Physics 101: Lecture 02

Forces: Equilibrium Examples

- Today's lecture will cover Textbook Sections 2.1-2.7

Phys 101 URL:

http://courses.physics.illinois.edu/phys101/

Read the course web page!

Office hours start next week; see web page for locations & times.

About the Schedule

My Lecture Slides (Posted after Lecture)

AY 2011-2012 Lecture Slides

Reading Assignments

- Home page
- Schedule
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- Course Grading
- Required Materials
- Office Hours
- Contact Information
- Practice Exams
- Exam Information
- James Scholar Credit
- Section Information
- Tutor List

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Week	Date	Checkpoint	Lecture	Lecture handouts	Lab	Discussion	Homework	Exam
1	Monday 8/26/2013	Checkpoint 1	Lecture 1 1.1-1.9 pdf ppt	Handout 1 pdf				
	Tuesday 8/27/2013							
	Wednesday 8/28/2013	Checkpoint 2	Lecture 2 2.1-2.7 pdf ppt	Handout 2 pdf		Discussion 1 Explanation 1		
	Thursday 8/29/2013							
	Friday 8/30/2013							
2	Monday 9/2/2013	Labor Day Holiday						
	Tuesday 9/3/2013						Homework 1	
	Wednesday 9/4/2013	Checkpoint 3	Lecture 3 Ch 3 pdf ppt	Handout 3 pdf	Lab 1	Discussion 2 Explanation 2		
	Thursday 9/5/2013				Lab 1			
	Friday 9/6/2013				Lab 1			

Overview

- Last Lecture
  - ➔ **Newton's Laws of Motion**
    - » FIRST LAW: Inertia
    - » SECOND LAW: $F_{net} = ma$
    - » THIRD LAW: Action/reaction pairs
  - ➔ Gravity $W = G\frac{M_{Earth}m}{r_{Earth}^2} = m\left(G\frac{M_{Earth}}{r_{Earth}^2}\right)$

    $\simeq mg$ (near Earth's surface!)
- Today
  - ➔ **Forces as Vectors**
  - ➔ **Free Body Diagrams to Determine F_{net}**
    - » Draw coordinate axes, each direction is independent.
    - » Identify/draw all force vectors
  - ➔ Friction: kinetic $\mathbf{f = \mu_k N}$; static $\mathbf{f \leq \mu_s N}$
  - ➔ Contact Forces – Springs and Tension

Forces as Vectors

- Last lecture we calculated the force of gravity on a book (i.e. its WEIGHT):

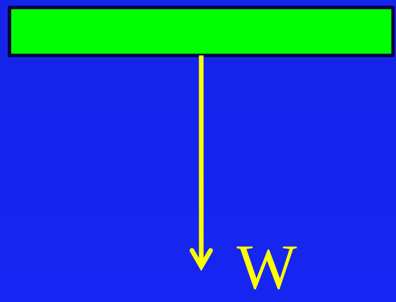
  Calculate the gravitational force on a 3 kg book held 1 meter above the surface of the earth.

  $W = G\, M_{Earth}\, m / r_{Earth}{}^2$

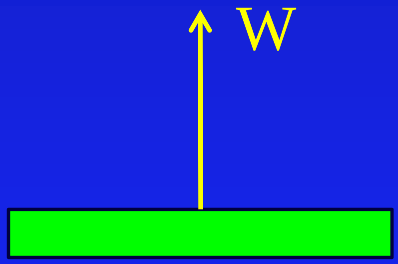
  $= (6.7\text{x}10^{-11}\ m^3 / (kg\ s^2))\ (6\text{x}10^{24}\ kg)\ (3\ kg) / (6.4\text{x}10^6 + 1)^2\ m^2$

  $= 29.4\ kg\ m/s^2 = 29.4\ N$

- We missed something: The direction!



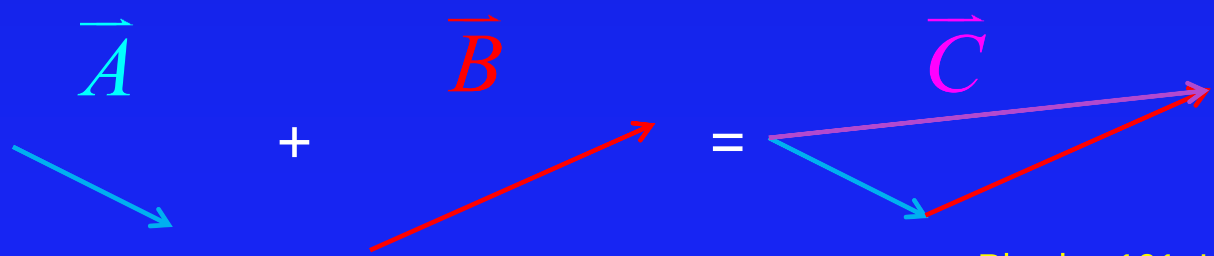
is different than



Forces as Vectors

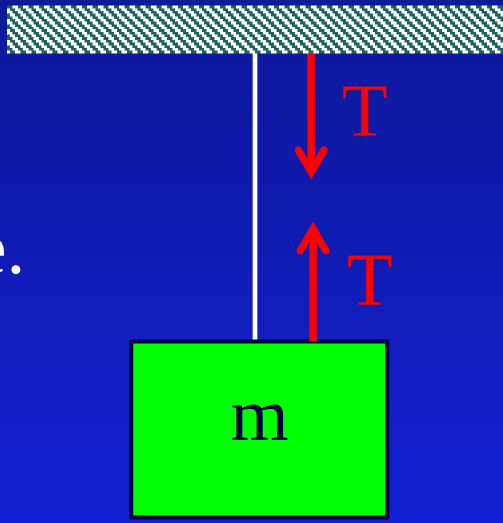
- A quantity which has both magnitude and direction is called a VECTOR; FORCES are VECTORS
- Usually drawn as an arrow pointing in the proper direction, where the length indicates the magnitude

- This is an example of VECTOR ADDITION: to add vectors, you place them head to tail, and draw the RESULTANT from the start of the first to the end of the last



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.



- Now we are ready to do some physics!

QUESTION:

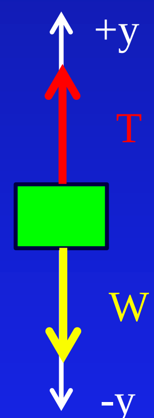
We suspend a mass m = 5 kg from the ceiling using a string. What is the tension in the string?

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: Draw a simple picture (called a Free Body Diagram), and label your axes!



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

➔Step 3: Use your drawing to write down Newton's 2nd law

$F_{Net} = ma$ In equilibrium, everything is balanced! $a = 0$

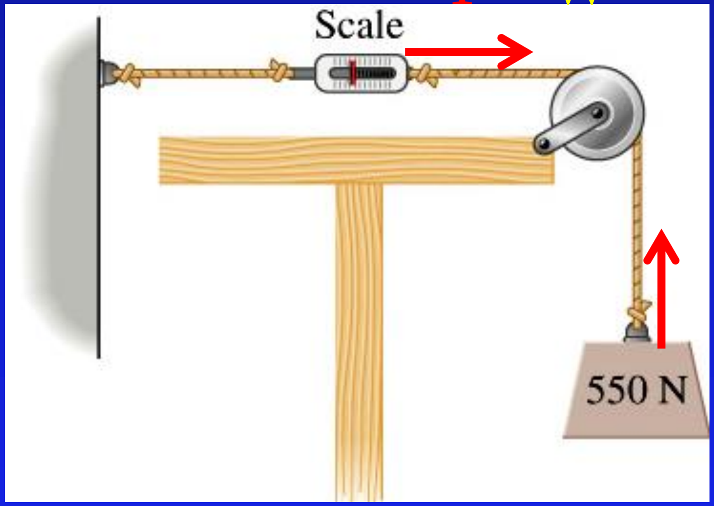
$T - W = 0$ $T = W = mg = (5\text{ kg})*(9.8\text{ m/s}^2) = 49\text{ N}$

Prelecture!

- What does scale 1 read? (88% got correct!)

- A) 225 N B) 550 N C) 1100 N

T = W



T = W

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

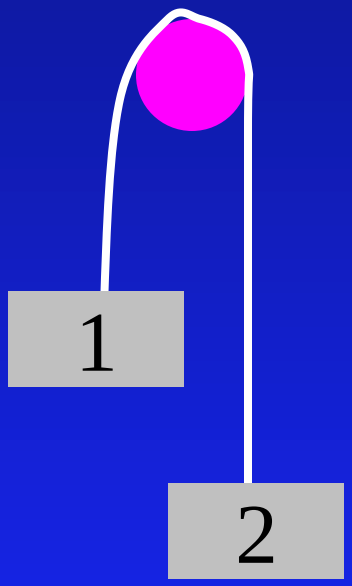
Tension ACT

- Two boxes are connected by a string over a frictionless pulley. **In equilibrium**, box 2 is lower than box 1. Compare the weight of the two boxes.

A) Box 1 is heavier

B) Box 2 is heavier

C) They have the same weight



Step 1 – Draw!

Step 2 – Forces!

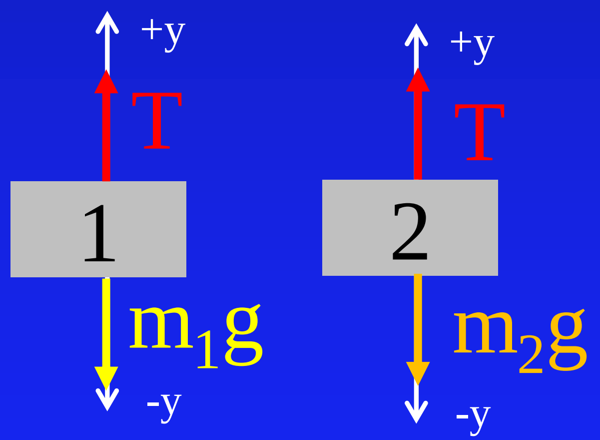
Step 3 – Newton's 2nd!

$F_{Net} = m\,a$

1) $T - m_1\,g = 0$

2) $T - m_2\,g = 0$

$\Rightarrow m_1 = m_2$



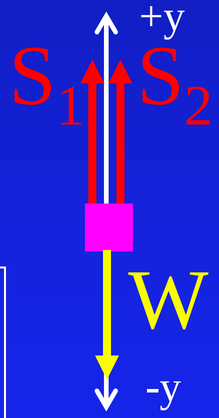
Another Force Example: Springs

- Force exerted by a spring is directly proportional to its displacement x (stretched or compressed).

$$F_{spring} = -k\,x$$

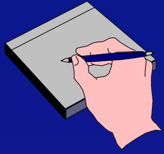
- Example: When a 5 kg mass is suspended from a spring, the spring stretches x_1 = 8 cm. If it is hung by two identical springs, they will stretch x_2 =

A) 4 cm B) 8 cm C) 16 cm



1 Spring	2 Springs
$S_1 - W = 0$	$S_1 + S_2 - W = 0$
$S_1 = W$	$kx_2 + kx_2 = 2kx_2 = W = mg$
$kx_1 = mg$	$x_2 = mg/(2k) = (5kg)*(9.8m/s^2)/(2*612.5N)$
$k = mg/x_1 = 612.5$ N/m	So: x_2 = 4 cm.

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

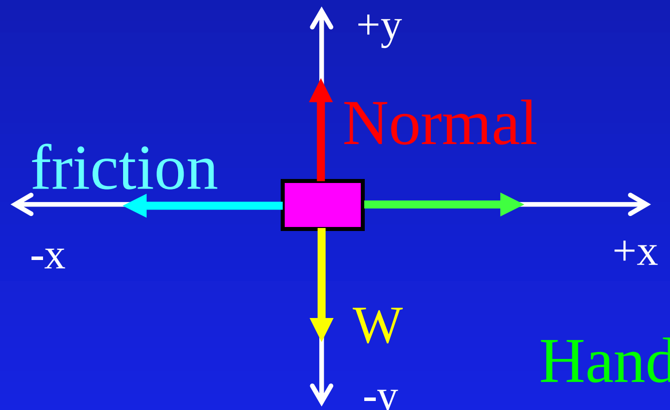
We do exactly the same thing as before, except in both x and y directions!

Step 1 – Draw!

Step 2 – Forces!

Step 3 – Newton’s 2nd ($F_{Net} = ma$)!

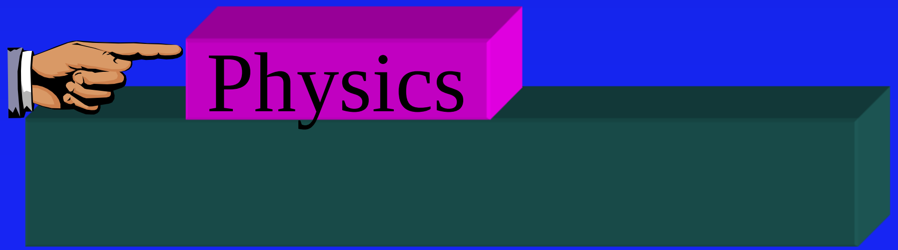
Treat x and y independently!



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

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

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.

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

$$F_{Net,\,x} = H - f = 0 \qquad H = f$$

- Magnitude of frictional force is proportional to the normal force and always opposes motion!
  - ➔ $f_{kinetic} = \mu_k N$ — μ_k coefficient of Kinetic (sliding) friction
  - ➔ $f_{static} \leq \mu_s N$ — μ_s coefficient of Static (stationary) friction

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

$$= (0.75)*(1\ kg)*(9.8\ m/s^2)$$

$$H = 7.35\ N$$

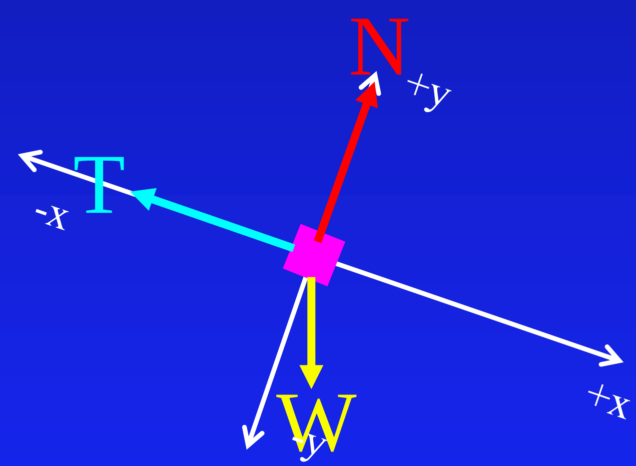
Forces in 2 Dimensions: Ramp

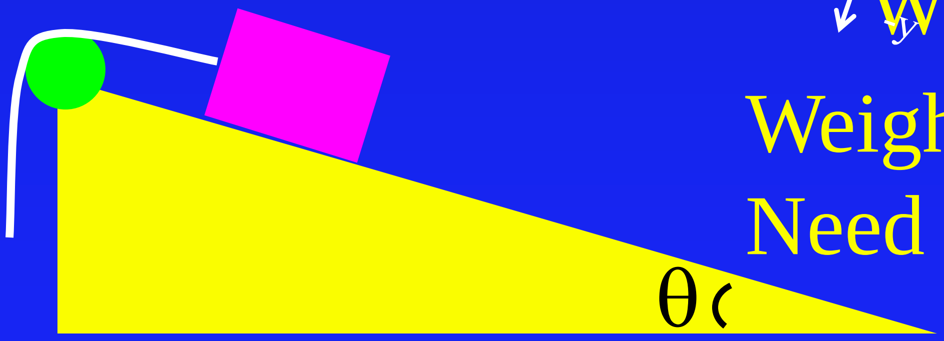
Calculate tension in the rope necessary to keep the 5 kg block from sliding down a **frictionless** incline of 20 degrees.

Step 1 - Draw!

You should draw axes parallel and perpendicular to motion!

Step 2 - Forces!

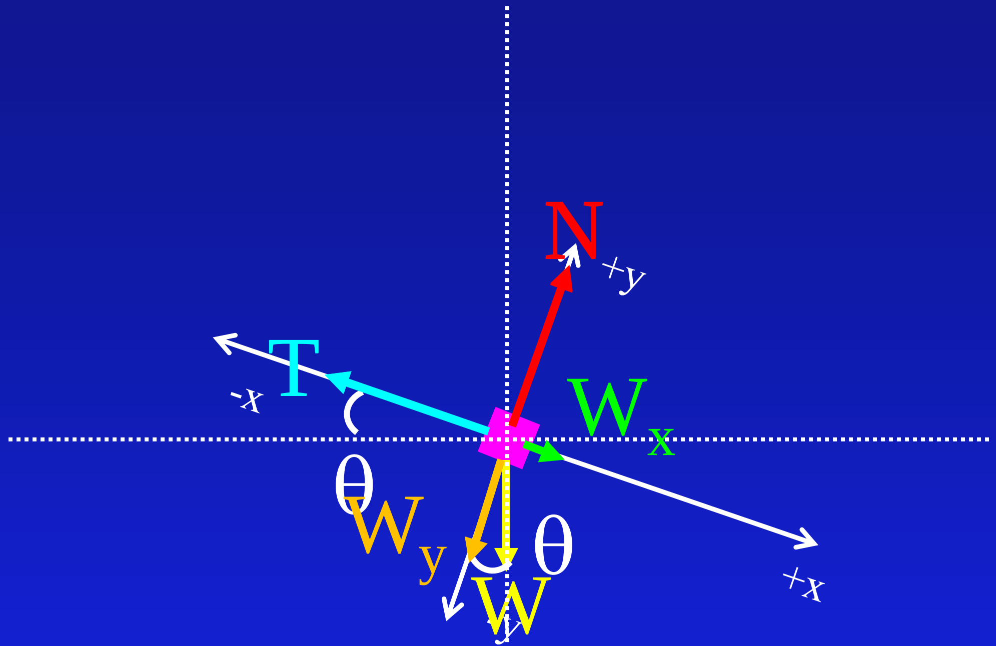




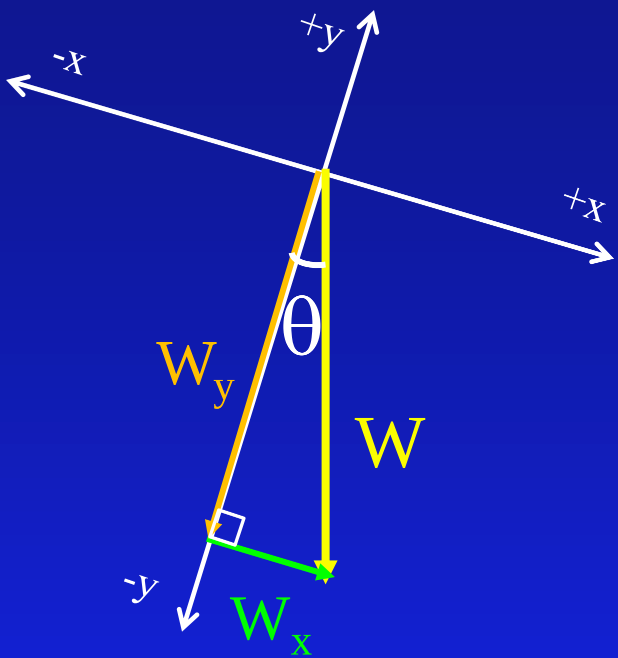
Weight is not in x or y direction!

Need to DECOMPOSE it!

Vector Decomposition



Now: Step 3 – Newton's 2nd!



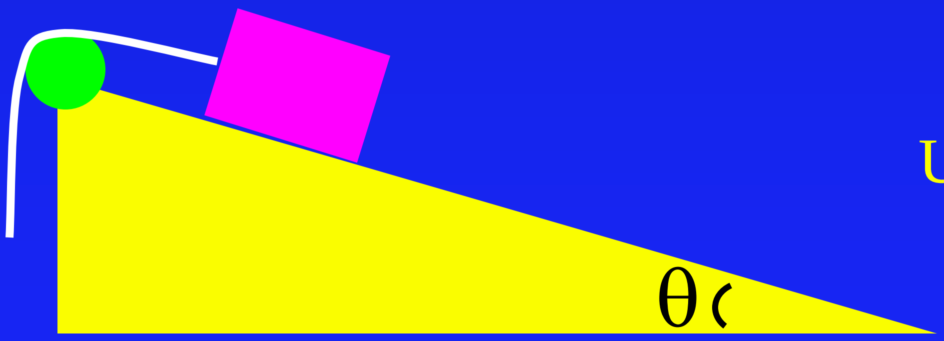
Split W into COMPONENTS parallel to axes

Note that

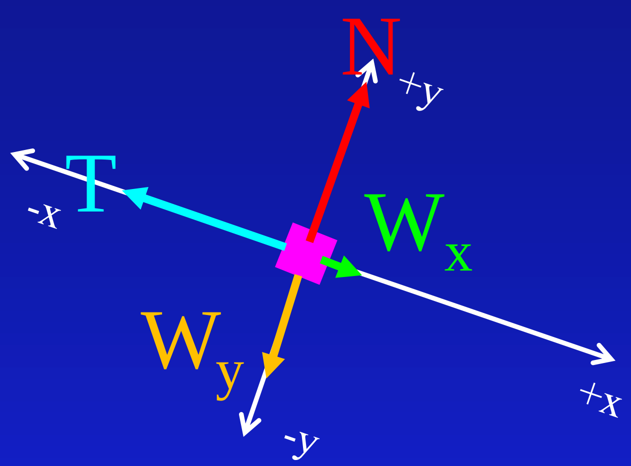
$$\vec{W} = \vec{W}_y + \vec{W}_x$$

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

$W_y = W \cos\theta$

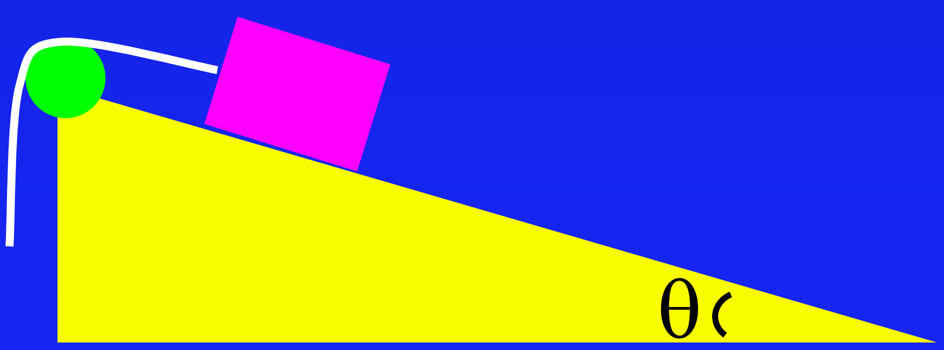


Calculate force necessary to keep the 5 kg block from sliding down a frictionless incline of 20 degrees.



$W_x = W \sin\theta$

$W_y = W \cos\theta$



Now: Step 3 – Newton's 2nd!

x direction:

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

System is in equilibrium (a = 0)!

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

$$W_x - T = 0$$

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

$$= mg \sin\theta$$

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

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

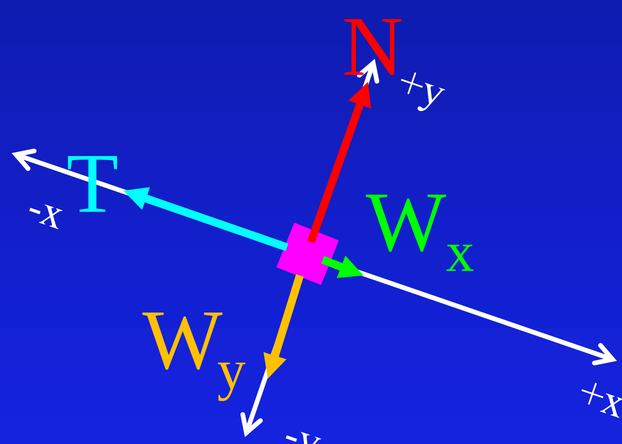
Normal Force ACT

What is the normal force of the ramp on the block?

A) $N > mg$　　B) $N = mg$　　C) $N < mg$

$W_x = W \sin\theta$

$W_y = W \cos\theta$



y direction:

$F_{net,\,y} = ma_y$

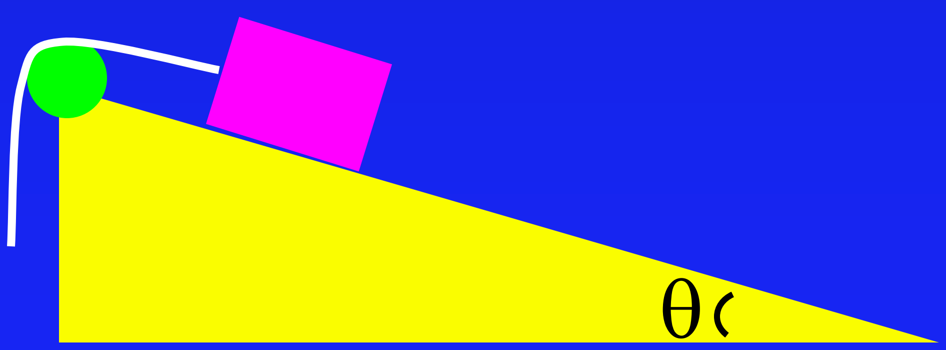
Equilibrium $(a = 0)$!

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

$N - W_y = 0$

$N = W_y = W \cos\theta$

$N = mg \cos\theta$



Summary

- Contact Force: Tension
  - ➔Force parallel to string
  - ➔Always Pulls, tension equal everywhere
- Contact Force: Spring
  - ➔Can push or pull, force proportional to displacement
  - ➔$F = k\ x$
- Contact Force: Friction
  - ➔Static and kinetic
  - ➔Magnitude of frictional force is proportional to N
- Two Dimensional Examples
  - ➔Choose coordinate system; choose wisely!
  - ➔Analyze each direction independently

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 25 degrees, what is the magnitude of her force on the block?

x- direction: $F_{Net,\,x} = ma_x$

$P_x - f = P\cos(\theta) - f = 0$

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

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

y- direction: $F_{Net,\,y} = ma_y$

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

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

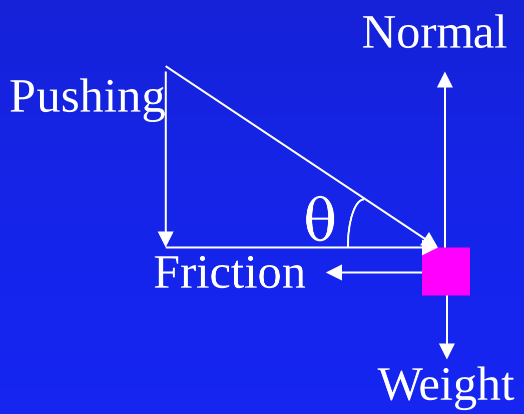
Combine:

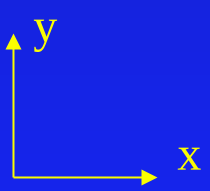
$(P\cos(\theta) / \mu) - mg - P\sin(\theta) = 0$

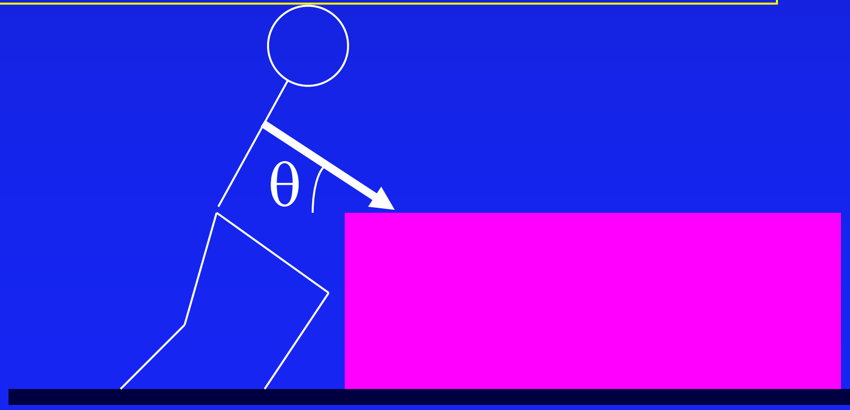
$P(\cos(\theta) / \mu - \sin(\theta)) = mg$

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

$P = 80$ N





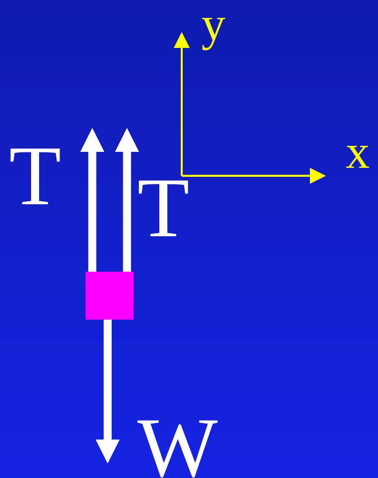


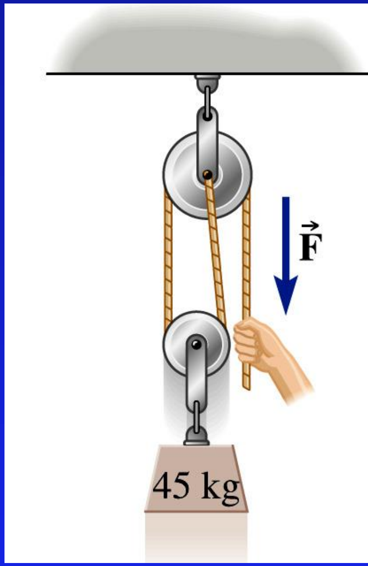
Tension Example:

- Determine the force 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





$F_{Net} = m\,a$

$T + T - W = 0$

$2\,T = W$

$T = m\,g / 2$

$= (45\text{ kg} \times (9.8\text{ m/s}^2)) / 2$

$= 220\text{ N}$

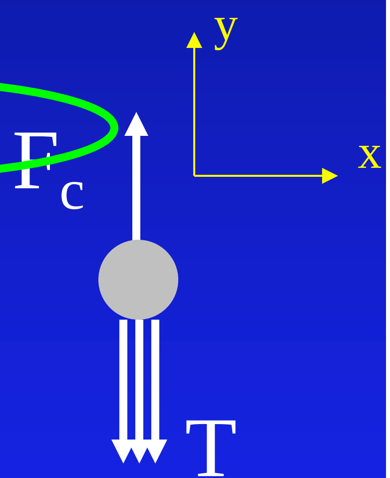
•Remember the magnitude of the tension is the same everywhere along the rope!

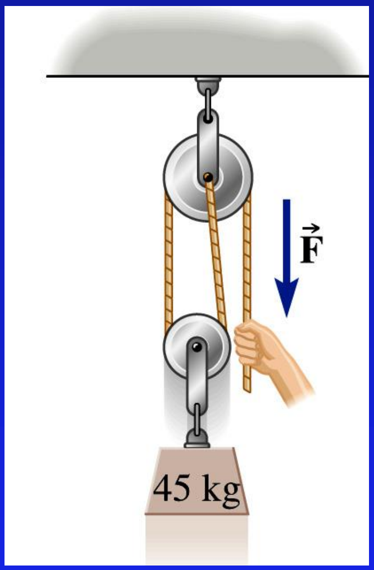
Tension ACT II

- Determine the force exerted by the ceiling to suspend pulley holding the 45 kg mass as shown in the picture.

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

D) 880 N E) 1100 N





$\Sigma F = m\,a$

$F_c - T - T - T = 0$

$F_c = 3\,T$

$F_c = 3 \times 220\text{ N} = 660\text{ N}$

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