PHYS 101 Lecture 5 Dynamics: Forces & Newton's Laws

Newton's 3 Laws of Motion

(1 and 2 now; 3 later)

- NEWTON'S FIRST LAW:
  - If there is zero net force on an object (body), then its speed and direction will not change. **Fred the Bear demo**
  - Inertia (**Air track demo, dishes demo, ball on string**)
- NEWTON'S SECOND LAW:
  - If a *nonzero net force* acts on an object, its motion will change according to this equation:

$$F_{Net} = ma \leftarrow \text{Acceleration}$$

↑ Net Force ↑ Mass

Newton's Laws of Motion

NEWTON'S SECOND LAW (abbreviate: N#2)

If a nonzero net force is acting on an object its motion will change:

$$\mathbf{F}_{Net} = m\boldsymbol{a}$$ (F and a are vectors)

- The *net force* is the **vector sum** of all the individual forces acting on an *object*.
- **To apply N#2, you must**:
  - ➔ Identify the *object* that you are analyzing.
  - ➔ identify *all forces* acting on the object.
  - ➔ You then add (as vectors) all forces to get the *net force*.

Please follow the regimen I'm teaching you

Two types of forces in PHYS101

- *Type 1: Contact forces* (must touch object to exert force)

  ➔ *Normal*: Perpendicular to surface

  ➔ *Friction*: Parallel to surface (two types: static and kinetic)

  ➔ *Tension*: ropes & strings

  ➔ *Springs*: $F = -kx$

  ➔ Other forces that touch object (e.g., a hand pushing)

  These forces act at the point of contact only

  This is a *complete list* of contact forces.

There are two types of forces we will study in PHYS 101

- *Type 2: Non-contact forces*: Action at a distance forces. Only one in Phys 101—gravitational force

➔In PHYS 101 we study gravitational force = weight

➔Near the earth's surface, $W = m_{object}\, g$

➔*Note: Any two masses will exert an attractive gravitational force on each other—more on that at a later lecture*

In Phys 102: electromagnetic force.

Applying Newton's Second Law: The Free-Body Diagram (FBD)

- A *free-body diagram (great tool for identifying forces)*:
  - ➔ isolates the object being analyzed
  - ➔ has labeled arrows (vectors) *for each individual force acting on the object*.
- The vector length is the magnitude of the force
- The vector direction is the direction in which the force acts
- The *net force* is the **vector sum** of all the forces acting on an *object*.
- A FBD should NEVER show a **net force.**
  - ➔ The net force is the sum of the forces in the FBD.
  - ➔ Draw the forces with tail starting on object

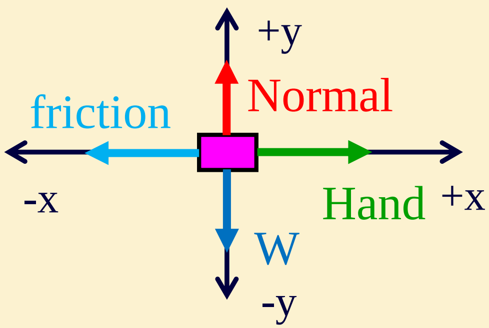
Applying Newton's Second Law

- 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 Law #2:
  - ➔draw a coordinate system
  - ➔apply Newton's Law #2 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.

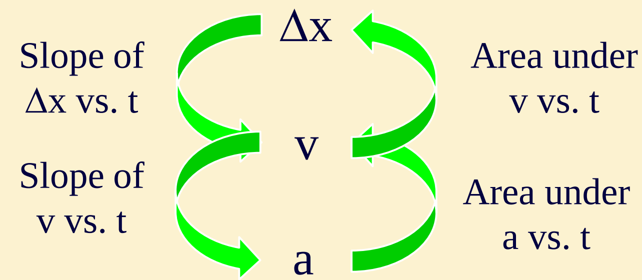
Overview

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



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



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

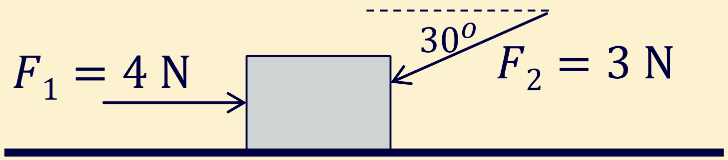
$$v = v_0 + at$$

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

Example

A block of mass $m = 0.4$ kg is being pushed by two different people with the forces shown. The floor is frictionless.

What is the acceleration of the block?

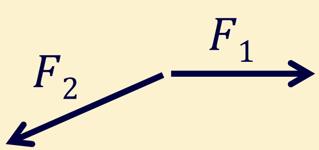


Isolate body: The block

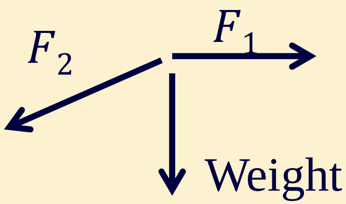
N means *Newtons* for units of force

1 N = 1 kg m/s^2

Clicker Q: Which FBD is appropriate for this situation?



A



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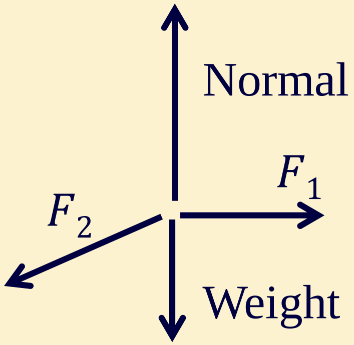

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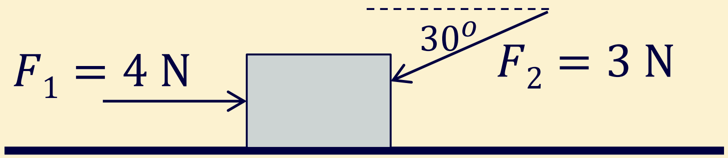
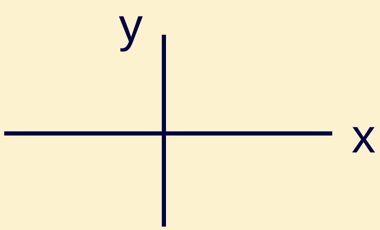
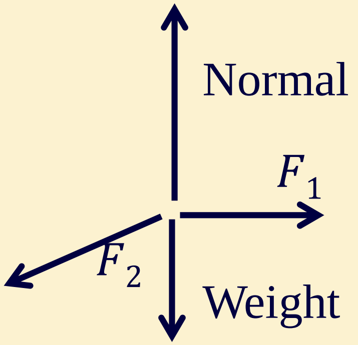
Example

A block of mass m=0.4 kg is being pushed by two different people with the forces shown. The floor is frictionless. What is the acceleration of the block?







Isolate body: The block

Using the standard coordinate system shown, let's decompose the forces in the x and y directions and apply Newton's Second Law.

x-direction

$$F_1 - F_{2,x} = ma_x$$
$$4N - 3N(\cos 30^o) = ma_x$$
$$4N - 2.6N = (0.4kg)\, a_x$$
Solve for a_x
$$a_x = (4N - 2.6N)/0.4kg = 3.5\ m/s^2$$

y-direction

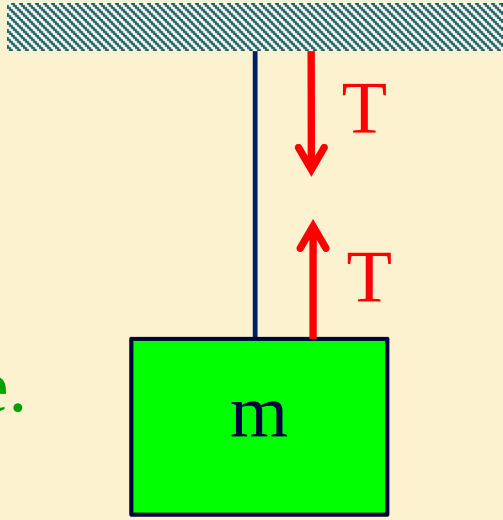
$$-F_{2,y} - W + N = ma_y$$
$$-3N(\sin 30^o) - mg + N = ma_y$$

Note: N>mg=3.92N

Clicker Q: What can you say about a_y? A) $a_y < 0$ B) $a_y > 0$ C) $a_y = 0$

So normal force must be: $N = W + F_{2,y} = (0.4kg)(9.8m/s^2) + 1.5N = 5.42N$

Another Example of a Force: Tension

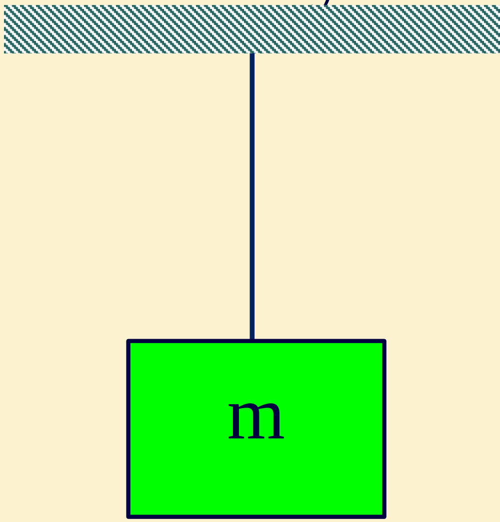


- Tension in an Ideal String, T:
  - ➔ Direction is parallel to string (only pulls)
  - ➔ Magnitude of tension is equal everywhere.

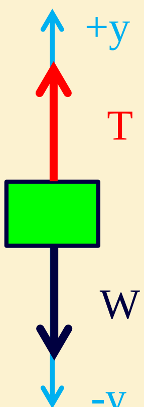
Newton's 2nd Law and Equilibrium Systems

We suspend a mass m = 5 kg from the ceiling using a string. What is the tension in the string?

- Every single one of these problems is done the same way!



➔ Step 1: Identify the object or body to be analyzed, and draw a Free Body Diagram, (label your axes!)



➔ Step 2: Identify and draw all force vectors   Weight, W   Tension, T

➔ Step 3: Use your drawing to determine F_{Net} in Newton's 2nd law

$F_{Net} = ma$ What is the acceleration in this case? $a = 0$

$T - W = 0$

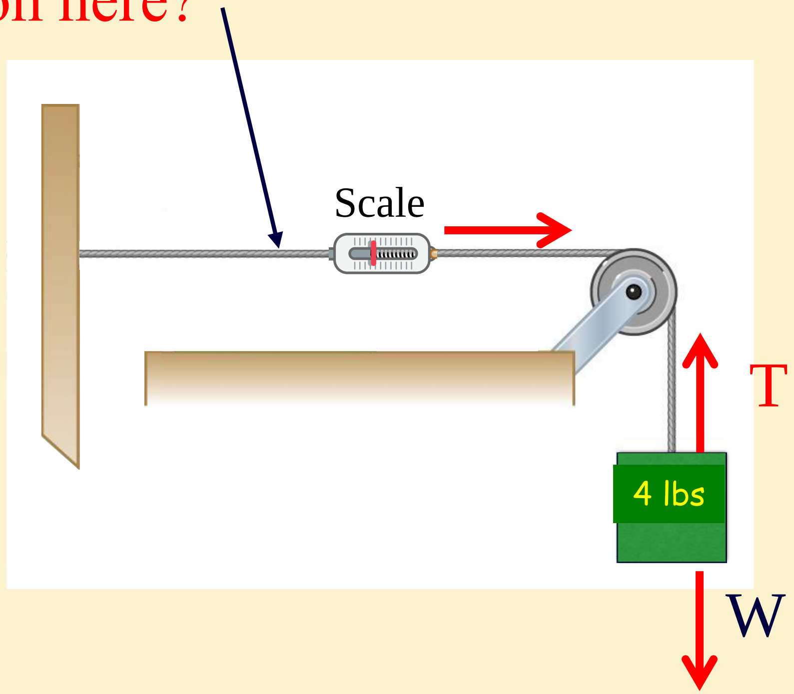
$T = W = mg = (5\ kg)x(9.8\ m/s^2) = 49\ N$

Clicker Q

What does scale read?

A) 2 lbs B) 4 lbs C) 8 lbs

What's the tension here?



The magnitude of tension in a ideal string is equal everywhere.

Demo

Related Clicker Q

What will the scale read if instead of being tied to the wall, the string has another equal mass hanging on the other side?

a) Half as much as before

b) The same as before

c) Twice as much as before

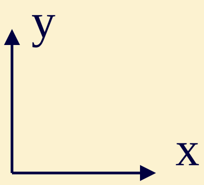
Demo

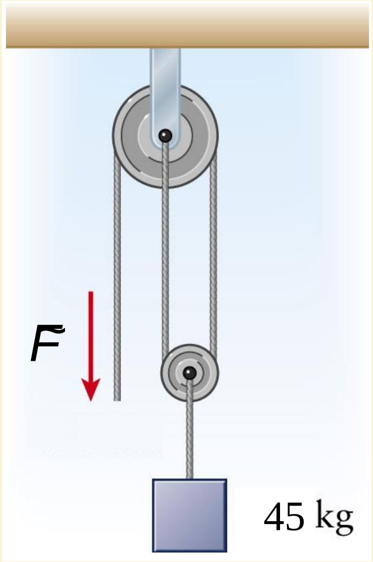
Tension Clicker Example:

- Determine the force, F, exerted by the hand to suspend the 45 kg mass as shown in the picture.

A) 220 N B) 440 N C) 660 N

D) 880 N E) 1100 N





Plan step 1: Isolate mass & lower pulley and draw FBD

Plan step 2: Apply Newton's #2:

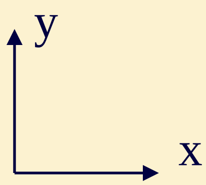
Remember: the magnitude of the tension is the same everywhere along the rope!

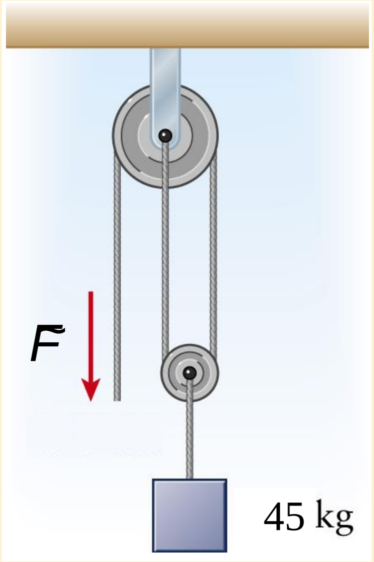
Tension Clicker II

- Determine the force exerted by the ceiling to suspend the top pulley as shown in the picture.

A) 220 N B) 440 N C) 660 N

D) 880 N E) 1100 N



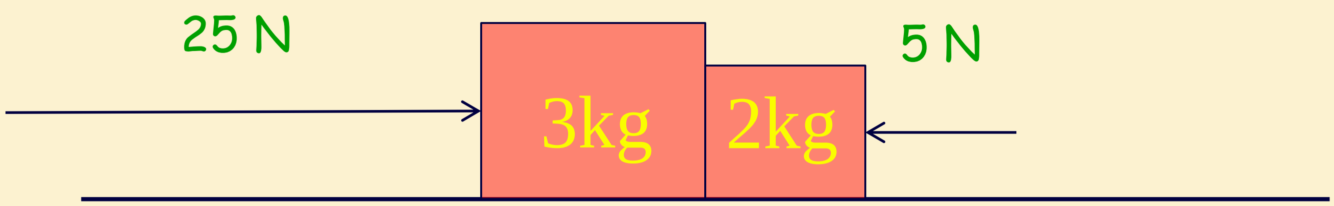


Isolate body (the top pulley) and draw FBD

Apply N#2 to top pulley

Clicker Q

Two blocks with masses shown are next to each other on a slippery surface (no friction). Two forces are applied in opposite directions as shown. What is the acceleration of the two blocks?

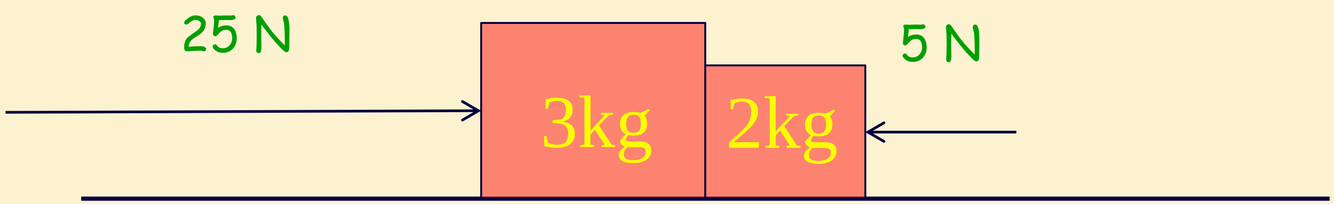


a) 5 m/s^2 b) 5.4 m/s^2 c) 5.8 m/s^2 d) 2.9 m/s^2 e) 4 m/s^2

Clicker Q #2

What is the magnitude of the force that the 3 kg block exerts on the 2 kg block at the interface?

Recall: a=4 m/s^2

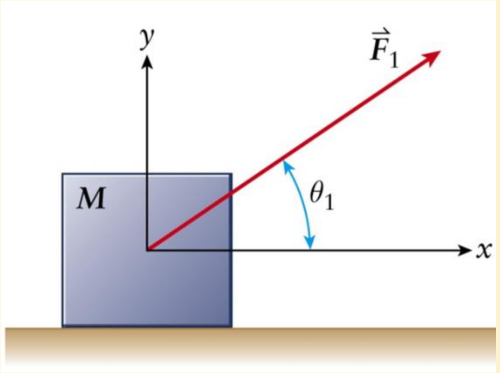


a) 25 N   b) 20 N   c) 5 N   d) 13 N   e) 15 N

Checkpoint 3

You pull a box with a rope along a frictionless table as shown in the figure below. How does the magnitude of the normal force compare to the weight of the box?

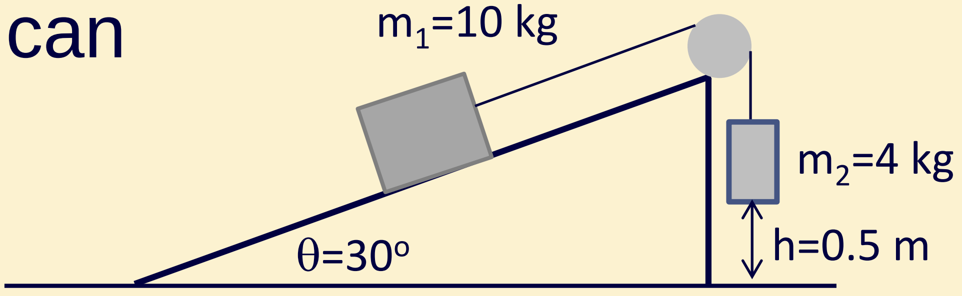
A) the magnitude of the normal force is the same as the weight
B) the magnitude of the normal force is greater than the weight
C) the magnitude of the normal force is smaller than the weight



Another great example

Incline is frictionless, pulley massless.

Find as many things as you can

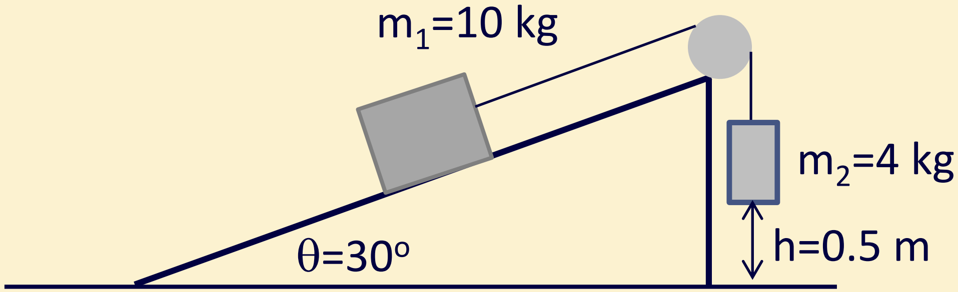


Direction of motion

N=

T=

a=



Key points:

|a| is same for both masses

Align coordinates for mass 1 w/ incline

To finish problem:

$T - m_1 g \sin\theta = m_1 a$ (this is the x component of F = ma for mass 1)

$T - m_2 g = -m_2 a$ (this is the y component of F = ma for mass 2)

Two equations, two unknowns. Solve! I did this by subtracting the second equation from the first, to get

$T - T - m_1 g \sin\theta + m_2 g = m_1 a + m_2 a$

Or

$g (m_2 - m_1 \sin\theta) = (m_1 + m_2) a$ Solve for a to get: $a = (m_2 - m_1 \sin\theta)/(m_1 + m_2)$.

Putting in numbers, $a = -0.7\ m/s^2$. Now I can go back and solve for T:

$T = m_2 g - m_2 a$

What's minus mean?

Putting in numbers, T = 42N.

To get N (normal force on m1) use y-component of F = ma for mass 1

Summary of Concepts

- Newton's Law #1 and #2
- Contact forces (e.g., friction, tension)
- Action at a distance forces (gravity)
- Problem Solving Tips for Applying N#2
  - ➔ Isolate body to be analyzed
  - ➔ Draw FBD, pick a coordinate system
  - ➔ Apply physics laws: $\mathbf{F}_{net}=m\mathbf{a}$
  - ➔ Use algebra to solve for quantities in x & y directions
  - ➔ Avoid making up your own rules!