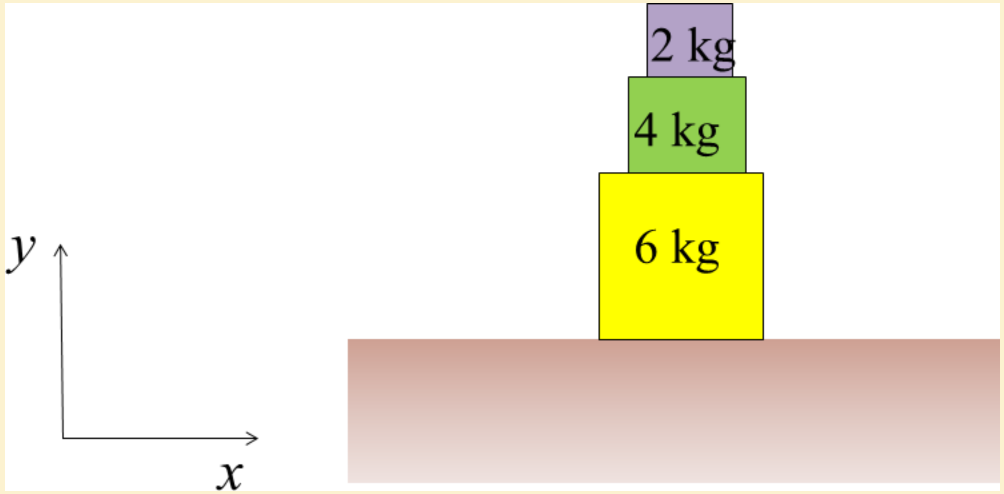
Normal Force Clicker Question

Which expression is accurate for the normal force exerted by the ramp on the block?

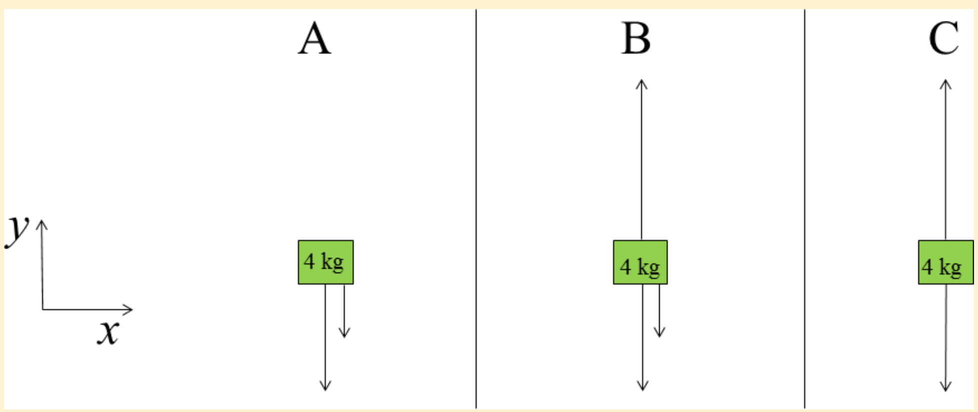
A) N > mg   B) N = mg   C) N < mg



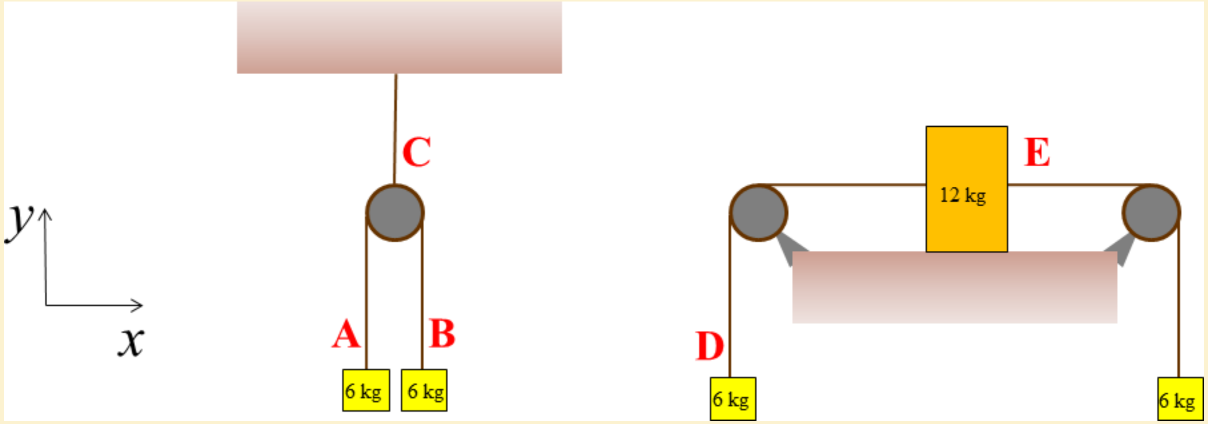
Checkpoint 3



Which is the free body diagram (green block)?



Checkpoint 4



Rank the tensions:

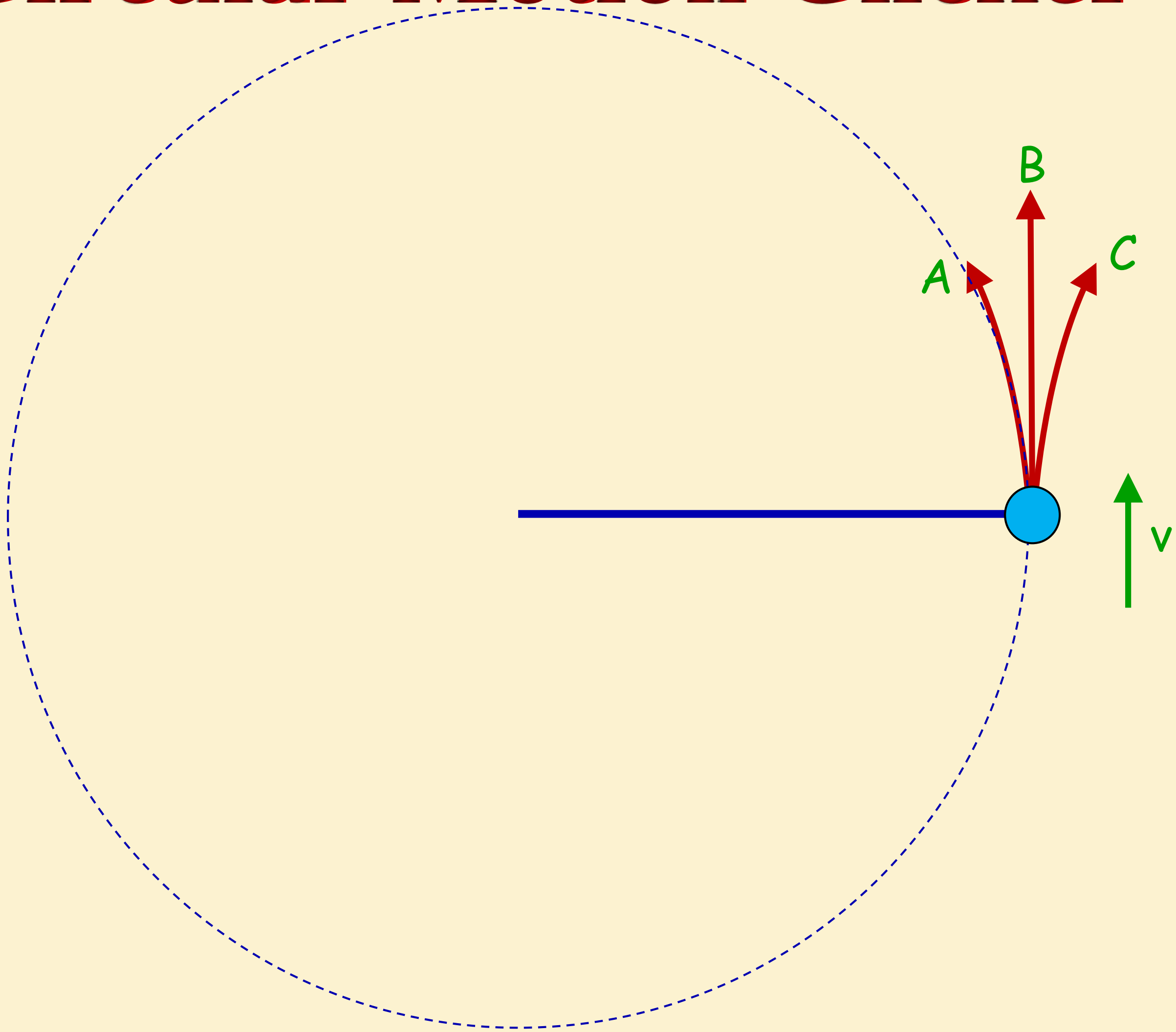
A. $T_A = T_B = T_D < T_C < T_E$

B. $T_D = T_A < T_B < T_C = T_E$

C. $T_A = T_B = T_C = T_D = T_E$

D. $T_A = T_B = T_D = T_E < T_C$

Circular Motion Clicker Q



A ball is going around in a circle attached to a string. If the string breaks at the instant shown, which path will the ball follow (demo)?

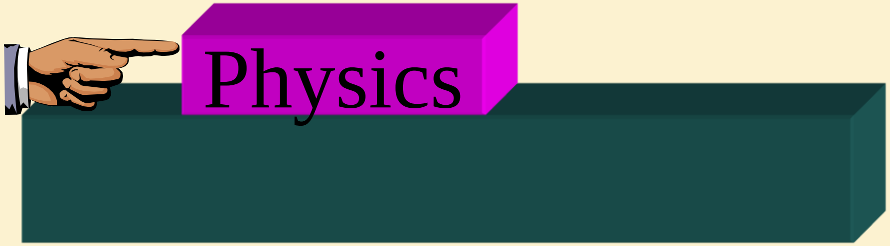
Friction

- Friction comes in two types: Kinetic and static
- Today we deal with kinetic friction, the easier of the two

2-Dimensional Equilibrium example

An example with Friction

$\boxed{\text{Calculate force of hand}}$ to keep a book sliding at ***constant speed (i.e. a = 0)***, if the mass of the book is 1 Kg, the coefficient of static friction is μ_s=0.84, and the coefficient of kinetic friction is μ_k=0.75



Before solving problem, let's discuss friction

Friction comes in two types: Kinetic and static

Today we deal with kinetic friction, the easier of the two

1. **Kinetic friction**: Object must be sliding on a rough surface to experience kinetic friction—kinetic implies motion, so it is friction when something moves. Direction in which it acts depends on situation:

$$\mathbf{F_k = \mu_k N}$$

μ_k is the **coefficient of kinetic friction** a number between 0 and 1.

μ_k depends on the two surfaces that rub against each other.

2 Dimensional Equilibrium!

Calculate force of hand to keep a book sliding at ***constant speed (i.e. a = 0)***, if the mass of the book is 1 Kg, μ_s=.84 and μ_k=.75

Apply Newton's 2nd law in both x and y directions (x & y are independent)!

Plan step 1 – Identify object,

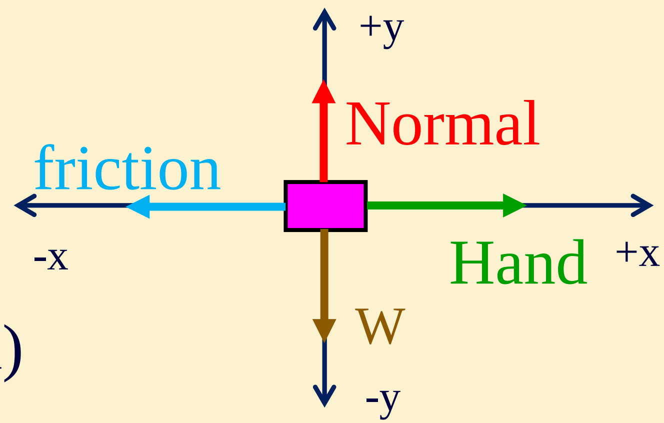
Plan step 2 – Pick coordinate system

Plan step 3 – Identify Forces (draw FBD)

Plan step 4 – Apply Newton's 2nd ($F_{Net} = ma$)

Plan Step 5 – Solve for force of the hand

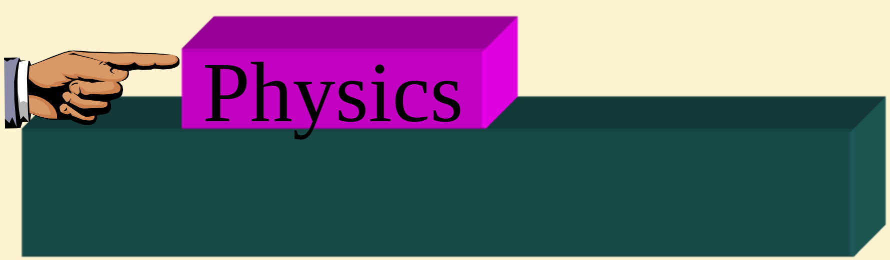
Treat x and y independently!



$$F_{Net,\,y} = N - W = ma_y = 0$$

$$F_{Net,\,x} = \boxed{H} - f_k = ma_x = 0$$

This is what we want!



Calculate force of hand to keep the book sliding at a ***constant speed (i.e. a = 0)***, if the mass of the book is 1 Kg, μ_s = .84 and μ_k=.75.

Plan Step 5 - Solve for force of the hand

$F_{Net,\,y} = N - W = 0 \Rightarrow N = W = mg$

$F_{Net,\,x} = H - f_k = 0 \Rightarrow H = f_k$

- Magnitude of kinetic frictional force is proportional to the normal force and always opposes motion!

$\rightarrow f_k = \mu_k N$

μ_k coefficient of Kinetic (sliding) friction

$$H = f_k = \mu_k N = \mu_k W = \mu_k mg$$

$$= (0.75)\text{x}(1\ \text{kg})\text{x}(9.8\ \text{m/s}^2)$$

Note: In this case N=weight since surface was horizontal

$$\boxed{H = 7.35\ \text{N}}$$