Dynamics

Lesson Structure

- Component vs Resultant Forces
- 1) Component Forces
  - Free Body Diagrams
  - Introduction to 5 common forces
  - Newton's 3rd Law
- 2) Resultant Forces
  - Newton's 1st Law
  - Newton's 2nd Law
- 3) Vector Diagrams

- Breaking The Magician's Code - Levitation Tricks
- 1) Levitating Girl 1 (https://www.youtube.com/watch?v=OAHsY_w4lcM)
- 2) Levitating Girl 2 (https://www.youtube.com/watch?v=F64L4CtGshw)
- 3) Flying (https://www.youtube.com/watch?v=O0MOVgzSU_E)
- 4) Walking on Water (https://www.youtube.com/watch?v=z0ukAescNC0)

movie clip

- GI Joe: retaliation: http://www.youtube.com/watch?v=SlrA-vPOGVQ
- How did Cobra Commander explain how the rod reaches Earth?
- Reel Physics: http://www.youtube.com/watch?v=BTYOc8b776E

demo for Newton 3rd Law

- A magnet attracts a paperclip, but does the paperclip attract back the magnet?
- Zero gravity demo: http://www.youtube.com/watch?v=cP0Bb3WXJ_k

In this unit

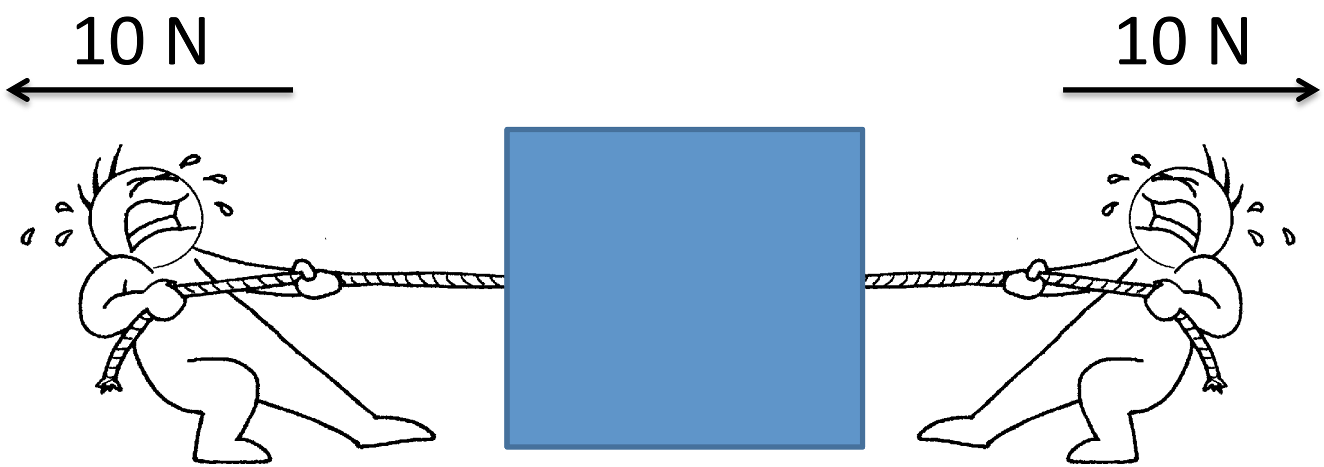
- In the previous unit, we studied the motion of moving objects
- In this unit, we will study what causes objects to move (or not move)
- This unit is largely concerned with the study of forces
- A force is a push or a pull
- All forces are vectors

What is a Force?

- A force is a push or a pull
- All forces are vectors
- The S.I. unit for force is Newtons (N)

Component vs Resultant Forces

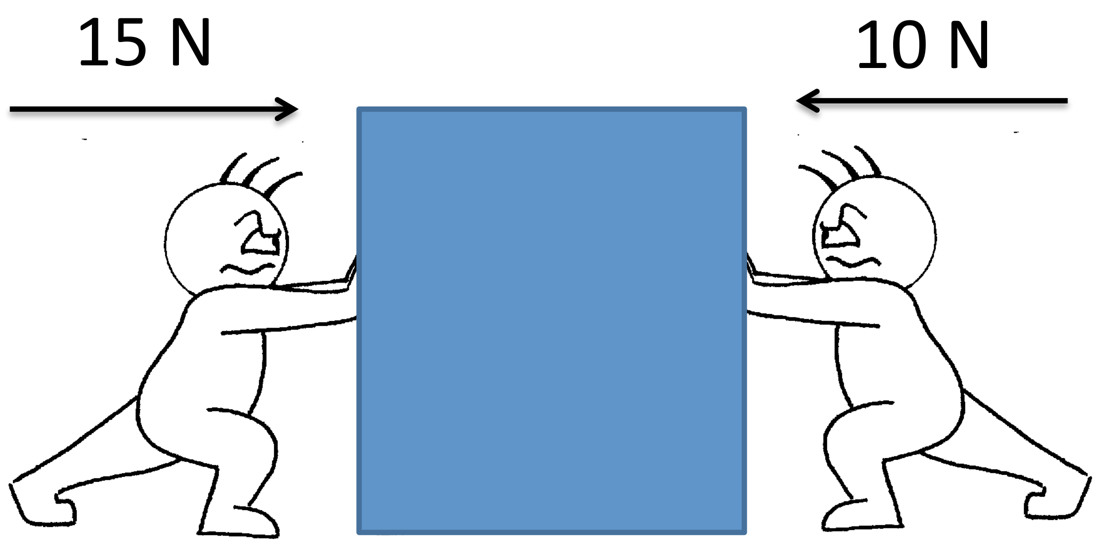
- Consider the situation below
- How many forces are acting on the block?
- What is the overall force acting on the block?



- Each 10 N force is called a <u>component force</u>
- The <u>resultant force</u> is zero

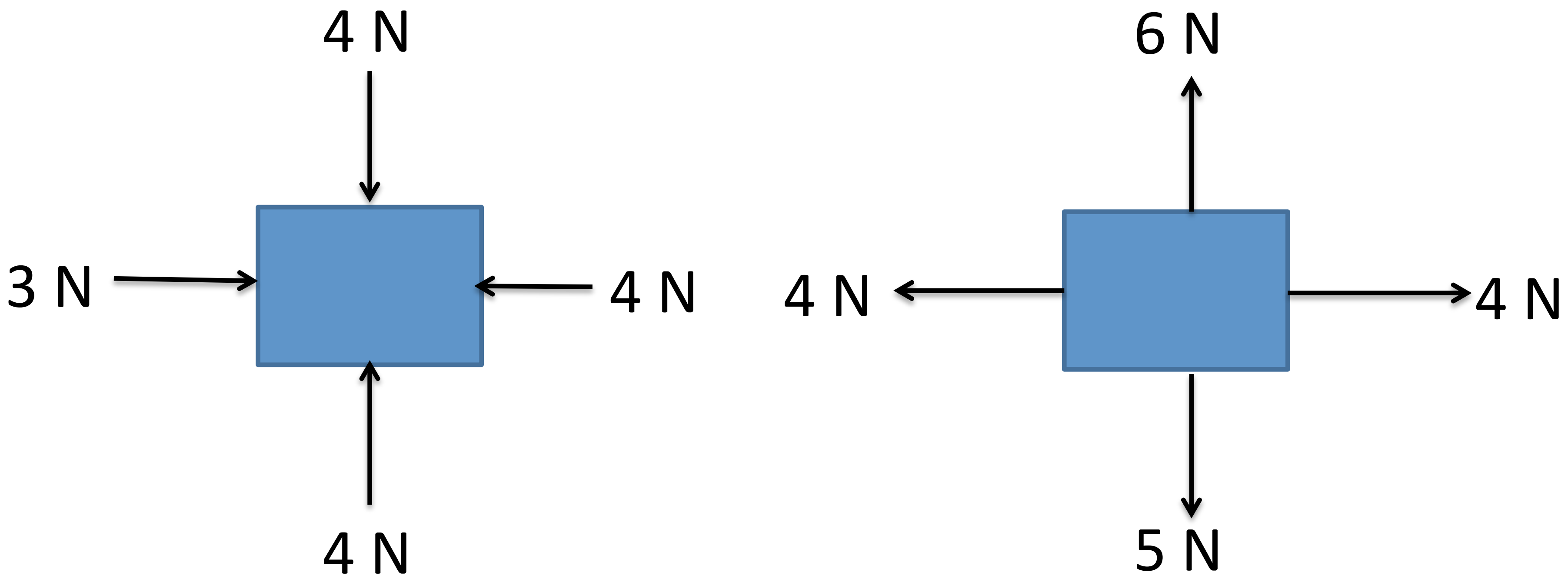
Component vs Resultant Forces

- What are the resultant forces for each of the situations below?



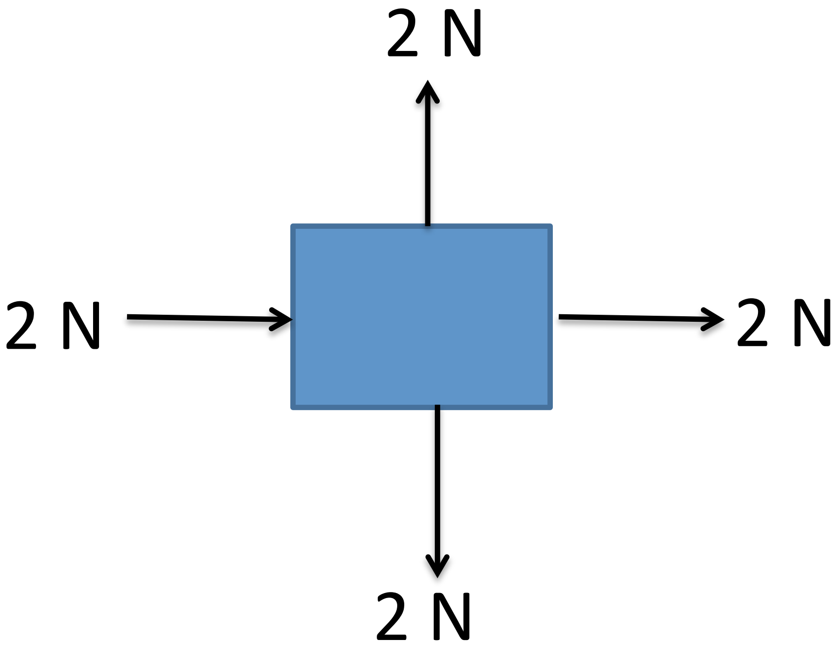
Component vs Resultant Forces

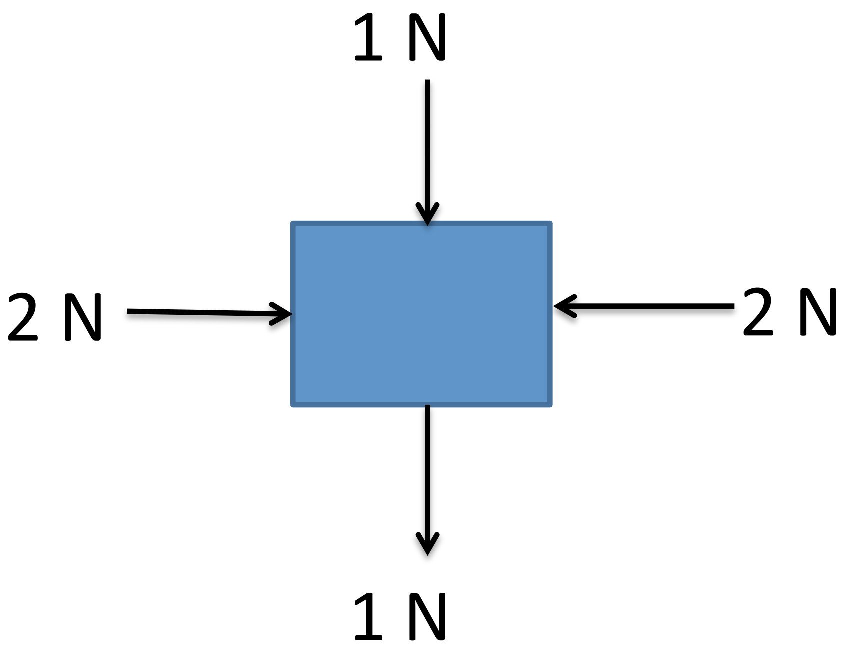
- What are the resultant forces for each of the situations below?



Component vs Resultant Forces

- How about these?





Component vs Resultant Force

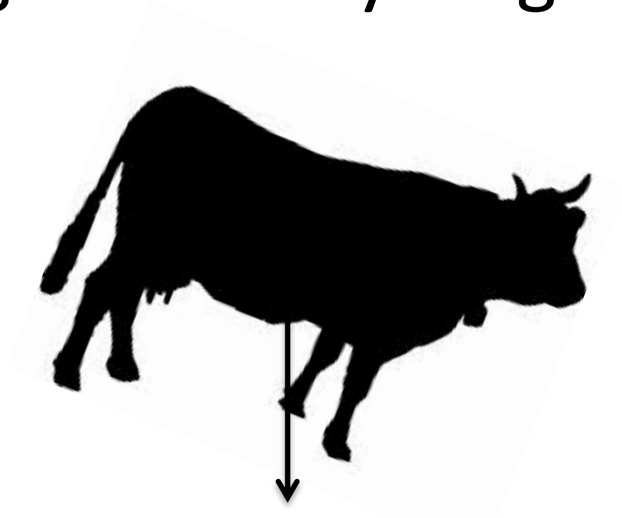
- Each individual push or pull is called a component force
- The vector sum of all the component forces is called the resultant force
- You will learn more about vector sums at the end of this unit

Free Body Diagrams

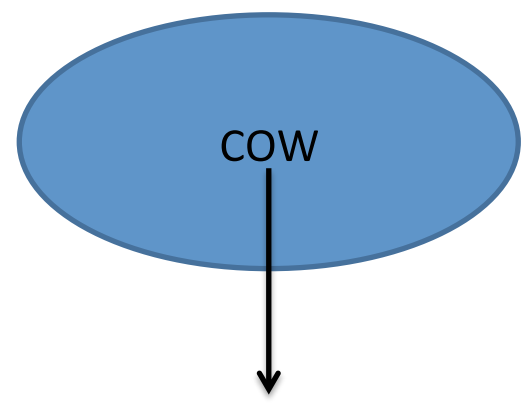
- A free body diagram is a diagram used to describe the forces acting on an object
- It only describes the forces acting on ONE single object, and not other objects connected to it
- Forces are represented by arrows.
  - Direction of arrow represents direction of force
  - Length of arrow represents magnitude of force
  - Each arrow must be labelled

Free Body Diagrams

- Objects are typically represented either using a silhouette of the object itself, or a simplification thereof.
- E.g. free-body diagram of a cow in free fall



Gravitational Force (Weight)



Gravitational Force (Weight)

Types of Component Forces

- Forces can be classified into 2 broad categories: contact forces & long range forces.
- Contact forces require an object to physically touch something else in order for the force to take effect
- Non-contact do not require physical contact for the force to take effect

Types of Component Forces

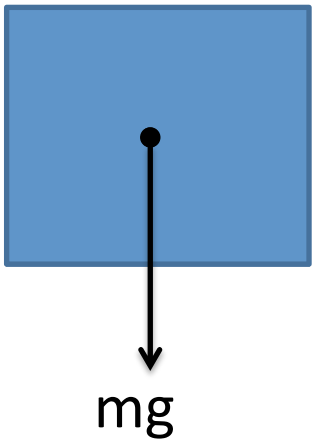
Contact Forces	Non-Contact Forces
Normal Reaction Force	Gravitational Force (Weight)
Friction	Electric Force
Tension	Magnetic Force
Air Resistance (Drag Force)	Electromagnetic Force

5 types of component forces

- For this unit: you need to be familiar with these 5 common forces:
- 1) gravitational force (weight)
- 2) normal reaction force
- 3) tension
- 4) friction
- 5) air resistance

Gravitational Force

- To draw gravitational force of a free body diagram, locate the center of gravity of the object (typically the center of the object)
- Draw an arrow downwards (towards the center of the Earth)
- Label the arrow "mg"



Gravitational Force

- What is g?
- g is called gravitational field strength
- On Earth, g = 10 Nkg^{-1}
- In layman English, we might say "my weight is 60 kg"
- This is incorrect!
- 60 kg is mass, not weight (recall Unit 1)
- Weight = mg
- A 60 kg man has a weight of 600 N

Practice Task

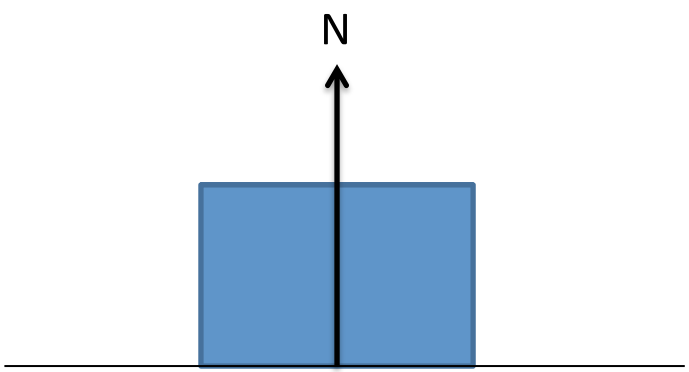
- 1) Draw a free body diagram of a bowling ball falling from the sky (no air resistance)

Normal Reaction Force

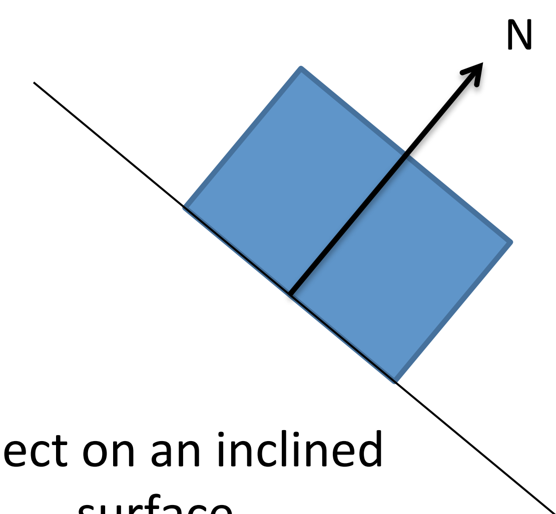
- Sometimes called “normal contact force”
- The normal contact force is the force objects exert on each other when they press each other
- Normal contact force is always a push force
- Usually represented by symbol “N” or “n”
- “Normal” here refers to “perpendicular”
- The direction of normal contact force is always perpendicular to the surface of contact

Normal Reaction Force

- To draw normal contact force on a free body diagram, locate the surface of contact
- Draw a force originating from the middle of the contact surface, going perpendicular and away from the surface
- Label the arrow "N" or "n"



Object on the ground



Object on an inclined surface

Practice Task

- 2) Draw a free body diagram of a book resting on a table

Test Yourself!

- A layman may say that "the weight of the man is causing the plank to bend" Is this explanation correct?
- Draw the free body diagram of the plank. Is the weight of the man acting on the plank?
- The more correct description is the <u>normal reaction force</u> exerted by the man on the plank is causing it to bend.

Tension

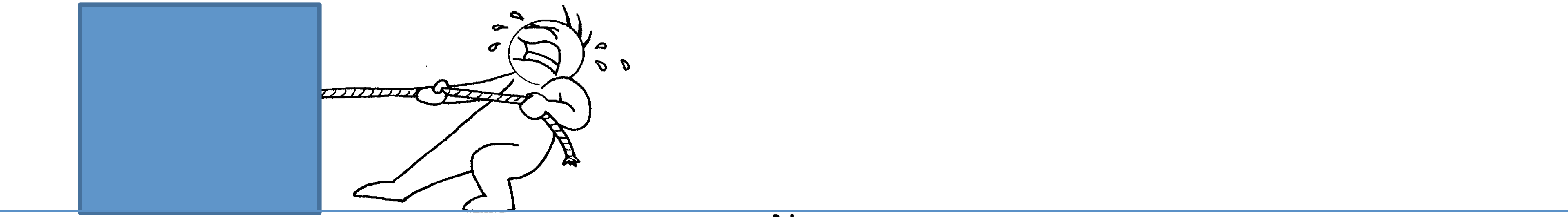
- Tension is the force exerted by a taut string, rope, spring, etc. pulling on an object
- Usually represented by symbol "T"
- Tension is always a pull force
- To draw tension in a free body diagram, locate the point where the string is pulling the object
- Draw an arrow originating from that point, in the same direction as the string
- Label the arrow "T"

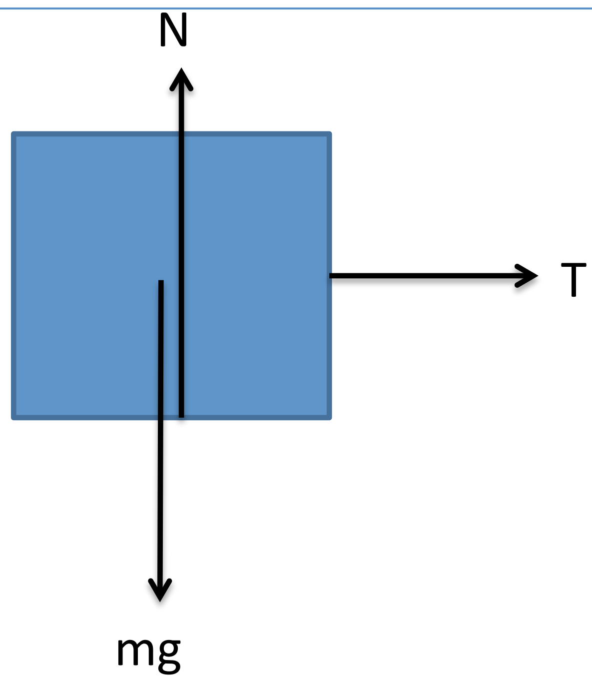
Tension

- Consider the case of a suspended & stationary pendulum bob:

Practice Task

- 3) Draw a free body diagram of a box on the smooth ground being pulled by a rope



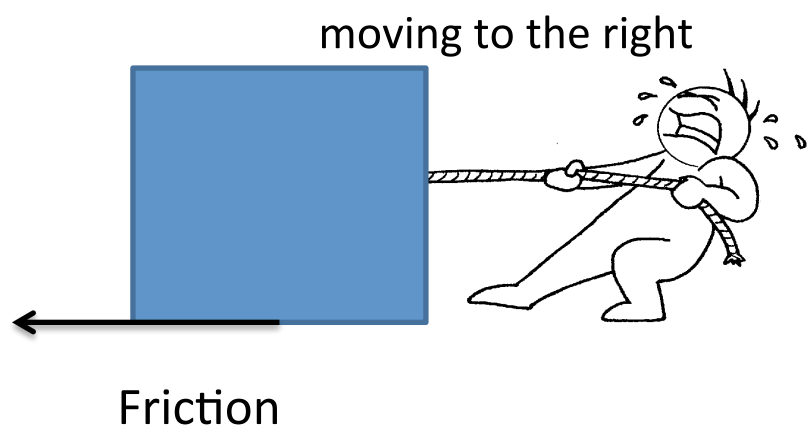


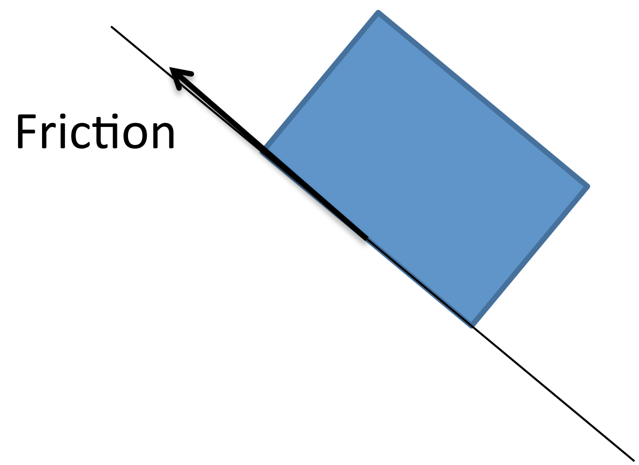
Friction

- Friction is the contact force that opposes of tends to oppose motion between surfaces in contact
- There is no symbol for friction. Either spell the word out in full, or use “$F_{friction}$“
- To draw friction in a free body diagram, identify the contact surfaces, and draw an arrow parallel to the surfaces, in the direction which would oppose motion

Friction

- If an object is moving in one direction, friction <u>acts in the opposite direction</u>
- If friction is holding up an object which would otherwise slide away, friction <u>acts in the direction opposing the sliding</u>





Practice Task

- 4) Same scenario as 3, but now floor is rough instead of smooth
- Note: “rough” indicates that friction is present, “smooth” indicates that friction is negligible

Air Resistance (Drag Force)

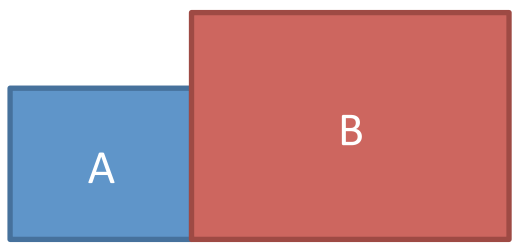
- Air Resistance is similar to friction in that it is a force which opposes motion
- There is no air resistance if the object is not moving.
- The faster the object is moving, the greater the air resistance.
- We will discuss more on air resistance in Unit 4

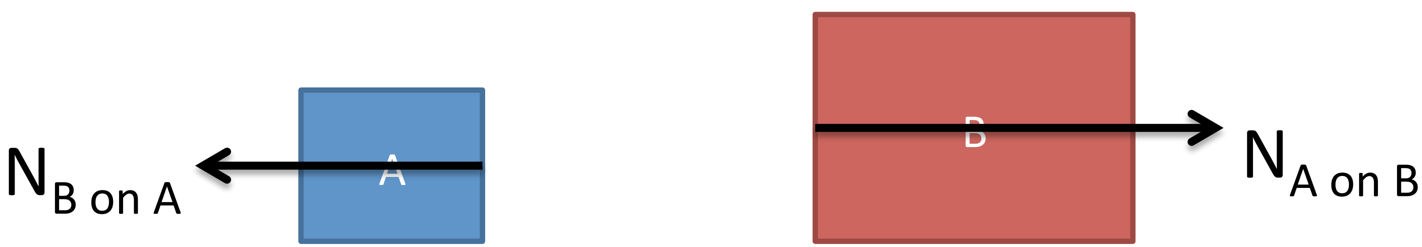
Newton's Third Law

- When object A exerts a force F on object B (i.e. $F_{A\ on\ B}$), object B exerts an equal and opposite force back to object A ($F_{B\ on\ A}$)
- These two forces are called an "action-reaction pair"
- "For every action, there is an equal and opposite reaction"

Newton's Third Law

- Box A pushes Box B
- Box A exerts a normal reaction force on Box A
- By Newton's Third law, Box B will exert an equal and opposite normal reaction force on Box A





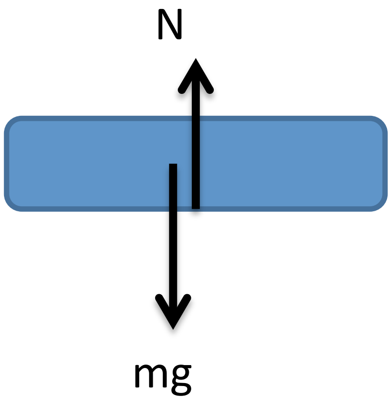
Newton's Third Law

- 4 Rules for action-reaction pairs:

1. They must be the same magnitude
2. They must be acting in the opposite direction
3. They must act on two separate objects
4. They must be the same type of force

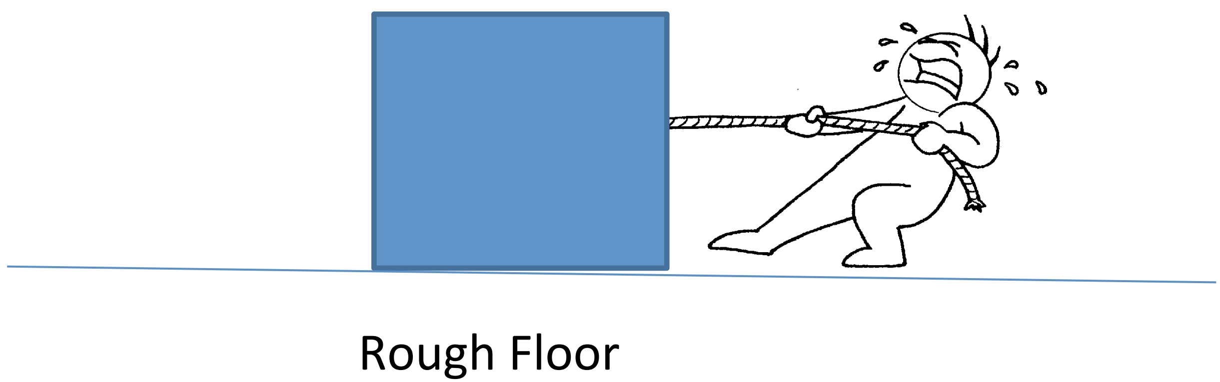
Test Yourself

- A book is resting on the table. There are two forces acting on it, its weight and the normal reaction force from the table. Are these two forces action-reaction pairs?



Practice Task

- Identify the action-reaction pairs interacting with the box in the situation below:



Newton’s Third Law and Friction

- Usually, we talk about friction as slowing down an object
- Yet, sprinters and soccer players intentionally put spikes or studs on their shoes to increase friction. Why?
- Question: can we walk if there is no friction between us and the ground?
- Video: http://www.youtube.com/watch?v=g_tTt6v_Okk

Newton’s Third Law and Friction

- How does walking work?
- When we walk, our legs are exerting frictional force on the ground backwards
- By Newton’s Third Law, the ground exerts an equal and opposite force back on our leg (forwards)
- This force is the force which helps us to move forwards
- Same principle for how a wheel works

Summary

- Component vs Resultant Forces
- Component Forces
  - 5 common types of component forces & Free Body Diagrams
    1. Gravitational Force (W = mg)
    2. Normal Reaction Force
    3. Tension
    4. Friction
    5. Air Resistance
  - Newton's Third Law (N3L)
    - N3L and Friction

Quiz 3A

Assignment 3A

- TYS Topic 3
- Paper 1 Qn: 2,9, 11, 16, 17, 19
- Paper 2 Qn 1(a)-(b) [draw FBD on foolscap paper]

When Resultant Force = 0

- When resultant force = 0, it is said that forces are <u>balanced</u>
- There are two possibilities when resultant force = 0

1) Object is at rest OR
2) Object is in uniform motion
   – uniform motion means moving in a straight line at constant speed

- This principal is also called Newton's First Law (N1L)

Resultant Force and Motion

- Recall the distinction between resultant force and component force
- Key Principal for Dynamics: only the resultant force affects the motion of an object (not the component forces)

When Resultant Force = 0

- The inverse is also true:
- If an object is at rest, the resultant force MUST be zero
- If an object is in uniform motion, the resultant force MUST be zero
- This implies that the component forces must cancel out

Practice Task

- GLM pg 64, Qn 1

- GLM pg 65, Qn 2(a)-(b)

When Resultant Force $\neq 0$

- When an object has a non-zero resultant force, it will experience <u>acceleration</u>
- Recall that acceleration is a change in velocity
- Acceleration can manifest in two ways:

1) Change in speed
2) Change in direction

When Resultant Force ≠ 0

- The inverse is also true: if an object is accelerating, the resultant force MUST be non-zero (i.e. there must be a resultant force)
- The equation relating acceleration and resultant force is:
- $F_{resultant} = ma$
- This is also known as Newton's Second Law (N2L)
- $F_{resultant} = ma$ can be further combined with kinematics equations to solve numerical problems

Solving Problems

- Often you will be given several component forces, and asked to apply either N1L or N2L
- It is recommended that you draw a Free Body Diagram of the object
- This will help you to determine the resultant force
- Then apply N1L or N2L accordingly

Practice Task

- GLM Pg 54, Qn 3(b)-(c)
- GLM Pg 56, Qn 5(a)-(b)
- GLM Pg 55-56, Qn 4, assume friction remains constant throughout

Test Yourself

- The moon orbits around the Earth with constant speed
- Is there a resultant force acting on the moon?
- Yes! Recall that acceleration can be one of either two forms: changing speed OR changing direction
- The moon is constantly changing direction, means it has an acceleration, which means it has a resultant force

Case Study: Elevator

- Question: when you are in an elevator which is going upwards, is there a resultant force acting on you?
- Answer: this is trick question! Whether the elevator is going upwards is not important. The key question to ask is: is the elevator accelerating?

Case Study: Elevator

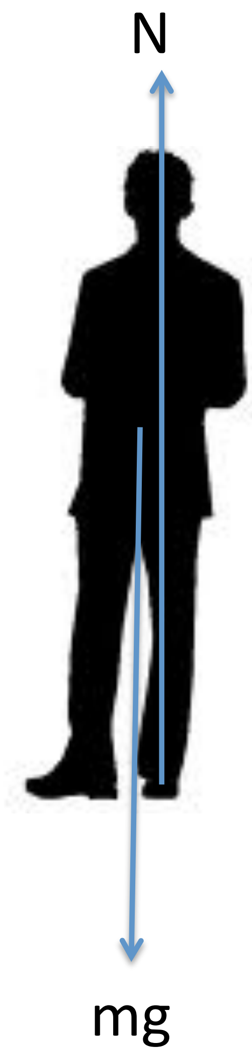
- At the start of the journey upwards, you accelerate upwards from rest. There is an upward resultant force acting on you.
- At the middle of the journey, you travel with constant velocity, i.e. uniform motion. There is no resultant force (N1L)
- At the end of the journey, you decelerate to a stop. There is a downward resultant force acting on you.

Case Study: Elevator

- Question: when you are in an elevator which is going upwards, do you feel heavier or lighter?
- Answer: this is another trick question! At the start of the elevator journey you should feel heavier, in the middle you feel the same, and towards the end you should feel lighter. Try this out yourself!
- What is the explanation for this?

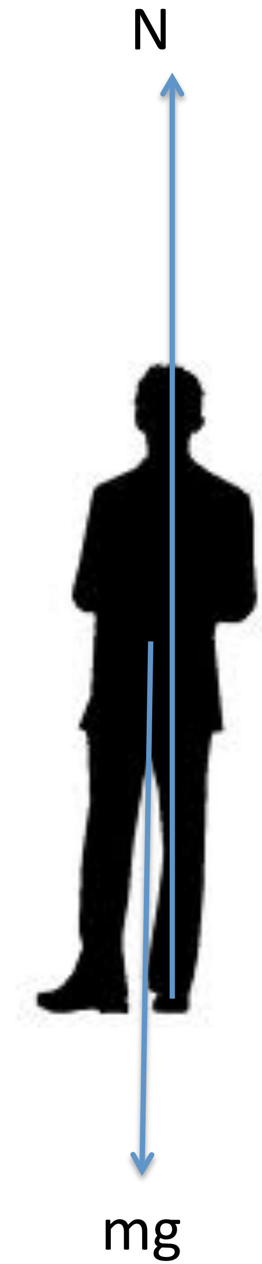
Case Study: Elevator

- When you "feel" your weight, what you are actually feeling is the normal reaction force of the elevator floor on your feet, pushing you upwards
- Free Body Diagram of you in elevator:
- When at rest, resultant force = 0
- N = mg
- The N we usually feel is equals to mg in magnitude



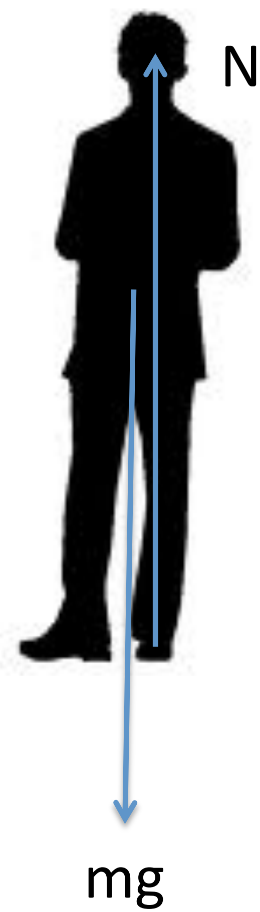
Case Study: Elevator

- At start of journey upwards, elevator is accelerating from rest
- There must be a resultant force upwards
- Hence, we deduce N > mg
- We feel heavier, because N is greater than what we usually feel



Case Study: Elevator

- At end of journey, elevator is decelerating to stop
- There must be a resultant force downwards
- Hence, we deduce N < mg
- We feel lighter, because N is less than what we usually feel



Quiz 3B

Assignment 3B

- Topic 3
- Paper 1 Qn 1, 3, 4, 5, 7, 8
- Paper 2 Qn 2

Vector Diagrams

- For this part of the lesson, you will need a protractor
- At the beginning of the lesson, we mentioned that the resultant force is the vector sum of all the component forces
- There is more than one method of solving a vector sum, but for your Physics syllabus you are required to learn the head to tail method

Terminology

- Direction of arrow represents direction of vector
- Length of arrow represents magnitude of vector

Tail
(of vector
arrow)

Head
(of vector
arrow)

Head to Tail Method

- Decide on a scale, and draw all vectors to scale
- Important: do not change direction of vectors!!
- When adding two vectors together, position the tail of the second vector to the head of the first vector (and henceforth)
- The resultant vector is from the tail of the first vector, to the head of the last vector

Question Type 1

- There are two types of questions for vector addition
- The first question type is when the question gives you two vectors (usually 2 forces) and ask you to find the resultant vector
- To solve, first decide on a scale
- Choose any one vector to draw first
- Use head to tail method to find resultant vector

Important!

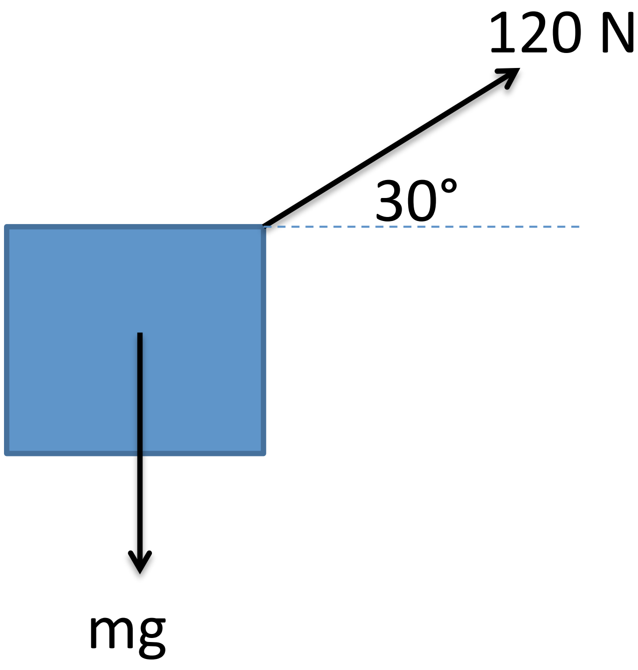
- If the question asks you to find a vector, you need to specify BOTH magnitude and direction of your final answer
- The best way to give direction is to say that it is X° clockwise/anti-clockwise from the given vector
- E.g. the resultant force is 7 N, 30° clockwise from the weight

Practice Task 1

- Find the resultant force when the following two forces are added together:
- (i) 5 N going directly to the right
- (ii) 7 N going directly to the top

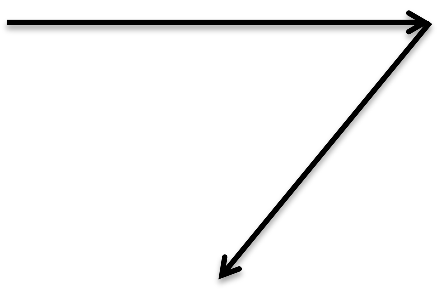
Practice Task 2

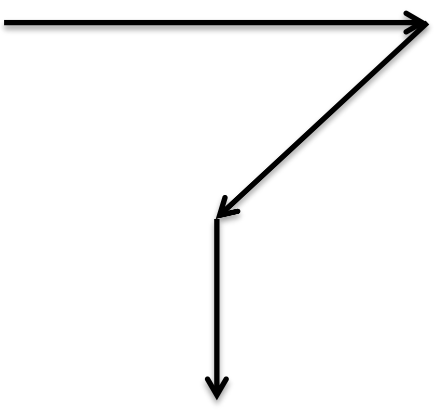
- By means of a vector diagram, find the resultant force acting on the box (of mass 8 kg) being pulled by a rope



What if…

- What is the resultant force for the following head-to-tail diagrams?





What if…

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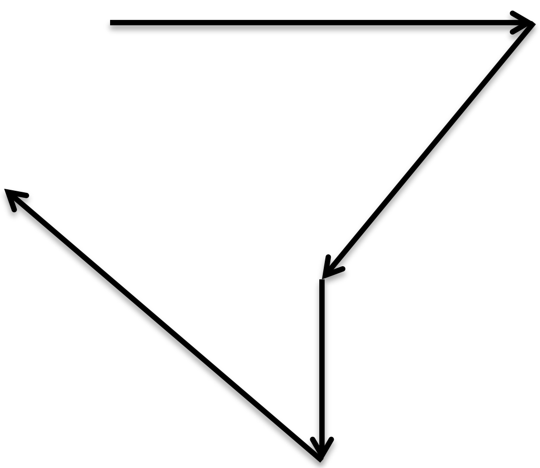
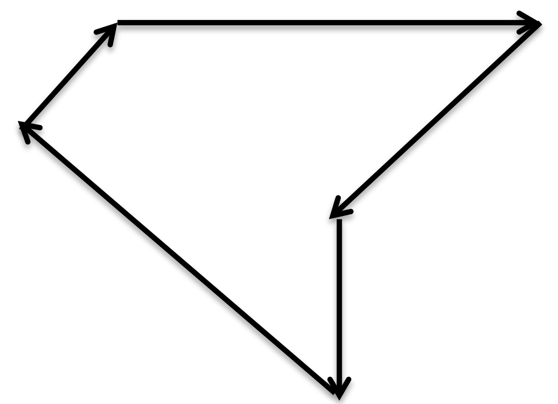




Question Type 2

- When the head-to-tail vector diagram forms a closed loop, it implies that there is no resultant vector (or the resultant is zero)
- If the vectors are forces, and the vector diagram forms a closed loop
- The resultant force is zero, and Newton's First Law applies

Question Type 2

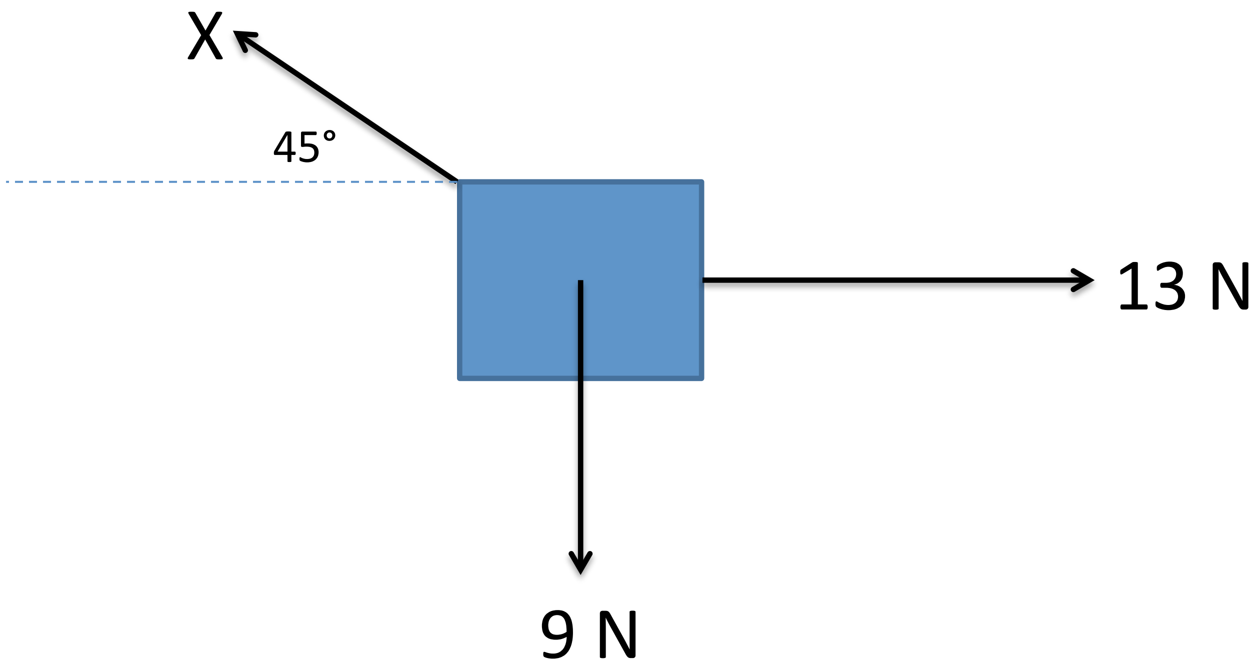
- For the second type of question, you will be required to draw a closed loop of exactly 3 forces (i.e. resultant force zero)
- Usually, two forces are given to you and you will be asked to find the third one.

Question Type 2

- To solve:
- 1) If direction of forces are not clear to you, draw the free body diagram
- 2) Identify the 3 forces which will form a closed loop
- 3) Decide on scale
- 4) Draw one force
- 5) Head-to-tail second force
- 6) Head-to-tail third (and final) force, which should form a close loop with the first force

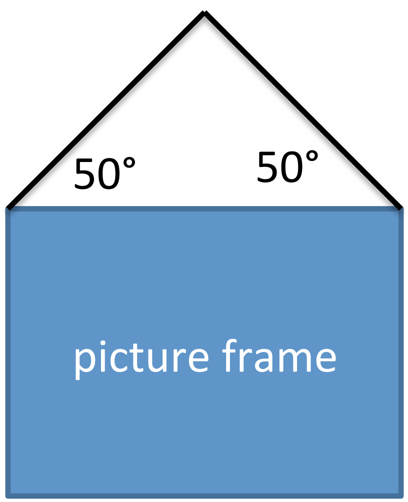
Practice Task 3

- The box in the diagram below is at rest. Find force X.



Practice Task 4

- The picture frame is suspended by two strings which are of equal tension. If the picture frame has a mass of 0.5 kg, determine the tension in each string.



Quiz 3C

Assignment 3C

- TYS Topic 1B
- Paper 1 Qn 5, 6
- Paper 2 Qn 1

- TYS Topic 3
- Paper 1 Qn 6, 12,