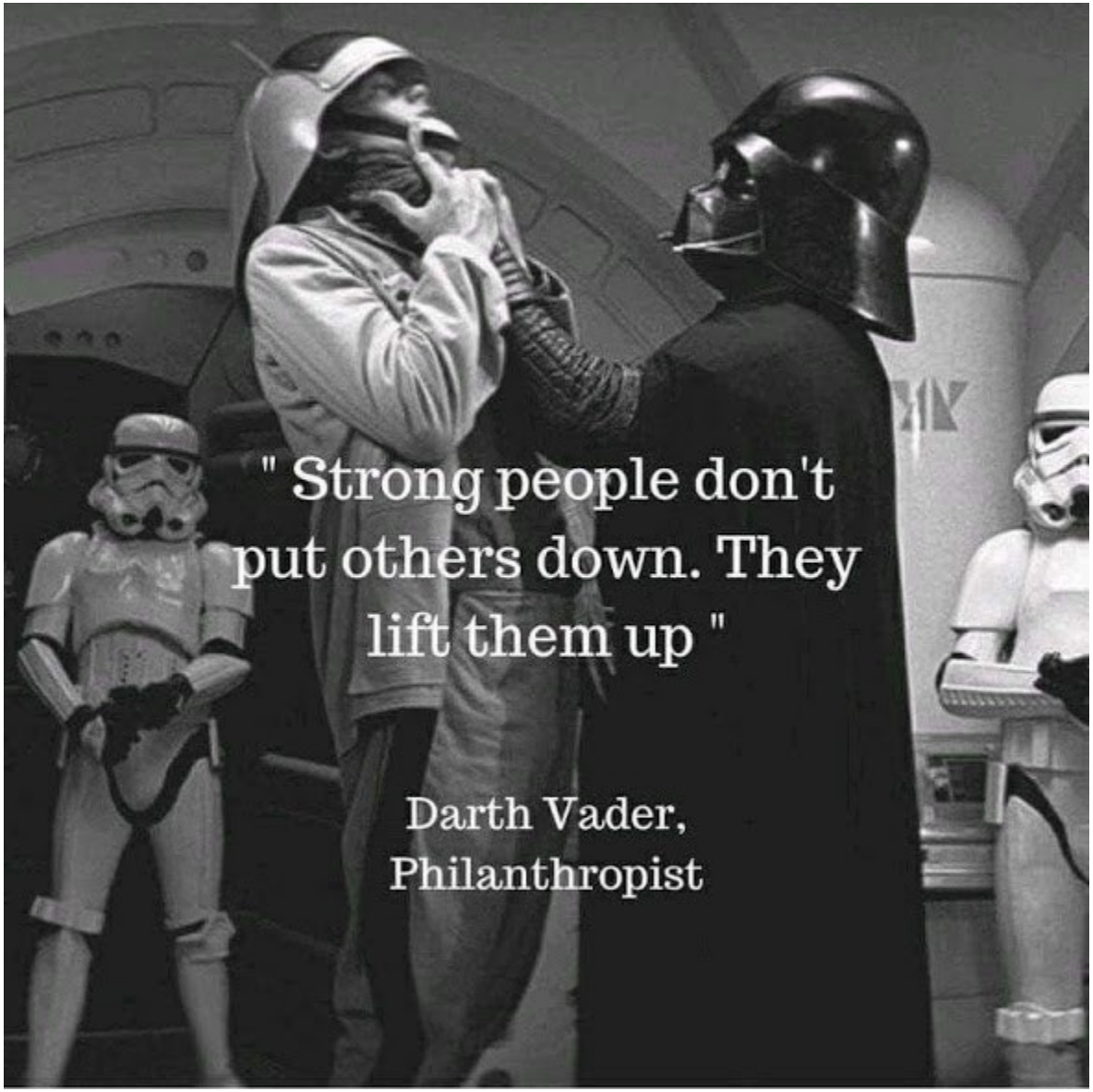
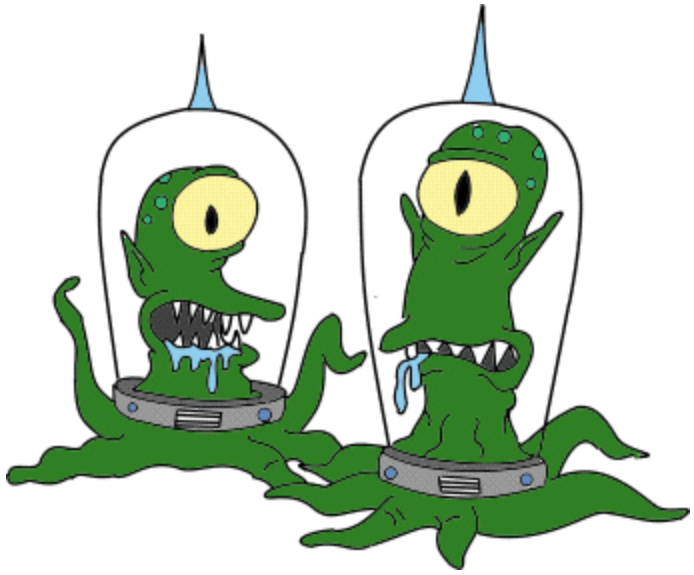
Chapter 3 Dynamics

Newton’s Laws


" Strong people don't put others down. They lift them up "
Darth Vader,
Philanthropist

Newton's 1st Law

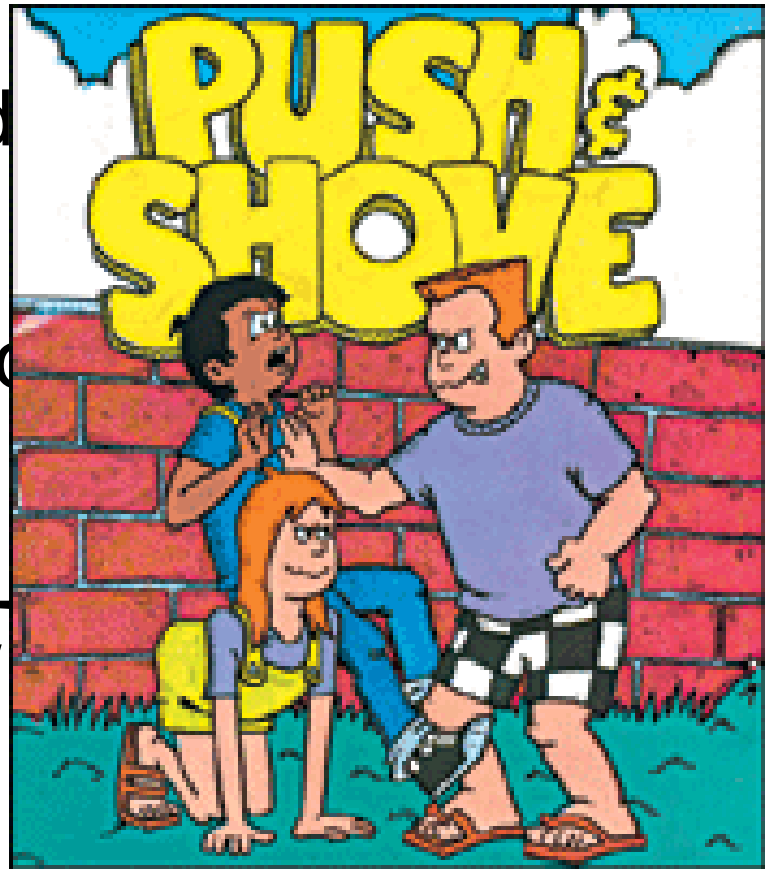
- Objects with mass have Inertia: the tendency to stay at rest (or moving!)
- The more mass an object has, the more difficult it is to accelerate



- Waiter trick
- AKA paper and funnel trick
- Penny and cardboard

Gaijin Yokozuna!?

Newton's 2nd



- The force necessary to mo
objects depends on:
  - mass
  - acceleration

F

- Ex 1: how much force is necessary to accelerate a 80kg student at 10 m/s^2?

$$F_{net} = ma = 80kg \cdot 10 \, {}^{m}\!/_{s^2} = 800N$$

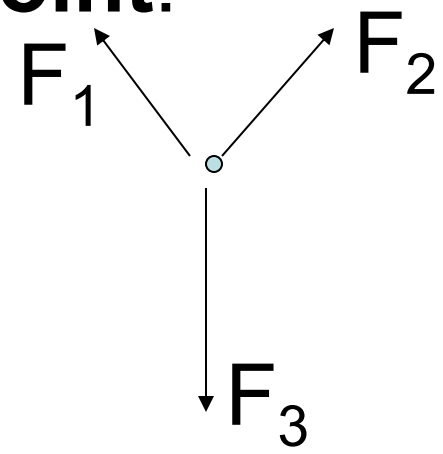
What do we mean “net” force?

- Net force is zero if there are no *unbalanced* forces
- We usually do not notice forces until they become unbalanced
- Ex. What are the forces acting on these suction cups?

Free Body Diagrams

- The point of a FBD is to simplify the dynamics involved
- We only point out the forces acting **on** the body in question
- To get to the point, we draw the body as a…

point!

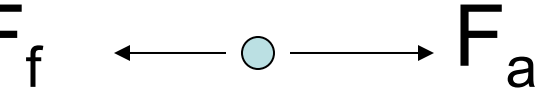


- The forces are drawn **pointing away** from the body

Any questions ?

What if there is more than one force?

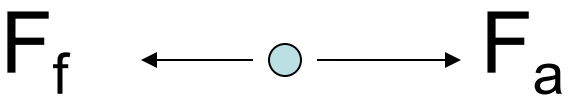
- Ex 2: Jordan applies a 50 N force to a 2.5kg book to slide it across the table. Find the acceleration if there is a 45 N friction force resisting this motion
- This is a vector equation, so we have to consider these opposing vector forces as having opposite signs



$$F_{net} = ma \qquad a = \frac{F_{net}}{m} = \frac{F_a + F_f}{m}$$

$$a = \frac{50N + (-45N)}{2.5kg}$$

$$\frac{5.0N}{2.5kg} = 2.0\,{}^{m}\!/_{s^2}$$



Solve for coefficient of friction

- If Dawn pulls Bradey (579N) across the floor with a 90N force at 40º above the horizontal, find μ

x	y
$F_{Mx} = 90\cos 40 \quad = 68.9N$	$F_{My} = 90\sin 40 \quad = 57.9N$
$F_f = -F_{Mx} = 68.9N$	$R = -F_g - F_{My}$
	$= -(-579) - 57.9$
$\mu = \frac{F_f}{R} = \frac{68.9}{521} \quad = 0.13$	$= 521N$

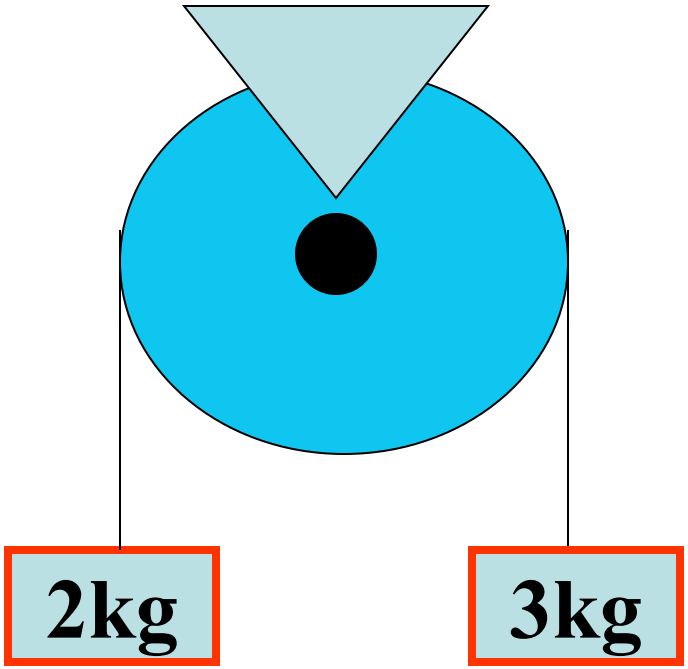
Exercises

- Start p. 66-7 #4,6
- #4 F=ma
- $F_g+F_T=ma$
- mg+(-65g)=ma
- a=(75(-9.8)+(-65)(-9.8))/75

Double Body Diagrams

1. **A diagram that has two (or more) masses in it [often involving inclined plane and/or pulley]**
2. **Consider what external forces are affecting the system as a whole. *What about tension!?***
3. **Decide what is negative (-) and what is positive (+) from the diagram, NOT from numbers!**

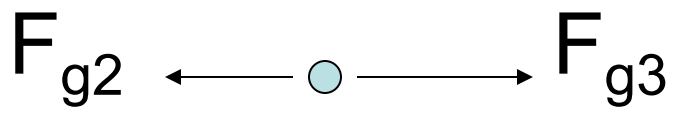
Example 1: "Simple" 2 body



5 kg

Considering the system

- We only have two external forces



$$F_{g2} = mg$$

$$= 2.0kg \times \left(-9.8 \, {}^{N}\!/_{kg} \right)$$

$$= 19.6N$$

$$F_{g3} = mg$$

$$= 3.0kg \times \left(-9.8 \, {}^{N}\!/_{kg} \right)$$

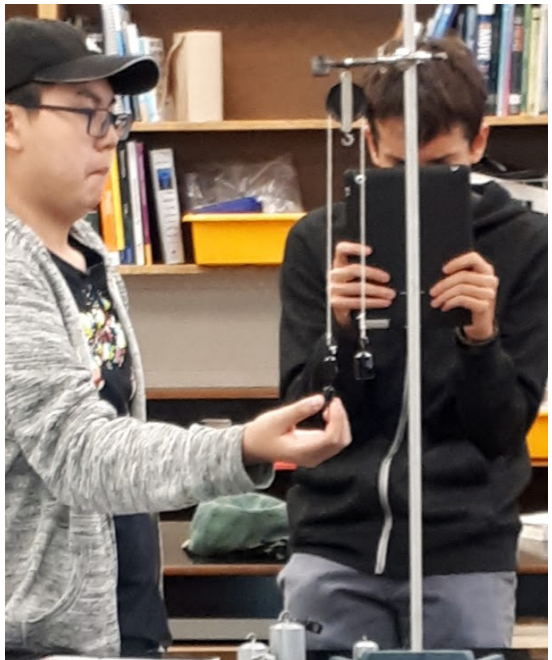
$$= 29.4N$$

Now use 2nd Law

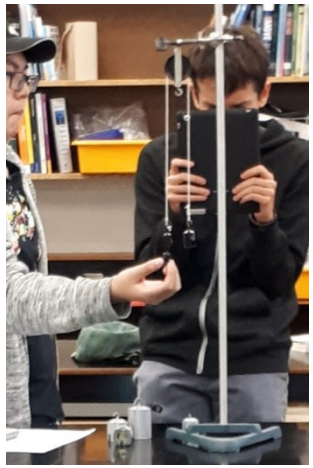
$$F_{net} = ma$$

$$a = \frac{F_{net}}{m} = \frac{29.4 + (-19.6)}{5} = 1.96 \frac{m}{s^2}$$

- Try it! Choose any random weights and measure acceleration ☺



Evaluation



- Compare your experimental results with the theoretical prediction

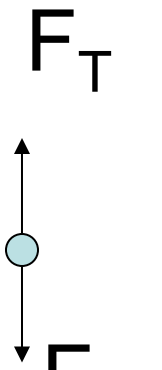
$$\%diff = \frac{\text{exp}\,erimental - theoretical}{theoretical} \times 100\%$$

$$\%diff = \frac{2.2 - 2.0}{2.0} \times 100\% = 10\%$$

- Finish with an analysis of sources of error and possible improvements

Now find tension

- Apply Newton's 2nd law to just one mass:



$$F_{net} = ma$$

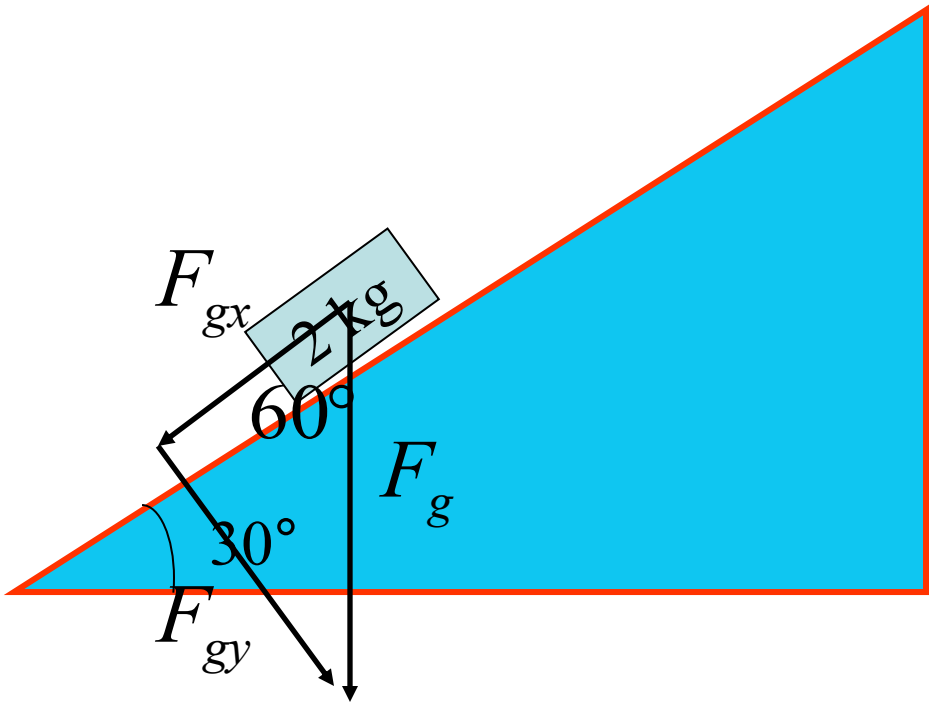
$$F_T + F_{g2} = ma \qquad F_T = ma - F_{g2}$$

$$= 2(1.96) - \left(-19.6N\right) \; = 24N$$

Try #3 p. 67

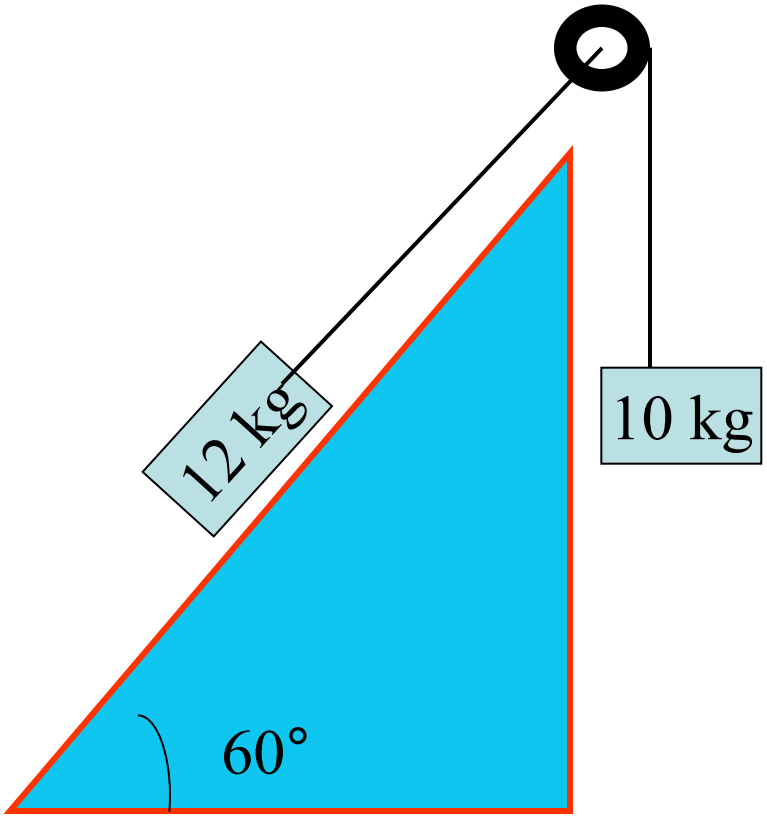
Inclined plane?

We can tilt our axes so x is parallel, y is perpendicular to the surface



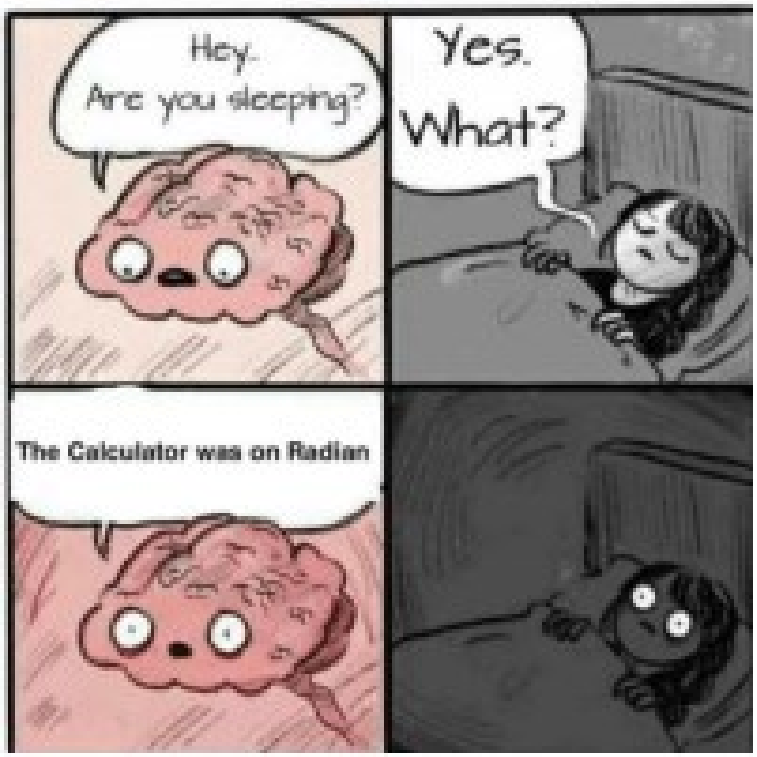
$a = F_{gx}/m = 4.9 m/s^2$

Example 2: Inclined 2 body



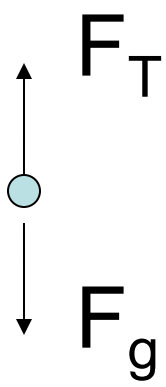
Considering the 12 kg mass

- We only have unbalanced forces in the x-direction

x	y
$F_{gx} = mg\cos\theta$ $F_{gx} = 12(9.8)\cos 30$ $F_{gx} = 102N$	

Considering the 10 kg mass

- We only have forces in the y-direction



$$F_g = mg = 10.0kg \times \left(-9.8 \, {}^{N}\!/_{kg} \right)$$

$$= 98N$$

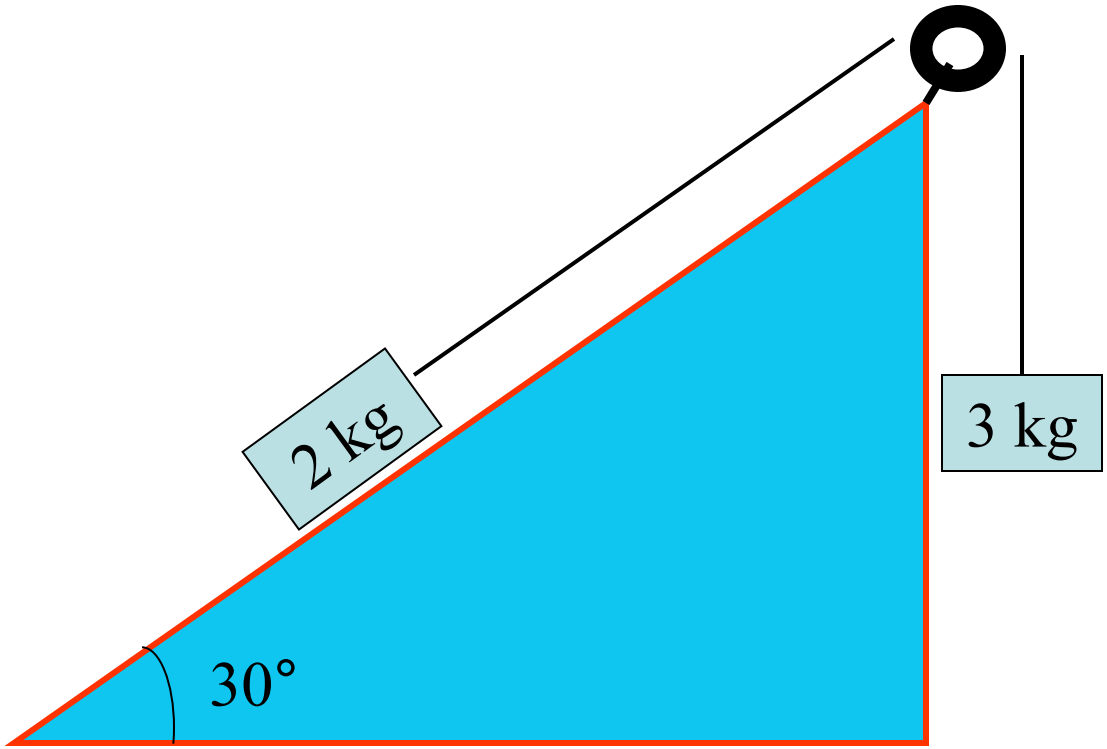
Considering The System

- Manually apply the correct polarity depending on which forces are opposing

$$F_{net} = ma \qquad F_{gx} + F_{g10} = ma$$

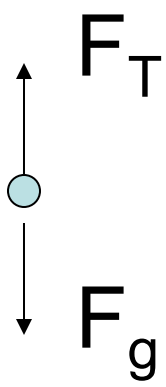
$$a = \frac{102N + (-98)N}{22kg} \qquad a = 0.17 \, {}^{m}\!/_{s^2}$$

Example 3: Inclined 2 body



Considering the 3 kg mass

- We only have forces in the y-direction



$$F_g = mg = 3.0kg \times \left(-9.8 \, {}^{N}\!/_{kg}\right)$$

$$= 29.4N$$

Considering Mass 1

- We only have unbalanced forces in the x-direction

x	y
$F_{gx} = mg\cos\theta$ $F_{gx} = -9.8N$	

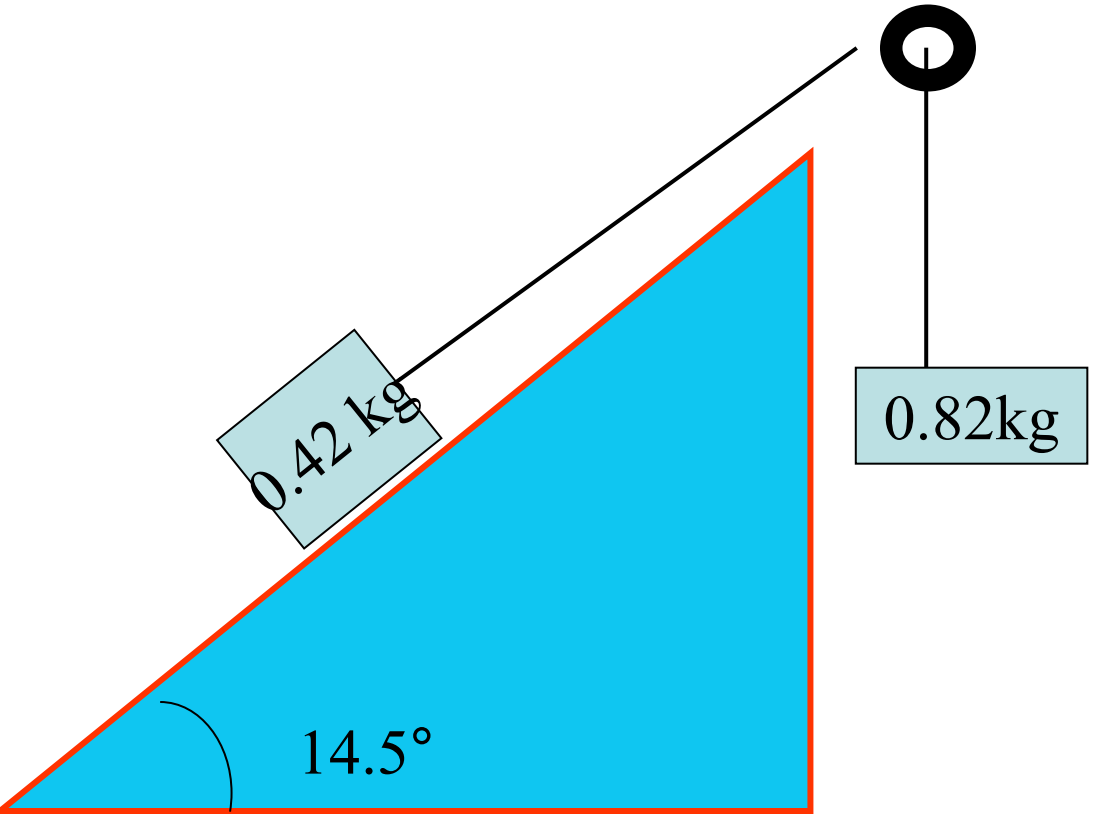
Considering The System

- Manually apply the correct polarity depending on which forces are opposing

$$F_{net} = ma \qquad F_{gx} + F_{g3} = ma$$

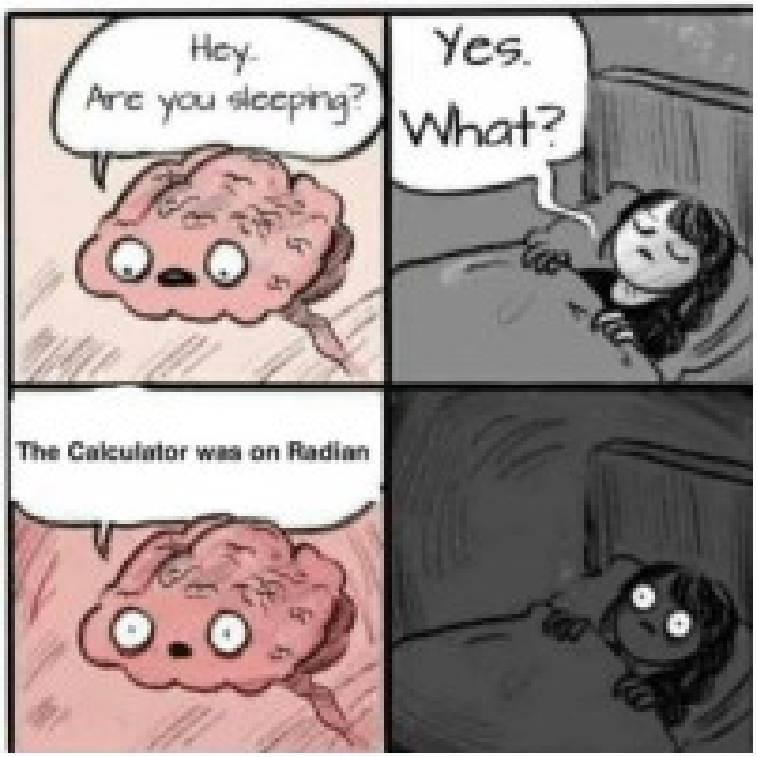
$$a = \frac{-9.8N + 29.4N}{5kg} \qquad a = 3.9 \, m/s^2$$

Experiment: Inclined 2 body
*Just one job: Find friction



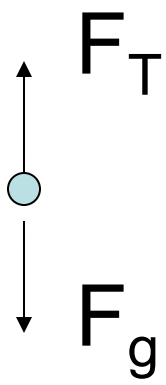
Considering mass 1

- We only have unbalanced forces in the x-direction

x	y
$F_{gx} = mg\cos\theta$ F=0.42(9.8)cos75.5 F=1.0 N	

Considering mass 2

- We only have forces in the y-direction



$$F_g = mg \quad = 8.0\text{N}$$

Finding acceleration

Use data from vidanalysis or stopwatch (take several trials) 1.2 1.8 2.4 3.0 2.6

Ex: $s=\cancel{ut}+1/2at^2$

$a = 2s/t^2$

$a = 2(0.5)/2.0^2$

$a = 0.25\ m/s^2$

Finding friction

$$F_{net} = ma$$

$F_{gx1} + F_{g2} + F_f = ma$

$F_f = ma - F_{gx1} - F_{g2}$

$F_f = (0.82+0.42)0.16 – (-1.0) - 8.0$

$F_f = 1.24(0.16) - 7.0$ N

$F_f = -6.8$ N

Theoretical acceleration

$$F_{net} = ma$$

$F_{gx1} + F_{g2} = ma$

$a = (F_{gx1} + F_{g2})/m$

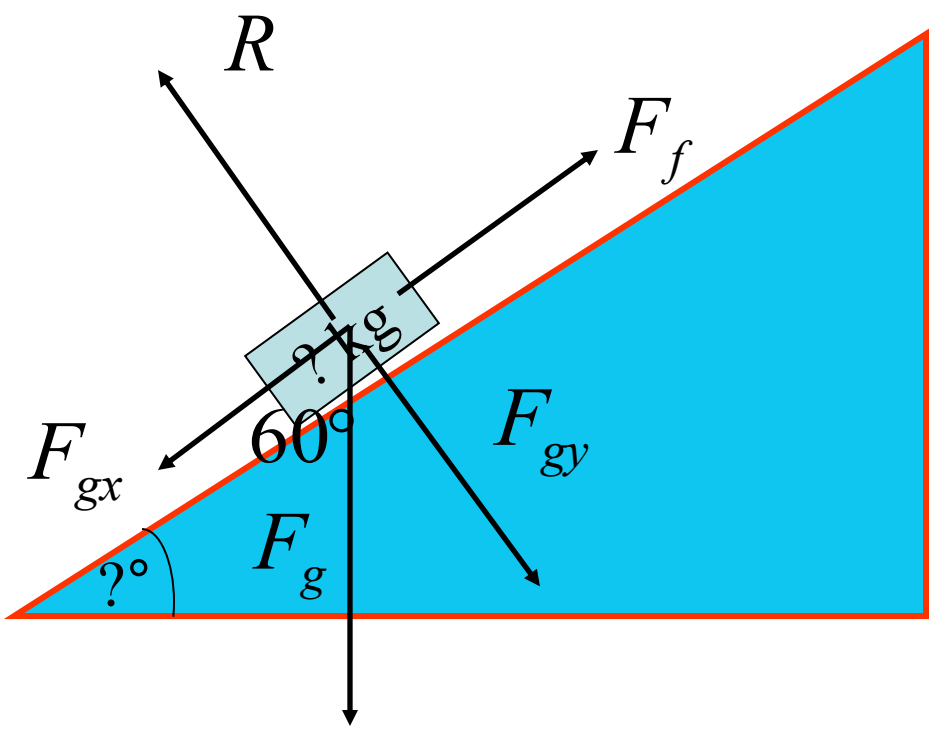
$a = (-1N + 8\ N)/(0.82+0.42)$

$a = 5.6\ m/s^2$

- Finish
- 3b) Us

$F_T+F_g=r$

Can we use an inclined plane to find the friction coefficient for a book on your table?



$$F_{gx}=F_f$$

$$mg\cos\theta=\mu R$$

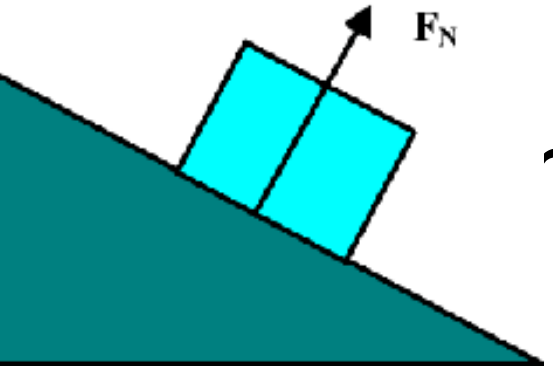
$$mg\cos\theta=\mu\, mg\sin\theta$$

$$\cot\theta=\mu$$

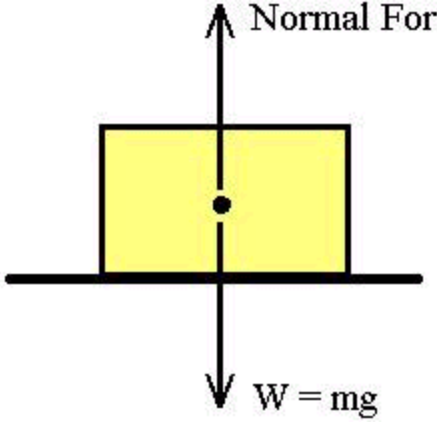
Newton's 3rd Law

- For every action there is an equal and opposite reaction
- When you hit something, it hits back!

You exert as much gravitational force on the Earth as it exerts on you



mal (Reaction)Fo

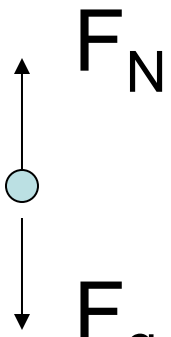


- When an object is in contact with a supporting surface, it pushes down on that surface
- Newton's 3rd Law states the surface pushes back with an equal and opposite force
- This is often (but not always!) equal to the object's weight, hence "apparent weight"

Simple case: object at rest

- Ex 3: What is the normal force acting on the 2.5 kg book resting on your desk?
  - What forces act on the book?

-Free body diagram



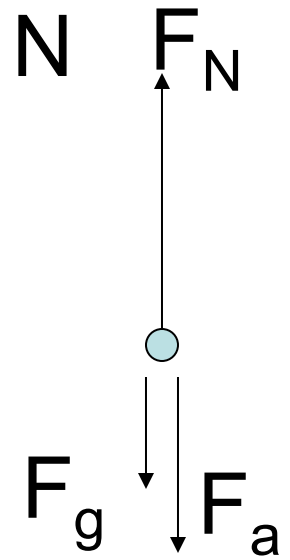
$$F_{net} = ma$$

$$F_g + F_N = 0$$

$$F_N = -mg = 24.5N$$

Extended object at rest

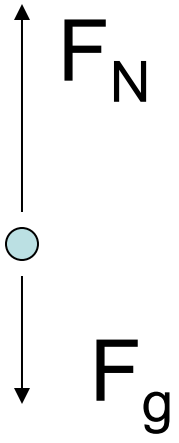
- Ex 4: what is the normal force acting on your book as you lean on it with a 35 N force?
  - What forces act on the book?
    - Gravity and Normal force, applied force
  - Free body diagram
  - Apply 2nd law



$$F_N = -F_g - F_a = -(-24.5N) - (-35N)$$

Accelerating object

- Ex 5: find the normal force acting on a 50 kg student accelerating upwards at 3.4 m/s^2
  - What forces act on the student?
    - Gravity and Normal force
  - Free body diagram
  - Apply 2nd law

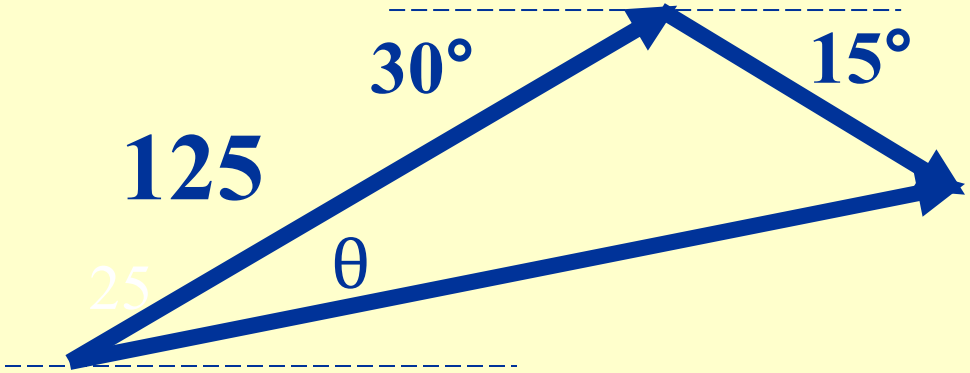


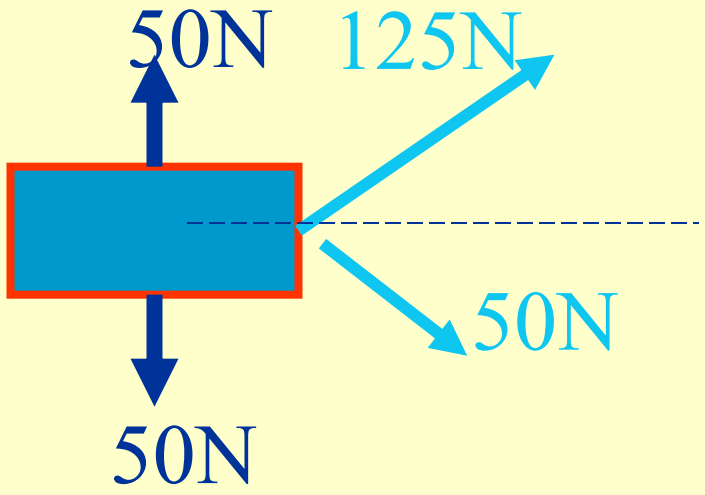
$$F_N = -(-490N) + (50kg \cdot 3.4\,{}^{m}\!/_{s^2}) \qquad F_N = 660N$$

Practice Quiz

1)a)Find the vector sum

Ex 1) Given diagram a)find F_N b)find a



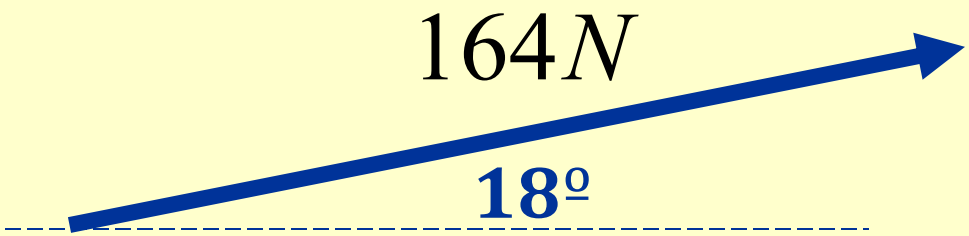


$$c^2 = a^2 + b^2 - 2ab\cos C \qquad c = 164N$$

$$\frac{\sin 135}{164} = \frac{\sin\theta}{50} \qquad \theta = \sin^{-1}\left(\frac{50\sin 135}{164}\right) = 12°$$

Practice Quiz

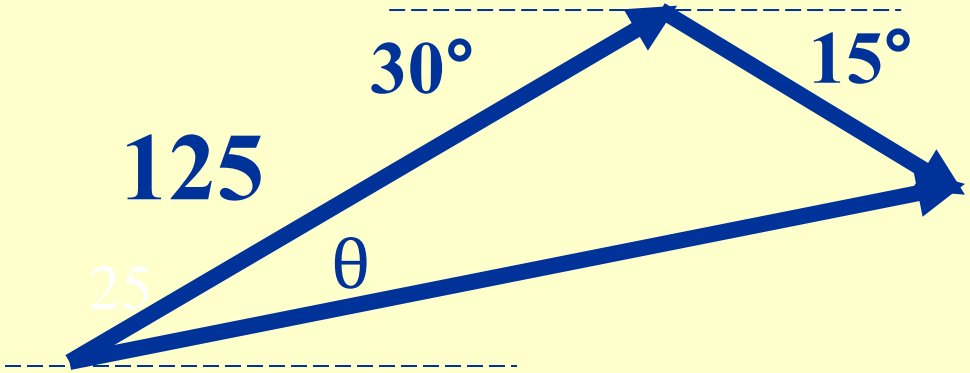
1)b)draw the resultant

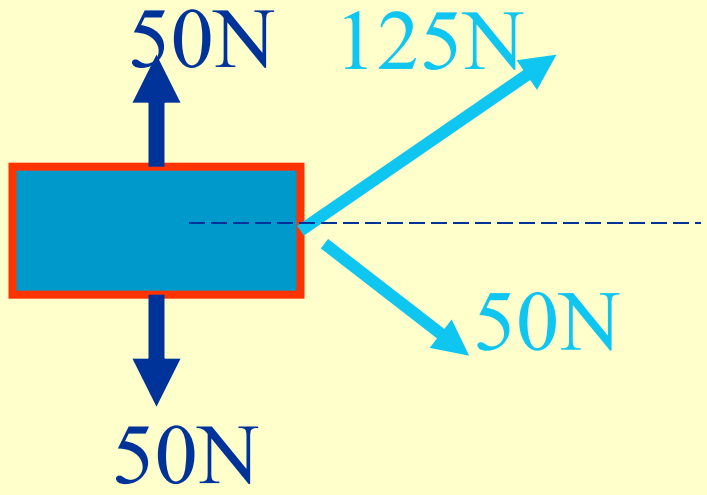


Practice Quiz

2)a)Find the vector sum

Ex 1) Given diagram a)find F_N b)find a

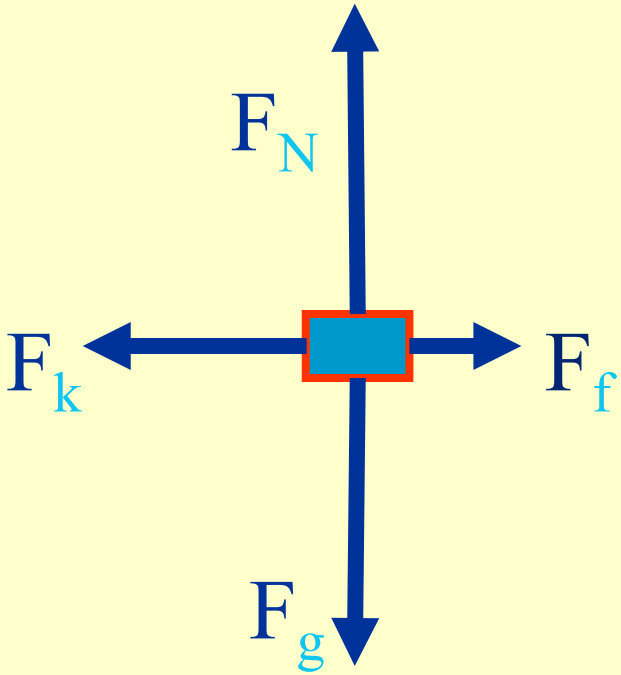




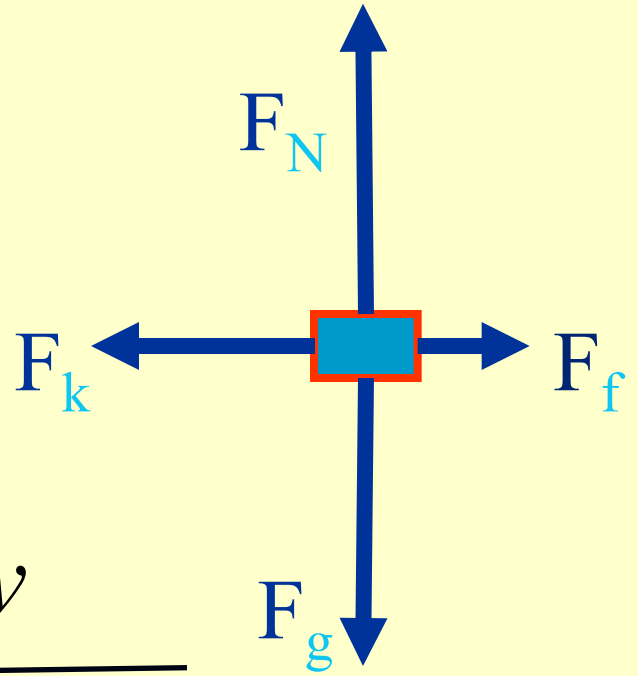
$$c^2 = a^2 + b^2 - 2ab\cos C \qquad c = 164N$$

$$\frac{\sin 135}{164} = \frac{\sin\theta}{50} \qquad \theta = \sin^{-1}\left(\frac{50\sin 135}{164}\right) = 12°$$

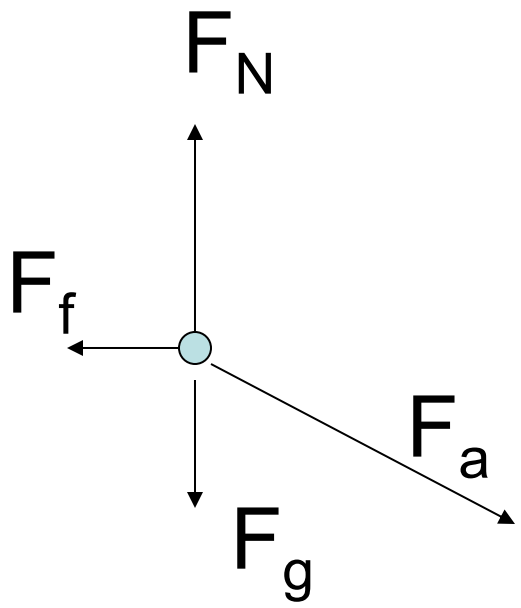
Ex 2) a) FBD



Ex 2) b) Find the "Kaz" Force



x	y
$F_{net} = ma$	$F_{net} = ma$
$F_a + F_f = ma$	$R = -F_g = 440(9.8)$
$F_a = 440(1.5) - 0.15(-4312)$	$R = 4312N$
$F_a = 1.3kN$	



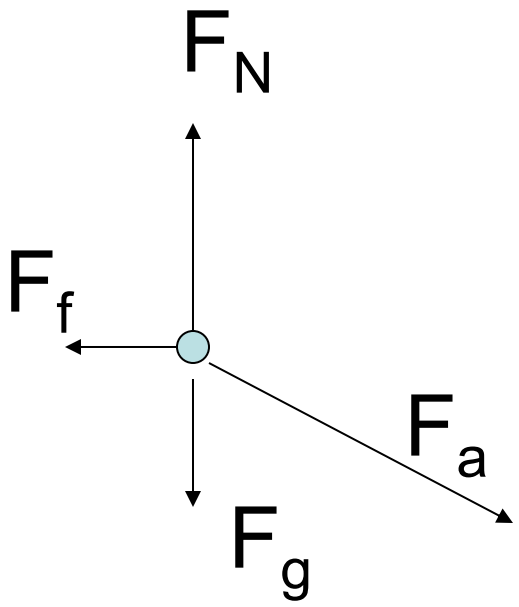
$$y$$

$$F_{net} = ma$$

$$F_g + F_{ay} + R = 0$$

$$R = -F_g - F_{ay} = -mg - 65N\sin(-25°)$$

$$F_N = 76.5N$$



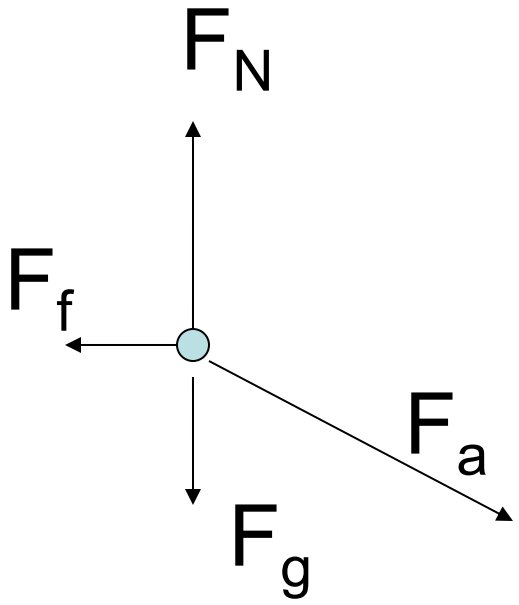
$$\chi$$

$$F_f = \mu R$$

$$F_f = 0.25 \times 76.5N$$

$$\dots$$

$$F_f = -19.1N\,?$$



$$x$$

$$F_{net} = ma$$

$$F_{ax} + F_f = ma$$

$$a = -\frac{F_f + F_{ax}}{m} = \frac{-19.1N + 65N\cos(-25°)}{5kg}$$

$$= 7.96 \, m/s^2$$

Friction

- Friction is a force between two objects sliding (or trying to slide) past each other
- Friction force increases when you have more:
  - force between the objects
  - roughness of the surfaces

Friction

- We find friction force is proportional to the Normal force and a “stickiness factor” μ (called the coefficient of friction)

$$F_f = \mu R$$

- Ex 1: find the friction force acting on your 2.5 kg textbook as it slides across the table if μ=0.55

Ex 1: m=2.5 kg, μ=0.55

$$y$$

$$R + F_g = 0$$

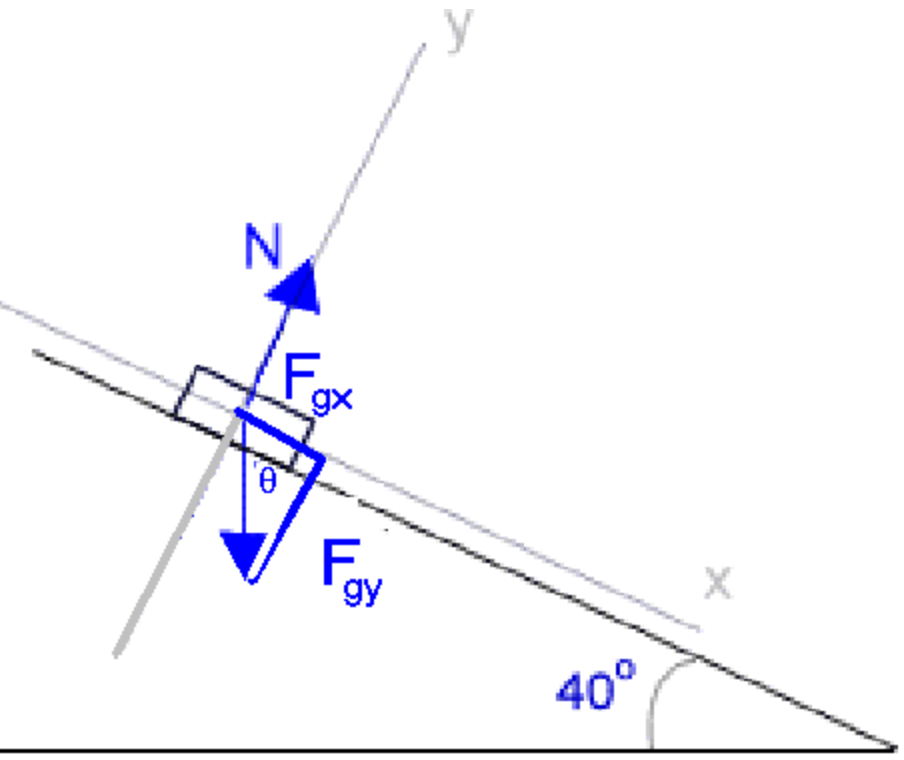
$$R = -F_g = -mg$$

$$\left|F_f\right| = \mu R = \mu mg$$

$$\left|F_f\right| = 0.55(2.5)9.8$$

$$\left|F_f\right| = 13.5N$$

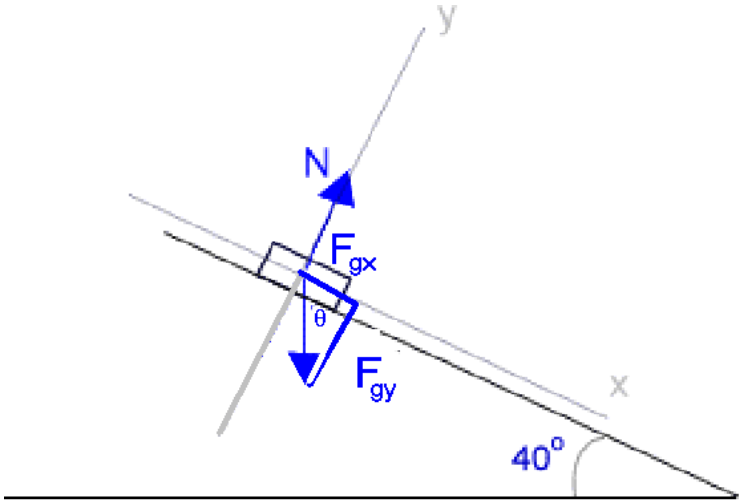
Object on an incline



- We can redefine x and y as parallel and perpendicular to the surface
- This means F_g must be resolved into components F_{gx} and F_{gy}

$$F_{gx} = F_g \cos\theta \qquad F_{gy} = F_g \sin\theta$$

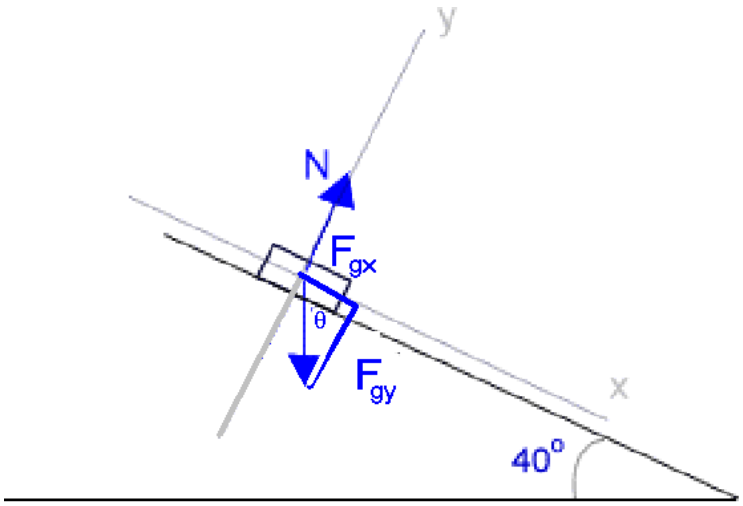
The catch!!!



- When we look at θ, we see it is usually NOT the angle given
- θ=90º - 40º =50º
- Since there is no y acceleration:

x	y
$F_{net} = ma$	$F_{net} = ma$
$F_{gx} = ma_x$	$R + F_{gy} = 0$

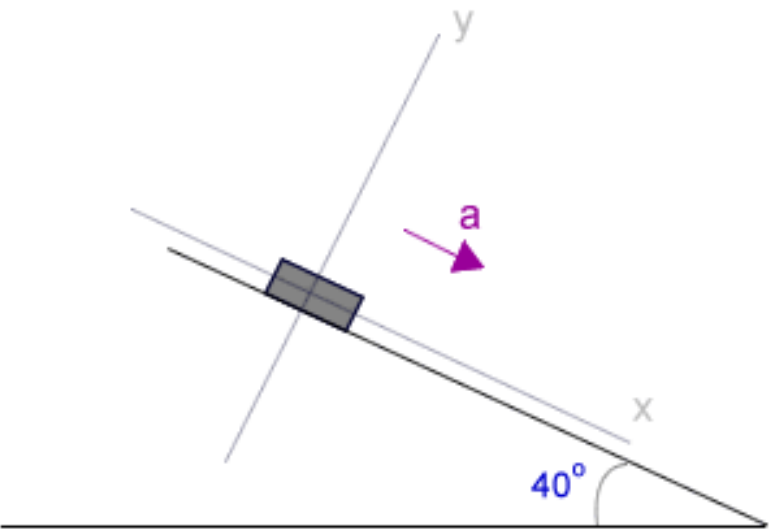
Find a, neglecting friction



- With no friction, the y direction takes care of itself
- In the x-direction:

x	y
$F_{gx} = ma_x$	$F_{net} = ma$
$F_{gx} = ma_x$	$R + F_{gy} = 0$

Ex: find a, neglecting friction



- The only acceleration will be in the x-direction
- The only x force is F_{gx}

$$F_{gx} = F_g \cos\theta = mg\cos\theta$$

$$F_{net} = mg\cos\theta = ma_x \qquad a_x = \frac{mg\cos\theta}{m} = g\cos\theta$$

Ex 1: find a, with μ =0.25, m=2.1kg

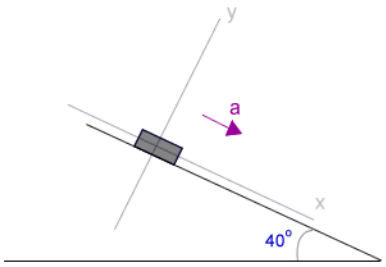
$$y$$

$$R + F_{gy} = ma_y = 0$$

$$R = -F_{gy} = -mg\sin\theta$$

$$\left|F_f\right| = \mu R = \mu mg\sin\theta$$

- We now have F_{gx} and F_f in the x-direction
- In order to find F_f we also need to look at the y-direction



$$x$$

$$F_{net} = F_{gx} + F_f = ma_x$$

$$a_x = \frac{mg\cos\theta - \mu mg\sin\theta}{m}$$

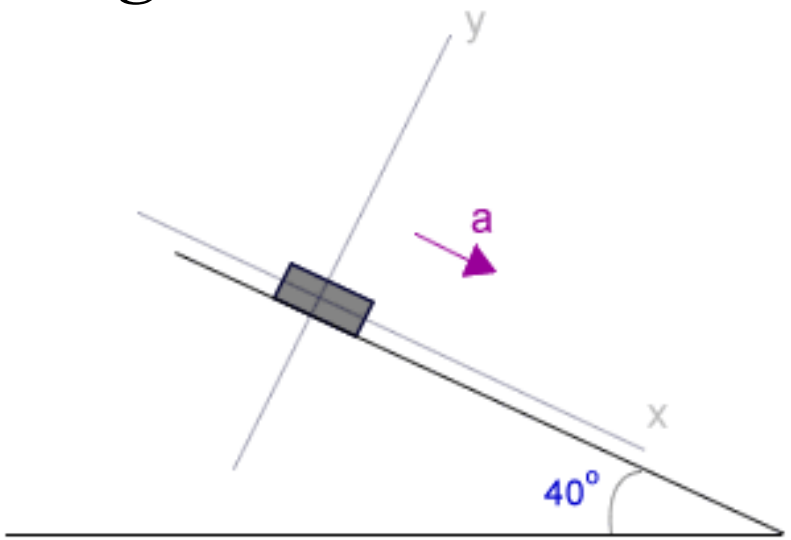
$$a_x = g(\cos\theta - \mu\sin\theta)$$

Ex 1: find a, with μ =0.25, m=2.1kg

$$F_{net} = F_{gx} + F_f = ma_x$$

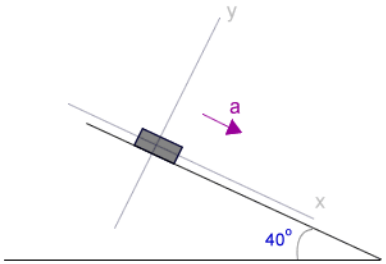
$$a_x = \frac{F_{gx} + F_f}{m} = \frac{13.2N + (-3.94N)}{2.1kg}$$

$$= 4.4 \, m/s^2$$



Ex #5 p. 67: find a, with μ =0.12, m=72kg, 35 degree slope

x	y
$F_{net} = F_{gx} + F_f = ma_x$	$R + F_{gy} = 0$
$\left\|F_f\right\| = \mu R = \mu mg\sin\theta$	$R = -F_{gy} = -mg\sin\theta$
$a_x = \dfrac{mg\cos\theta - \mu mg\sin\theta}{m}$	



$$a_x = g(\cos\theta - \mu\sin\theta) = 9.8(\cos 55 - 0.12\sin 55) = 4.66\,\frac{m}{s^2}$$

Questions

- Finish p. 67 #1-6
- Start Chapter Review p. 95 #1-2, 23-25

Ex 2: How steep?

- If you have enough power, the only limiting factor is μ
- For the critical case, friction force is at a maximum
- To barely make it up the hill, balance x forces

Ex 2: How steep for μ=1?

$$y$$

$$R + F_{gy} = ma_y = 0$$

$$R = -F_{gy} = -mg\sin\theta$$

$$x$$

$$F_f = \mu R = \mu mg\sin\theta$$

$$F_{net} = F_f + F_{gx} = 0$$

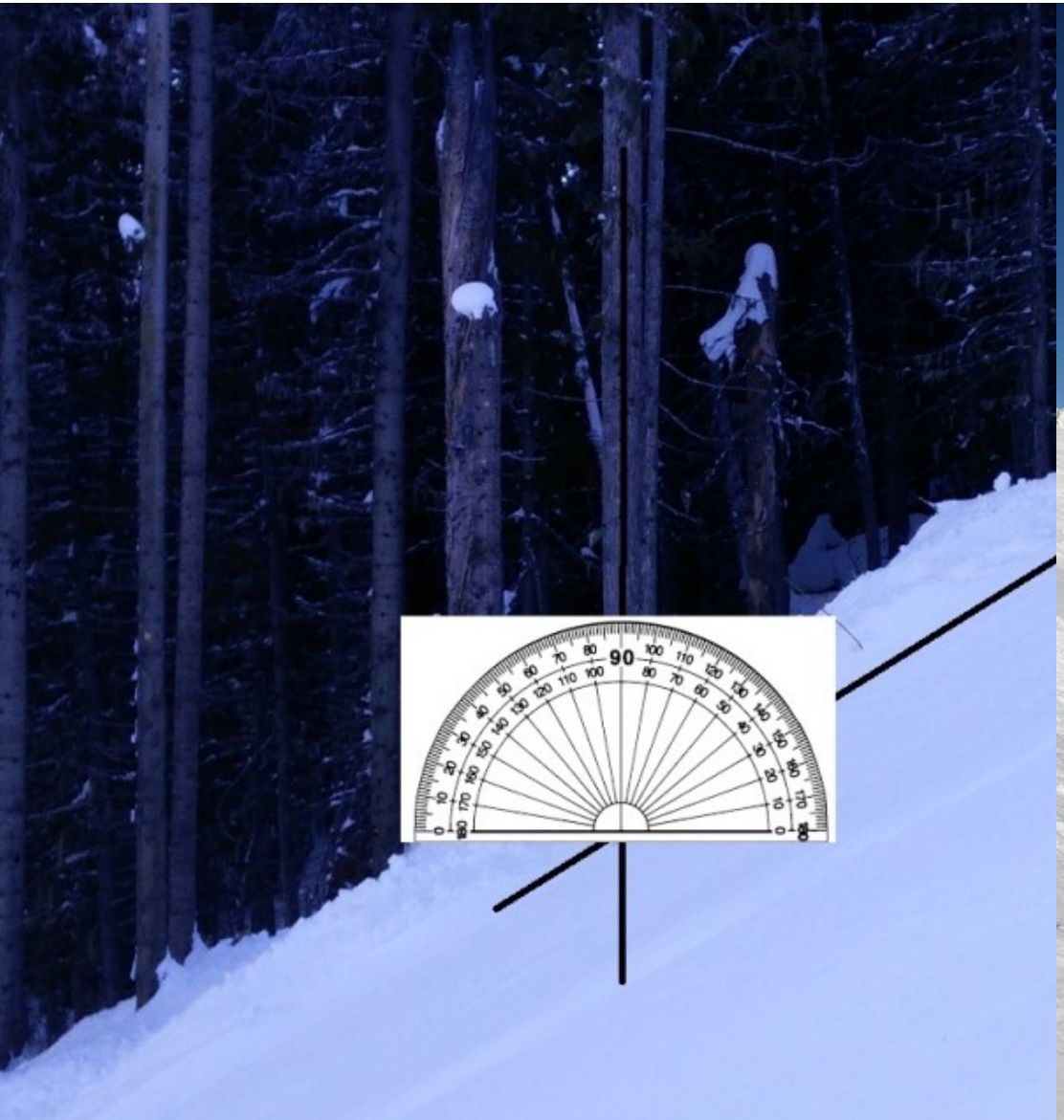
$$mg\cos\theta = \mu mg\sin\theta$$

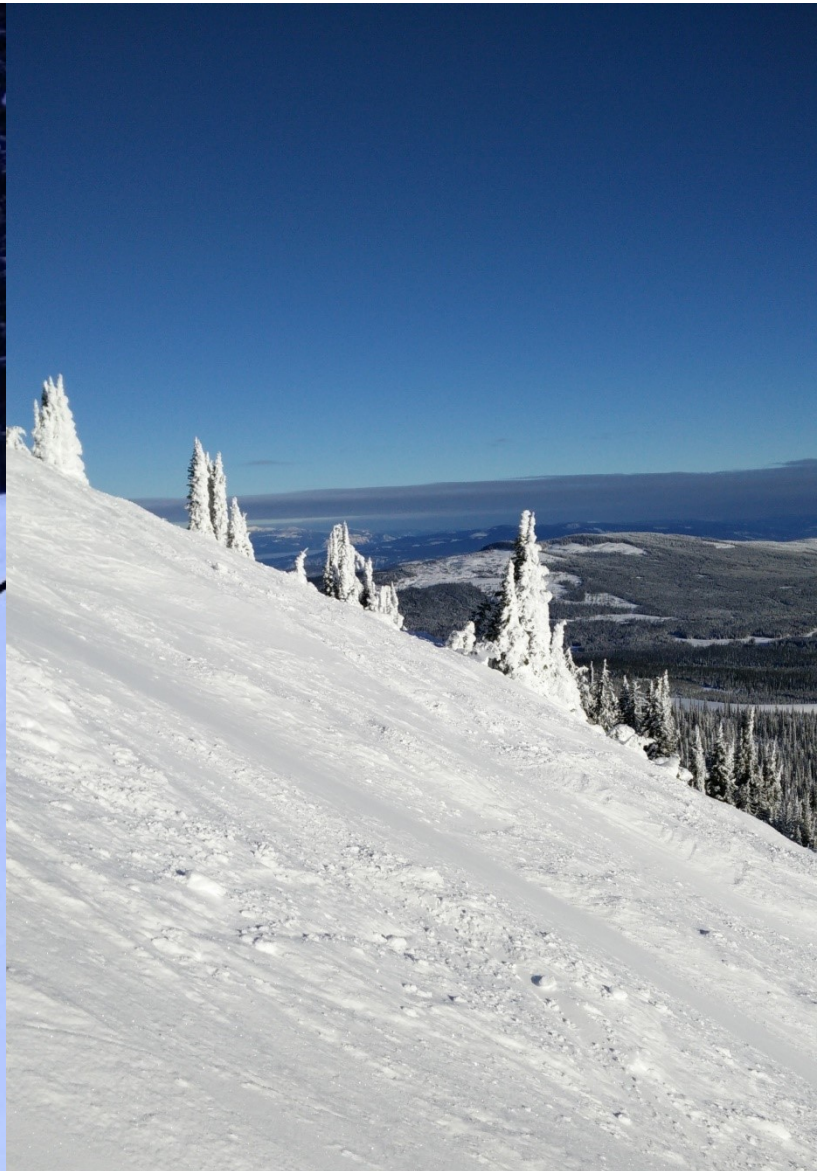
- We have $F_{gx} = -F_f$ in the x-direction
- In order to find F_f we also need to look at the y-direction

$$\tan\theta = \frac{1}{\mu}$$

$$\theta = \tan^{-1}\left(\frac{1}{\mu}\right)$$

How steep is a ?





Ex 2: How steep?

- How steep if μ =0.9?

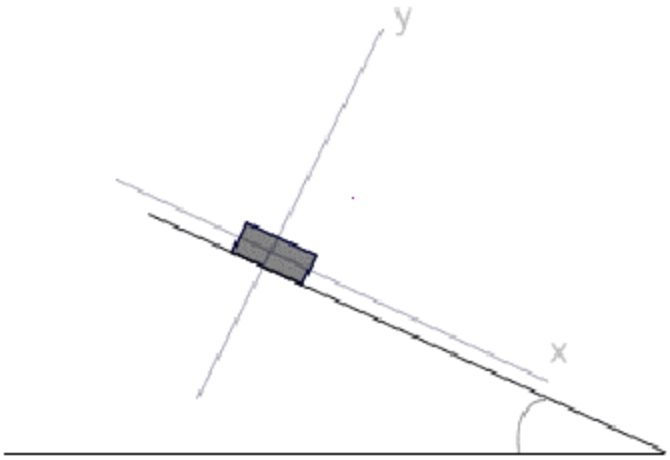
$$\theta = \tan^{-1}\left(\frac{1}{\mu}\right) \qquad \theta = \tan^{-1}\frac{1}{0.9} = 48°$$

- How steep if μ =0.1?

$$\theta = \tan^{-1}\frac{1}{0.1} = 84°$$

$$\phi = 6°$$

Ex 3: Find μ



- Dayton tilts the table until the object starts sliding.
- What is μ?

Ex 3: Find μ

$$y$$

$$F_N + F_{gy} = ma_y = 0$$

$$F_N = -F_{gy} = -mg\sin\theta$$

$$x$$

$$F_f = \mu F_N = \mu mg\sin\theta$$

$$F_{net} = F_f + F_{gx} = 0$$

$$mg\cos\theta = \mu mg\sin\theta$$

- Use the y direction to find the normal force
- $F_{gx} = -F_f$ in the x-direction at the point it just starts sliding

$$\tan\theta = \frac{1}{\mu}$$

$$\mu = \frac{1}{\tan\theta}$$

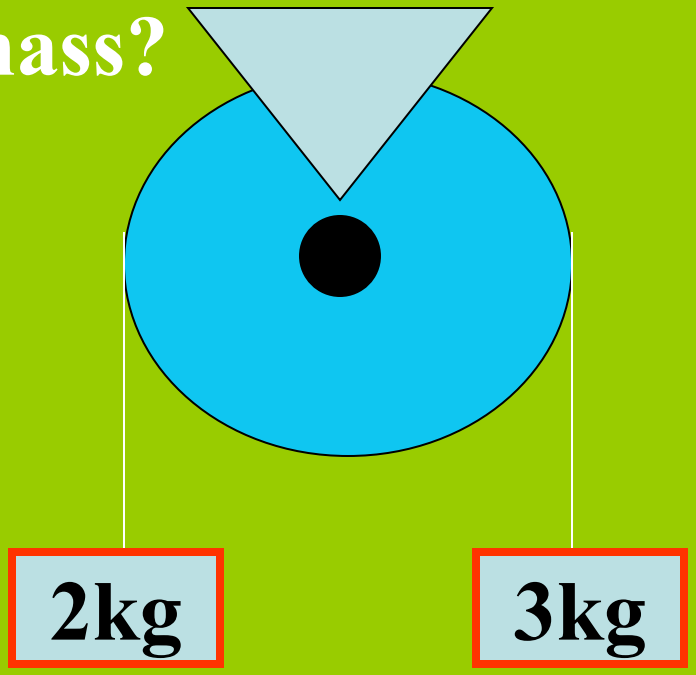
Double Body Diagrams

1. **A diagram that has two (or more) masses in it [usually involving inclined plane and/or pulley]**
2. **Consider what external forces are affecting the system as a whole. Don't worry about tension!**
3. **Decide what is negative (-) and what is positive (+) from the diagram, NOT from numbers!**

Example 1: Simple 2 body

Pulley Situation

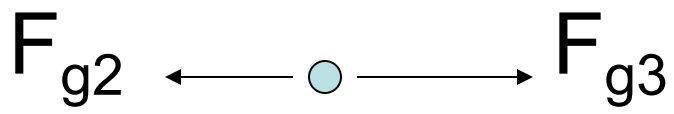
Ex 1) Given diagram, what is acceleration of 3kg mass?



a = That's for you to find out!

Considering the system

- We only have two external forces



$$F_{g2} = mg$$

$$= 2.0kg \times \left(-9.8 \, {}^{N}\!/_{kg} \right)$$

$$= 19.6N$$

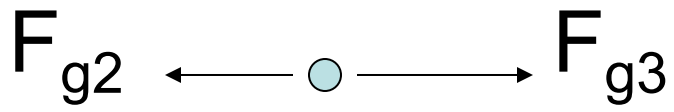
$$F_{g3} = mg$$

$$= 3.0kg \times \left(-9.8 \, {}^{N}\!/_{kg} \right)$$

$$= 29.4N$$

Considering the system

- Applying Newton's 2nd law:



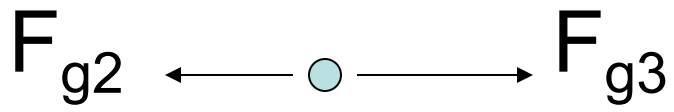
$$F_{net} = ma$$

$$a = \frac{F_{net}}{m} = \frac{F_{g2} + F_{g3}}{m} = \frac{-19.6N + 29.4N}{5kg}$$

$$= 1.96 \, m/s^2$$

Considering the system

- Applying Newton's 2nd law:



$$F_{net} = ma$$

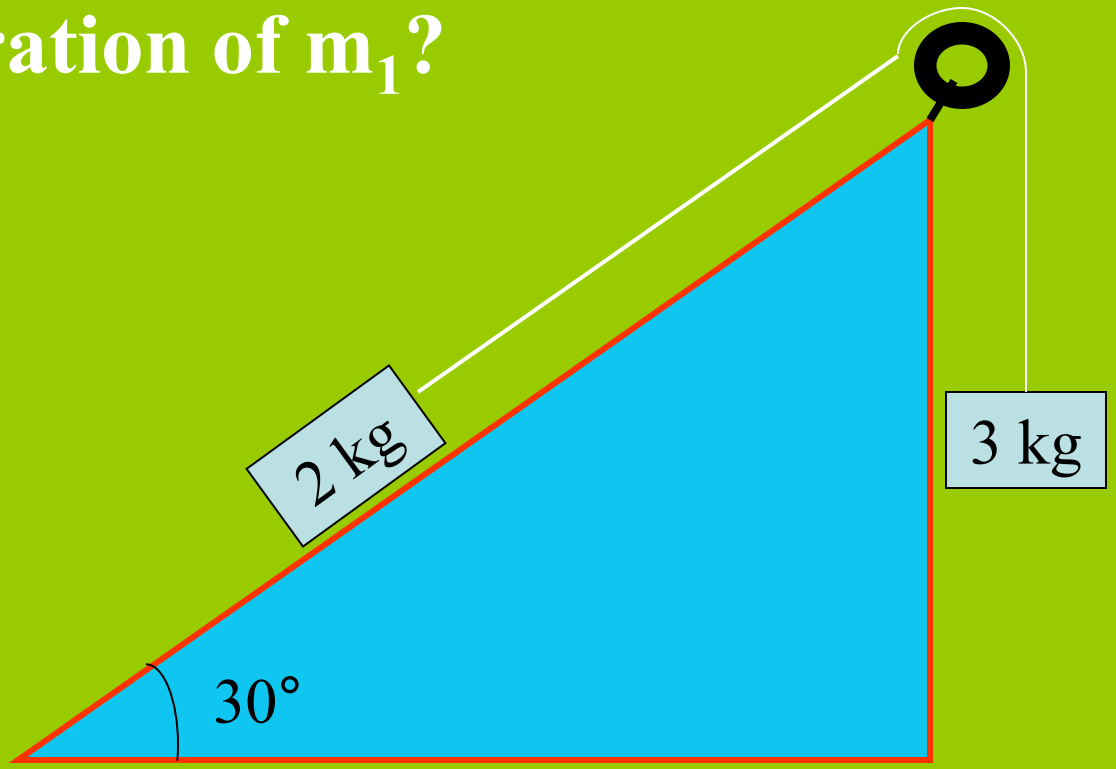
$$a = \frac{F_{net}}{m} = \frac{F_{g2} + F_{g3}}{m} = \frac{-19.6N + 29.4N}{5kg}$$

$$= 1.96 \, m/s^2$$

Example 2: Inclined 2 body

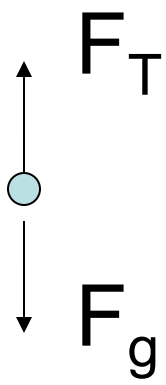
Double Body Diagram: neglect friction for now

Ex 1) Given diagram, what is acceleration of m_1?



Considering Mass 2

- We only have forces in the y-direction



$$F_g = mg = 3.0kg \times \left(-9.8 \, {}^{N}\!/_{kg}\right)$$

$$= 29.4N$$

Considering Mass 1

- We only have acceleration in the x-direction

x	y
	$F_{net} = ma$
	$F_N + F_{gy} = 0$
$F_{gx} = mg\cos\theta$	$F_N = -mg\sin\theta$
$F_{gx} = -9.8N$	

Considering The System

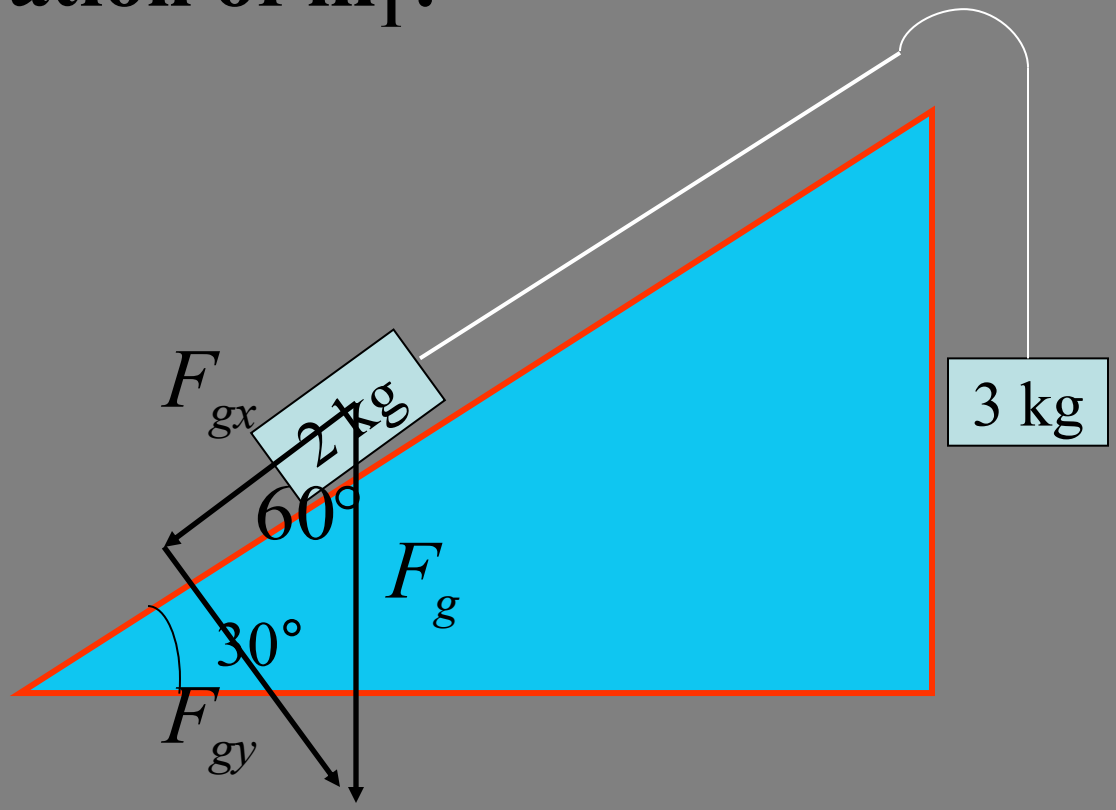
- We have to look at unbalanced forces and which ones are opposing to manually apply the correct polarity

$$F_{net} = ma \qquad F_{gx} + F_{g3} = ma$$

$$a = \frac{-9.8N + 29.4N}{5kg} \qquad a = 3.9 \, m/s^2$$

Now including friction:

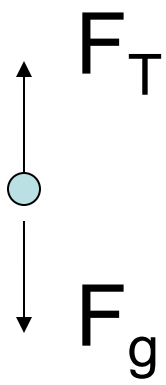
Ex 1) Given μ=0.23, what is the acceleration of m_1?



a = ?m/s²

Considering Mass 2

- We only have forces in the y-direction



$$F_g = mg = 3.0kg \times \left(-9.8 \, {}^{N}\!/_{kg}\right)$$

$$= 29.4N$$

Considering Mass 1

- We only have acceleration in the x-direction, but we have to balance y-forces to solve for friction

x	y
$F_f = -\mu mg\sin\theta$	$F_{net} = ma$
$F_f = 3.904N$	$F_N + F_{gy} = 0$
$F_{gx} = mg\cos\theta$	$F_N = -mg\sin\theta$
$F_{gx} = -9.8N$	

Considering The System

- We have to look at unbalanced forces and which ones are opposing to manually apply the correct polarity

$$F_{net} = ma \quad F_f + F_{gx} + F_{g2} = ma$$

$$a = \frac{-3.904N - 9.8N + 29.4N}{5kg}$$

$$a = 3.1 \, m/s^2$$

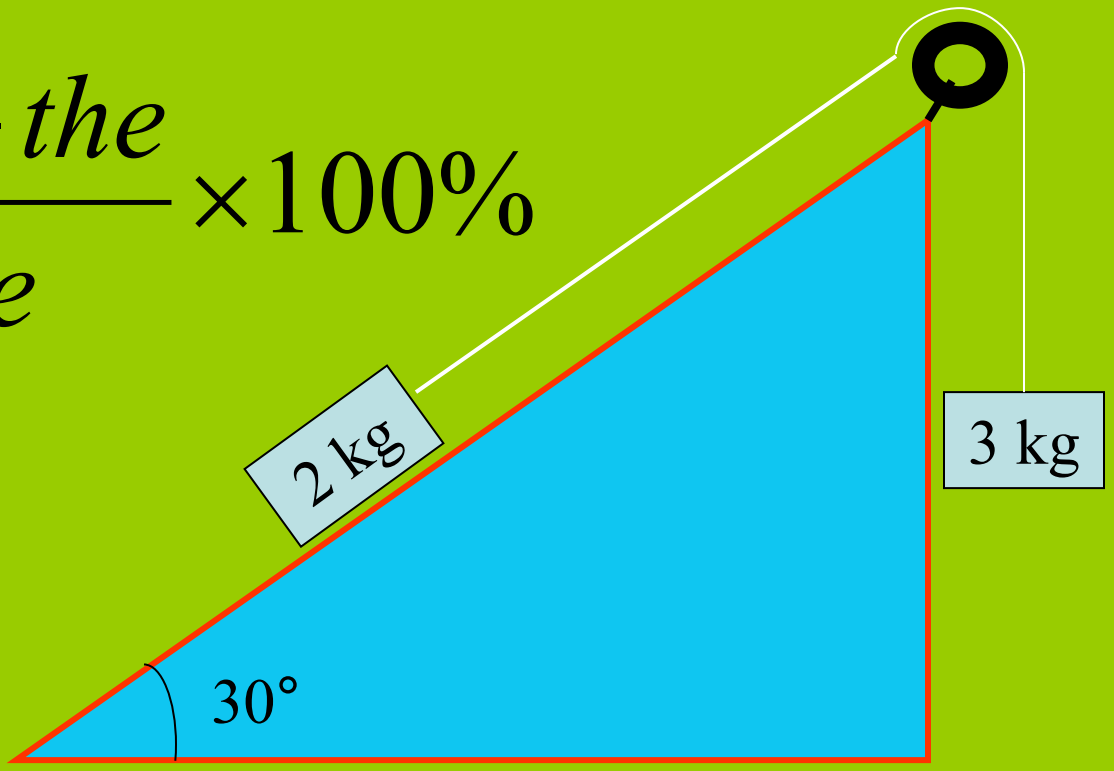
Exercises

- P. 66-7 #1-6
- Lab: design a 2 body system, find acceleration
- P. 95 Chapter Review 1,2,23-25, Test Yourself 5-7,9-10,12
- Test next week

2nd Law Lab

Design a Double Body system, calculate theoretical acceleration and compare to experimental (friction optional)

$$\frac{\text{exp} - the}{the} \times 100\%$$



Exercises

- Review Questions p. 95-98 1-23 (Bonus 24-27)
- Test Yourself p. 98-102 #1-13
- Quiz Wednesday
- Chapter Test Friday =-O