Physics 101: Lecture 06

Newton's Third Law and Two Dimensional Dynamics

EXAM 1

- Exam 1 will be held Wed 2/21 – Fri 2/23
- You MUST sign up for a time slot here:

https://my.physics.illinois.edu/undergrad/onlineexams/signup-student.asp

- Exam is computer administered in Loomis 257
- 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?

spooky rules

- We saw last lecture how not applying physics ideas can get us in trouble (blocks accelerating together).
- To avoid spooky rules, ask yourself before you jump into solving a problem, "Am I making this up or am I applying concepts and procedures I learned in the prelectures and in class?"

Procedure for applying Newton's Second Law:

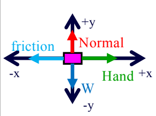
A "plan" for solving any N#2 problem

- 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.

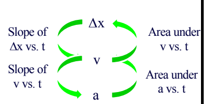
Overview

Moving back and forth across the ideas in the course thus far

Draw a FBD to determine F_{Net} ⇄ Apply Newton's 2nd Law to determine acceleration ⇄ Use Kinematics to determine/describe motion of the object



$$\vec{F}_{Net} = m\vec{a}$$



$x = x_0 + v_0t + 1/2\ at^2$

$v = v_0 + at$

$v^2 = v_0^2 + 2a(x-x_0)$

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.

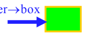
(Push demo; Fire extinguisher + cart)

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.

$F_{finger \to box}$



Finger pushes on box

$F_{finger \to box}$ = force exerted by finger on box

$F_{box \to finger}$

Box pushes on finger

$F_{box \to finger}$ = force exerted by box on finger

Third Law:

$F_{box \to finger} = - F_{finger \to box}$ (Action-reaction pair)

How to identify action-reaction force pairs

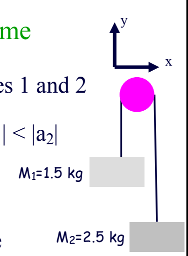
- Once given a force acting on body 1, ask: What body 2 exerts that force? Then the reaction force is the equal and opposite force that body 1 exerts on body 2.

Now: review Newton's Laws by doing 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) $|a_1| < |a_2|$

Since the two blocks move together at all times, they must have the same |acceleration| (if they didn't, the string would stretch or compress, which is not allowed)

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.

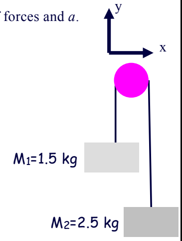
2. Pick usual coordinate system with origin on the ground and draw FBD

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

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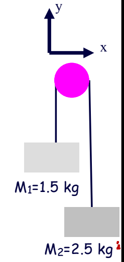
5. Use kinematics to find time to drop 0.8 m to table

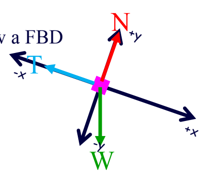
$a = (M_2 - M_1)g / (M_1+M_2)$
$a = 2.45\ m/s^2$
$\Delta y = v_0 t + \frac{1}{2} a t^2$
$\Delta y = \frac{1}{2} a t^2$
$t = \text{sqrt}(2\ \Delta y/a)$
$t = 0.81$ seconds

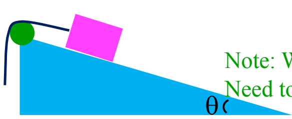


Forces in 2 Dimensions: Ramp

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

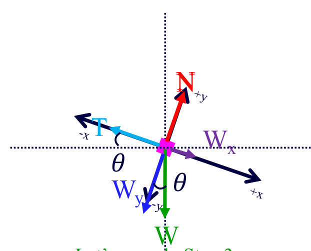
- **Big Idea**: Apply N#2 to the block.
- **Justification**: The block experiences forces and application of N#2 will let you find T.
- **Plan**: 1. Body is the block
  2. Pick coordinate system and draw a FBD
  3. Apply N#2 in x and y directions
  4. Solve for T.



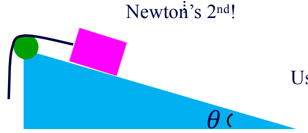


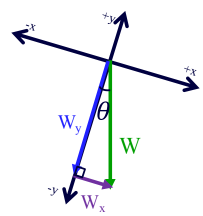
Note: Weight is not in x or y direction! Need to DECOMPOSE it!

Vector Decomposition



Let's now do Step 3 – Newton's 2nd!





Split W into COMPONENTS parallel to axes

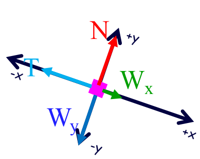
Note that

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

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.



$W_x = W \sin\theta$

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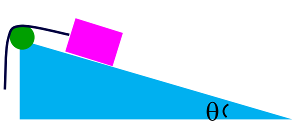


Step 3 – Newton's 2nd!

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

System is in equilibrium (a = 0)!

$F_{net,x} = 0$

$W_x - T = 0$

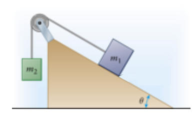
Step 4: Solve for T

$T = W_x = W \sin\theta$
$= mg \sin\theta$
$= (5kg)(9.8m/s^2) \sin(20^o)$

$T = 16.8$ N

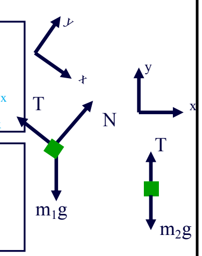
Pulley, Incline and 2 blocks

A block of mass m_1 = 2.6 kg rests upon a frictionless incline as shown and is connected to mass m_1 via a string over an ideal pulley. What is the acceleration of block m_1 if m_2 = 2.0 kg? Use θ=30°



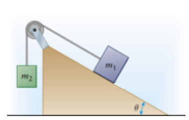
For m_1: BIG IDEA: N#2 and Plan Step
Draw FBD — See diagram
Apply N#2 in x-dir — $-T + m_1 g \sin(30) = m_1 a_{1x}$
$T = m_1 g \sin(30) - m_1 a_{1x}$

For m_2: BIG IDEA: N#2 and Plan Step
Draw FBD — See diagram
Apply N#2 in y-dir — $T - m_2 g = m_2(a_{2y})$
Note: $|a_{1x}| = |a_{2y}| = a$



Pulley, Incline and 2 blocks

A block of mass m_1 = 2.6 kg rests upon a frictionless incline as shown and is connected to mass m_1 via a flexible cord over an ideal pulley. What is the acceleration of block m_1 if m_2 = 2.0 kg?



Note: We have assumed a certain direction of motion (M2 rises and M1 moves down incline)—how would our results tell us we guessed wrong?

Use algebra to solve two equations in 2 unknowns

$T = m_1 g \sin(30) - m_1 a$ and $T - m_2 g = m_2 a$

Substitute T from first eqn into second eqn: $a = g\dfrac{m_1 \sin(30) - m_2}{m_1 + m_2}$

$m_1 g \sin(30) - m_1 a - m_2 g = m_2 a$

$m_1 g \sin(30) - m_2 g = m_1 a + m_2 a$

$g(m_1 \sin(30) - m_2) = (m_1 + m_2) a$

$a = -1.49 \text{ m/s}^2$

Blocks move in opposite direction