

Chapter 5 - Force and Motion

- What is force?
 - ✓ different types of forces
- What do forces do?
 - ✓ acceleration and mass
- Newton's 2nd Law
 - ✓ acceleration \rightarrow force and mass
- Newton's 1st Law
 - ✓ inertia
- Free-body diagrams

PHYS 22: Chap. 06, Pg 1

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Force and Newton's Laws

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Newton's Laws

- 1) An object continues in its state of rest, or its state of uniform velocity, as long as no net force acts on it. (also known as the **Law of Inertia**)
- 2) $\sum \vec{F} = m\vec{a}$ What does $\sum \vec{F}$ represent?
- 3) When Object A exerts a force on Object B, then B exerts an equal and opposite force on A.

$$\vec{F}_{AonB} = -\vec{F}_{BonA}$$

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Newton's First Law

Consider an object with no force acting on it. If it is at rest, it will remain at rest. If it is in motion, then it will continue to move in a straight line at a constant speed.

The first law tells us that an object that experiences no force will experience no acceleration.

Newton's Second Law

An object with mass m will undergo acceleration

$$\vec{a} = \frac{\vec{F}_{net}}{m}$$

where the net force $\vec{F}_{net} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \dots$ is the vector sum of all the individual forces acting on the object.

The second law tells us that a net force causes an object to accelerate. This is the relationship between force and motion. The acceleration points in the direction of \vec{F}_{net} .

Newton's Third Law

Every force occurs as one member of an action/reaction pair of forces. The two members of an action/reaction pair:

- act on two *different* objects.
- point in opposite directions and are equal in magnitude:

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Newton's First Law

- What is the "natural" tendency of matter?
 - old thinking: natural state is to be at rest
 - objects tend to stop if they are in motion
 - new thinking: natural state is to **resist acceleration**
 - objects tend to **remain in their initial state**

- An object will remain at rest or at constant velocity unless acted upon by a net external force.

- If there is no net force, there is no acceleration.

How Things Work: Sec. 1.1, Pg 3

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Catalog of Forces

- 1)
- 2)
- 3)
- 4)
- 5)
- 6)
- 7)
- 8)
- 9)
- 10)

- 1) Gravity
- 2) Spring force (elastic)
- 3) Tension (string or rope)
- 4) Normal force (\perp to a surface)
- 5) Friction (static or kinetic)
- 6) Drag (air or fluid resistance)
- 7) Thrust (rocket, propeller, fan,...)
- 8) Electric or magnetic force

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SYNTHESIS 5.1 A catalog of forces

When solving mechanics problems, you'll often use the directions and details of the most common forces, outlined here.

Weight

The weight force is always directed down.

Weight force (N) → $w = mg$ ← Mass (kg) → Free-fall acceleration (9.80 m/s^2)

The weight force is a long-range force. This formula applies near the earth's surface.

Normal force

The normal force is always perpendicular to the surfaces that touch.

There is no formula for the normal force; we use Newton's laws to determine the normal force.

Drag

The drag force is directed opposite the velocity.

Simple expressions exist for the drag force when the Reynolds number is high ($Re > 1000$: cars, balls, swimming fish) or low ($Re < 1$: falling dust, microorganisms in water).

For high Re , the drag is

Drag coefficient (dimensionless) → $D = \frac{1}{2} C_D \rho v^2$

Cross-section area (m^2) → $D_{\text{sphere}} = 6\pi\eta r v$

Speed (m/s) → Viscosity (Pa·s) → Radius (m) → Speed (m/s)

For low Re , the drag on a spherical object is

Static friction

The static friction force opposes motion, up to a maximum value.

Maximum value of the static friction force (N) → Coefficient of static friction (dimensionless) → Normal force (N)

$f_s = f_{s, \text{max}} = \mu_s n$

Kinetic friction

The kinetic friction force is directed opposite the velocity.

Coefficient of kinetic friction (dimensionless) → Normal force (N)

$f_k = \mu_k n$

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A Tour de Force

- A force is a push or a pull that acts on an object
 - **Contact forces**
 - objects in contact exert forces on each other
 - » you push on a box
 - » air pushes on a car (air resistance)
 - » tension in a rope
 - **Action at a distance**
 - gravity
 - electricity
 - magnetism

How Things Work: Sec. 1.1, Pg 8

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Newton's First Law

1 Law of Inertia: Objects resist change in motion

Objects do not resist **motion**, but **change in motion**

How much do they resist? It depends on their **MASS**.
The more massive an object, the more resistant it will be.

Easy to push

Hard to push

Mass: How much "stuff" (matter) an object has.

How Things Work: Sec. 1.1, Pg 9

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Inertia

Mass is an intrinsic property of a body that determines its **resistance to acceleration**

Inertia: resistance to **change in motion**
i.e. resistance to **acceleration**

⇒ **Mass** is a measure of **inertia**

Is mass the same as: **weight? NO**
size? NO
density? NO

Our everyday experience of mass comes mainly from trying to **accelerate** things

How Things Work: Sec. 1.1, Pg 10

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Physics Concept

- Inertia
 - A body at rest tends to remain at rest
 - A body in motion tends to remain in motion

A study of Inertia: a physics student at rest

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Newton's 1st Law in action!

1. Explain Newton's First Law of Motion in your own words.

!

Yakka Foob Mag. Grug PubbaMup Zink wattoo Gazark. Chumble Spuzz.

I LOVE LOOPHOLES.

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ConcepTest 4 **Newton's First Law**

You kick a smooth flat stone out on a frozen pond. The stone slides, slows down, and then eventually stops. You conclude that:

1. the force pushing the stone forward finally stopped pushing on it
2. no net force acted on the stone
3. a net force acted on it all along
4. the stone simply "ran out of steam"
5. the stone has a natural tendency to be at rest

After the stone was kicked, no force was pushing it along! However, there must have been some force acting on the stone to slow it down and stop it. This would be friction!!

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PHYS 21: Chap. 1, Pg 13

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ConcepTest 4b **Friction**

Can a frictional force ever act in the same direction as the motion of an object?

1. yes
2. no
3. I am not really sure



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PHYS 21: Chap. 1, Pg 13

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A box is sitting in the back of a flatbed truck.

a) If the truck gently accelerates, the box moves with the truck without slipping. Specifically, what is the force that makes the box move?

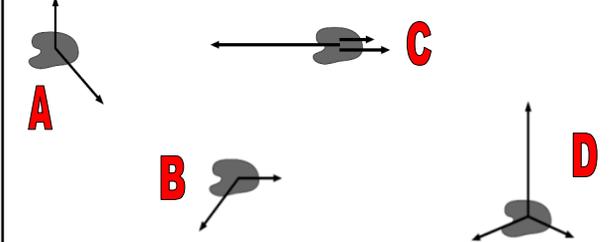
b) What happens if the truck accelerates too rapidly? Explain what is happening and why.

c) What would happen to the box if the truck bed was just a very smooth sheet of ice?



6.21

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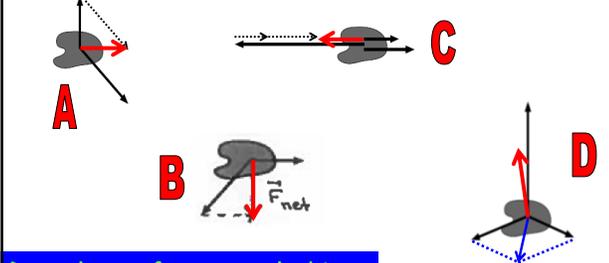


Draw the net force on each object.

5.1,2,14

PHYS 21: Chap. 5, Pg 16

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Draw the net force on each object.

4.2-4.3

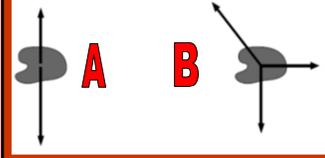
PHYS 21: Chap. 5, Pg 17

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ConcepTest 2 **Forces**

Which object is in equilibrium?

1. A
2. B
3. both
4. neither



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PHYS 21: Chap. 1, Pg 13

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Two forces are shown acting on each object. Draw a third force such that the object is in equilibrium.

5.22 PHYS 21: Chap. 5, Pg 19

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Two forces are shown acting on each object. Draw a third force such that the object is in equilibrium.

5.22

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Newton's 2nd Law

PHYS 22: Chap. 2, Pg 21

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Pushing a box

- consider pushing a box
- more force leads to more acceleration $\rightarrow a \propto F$
- more mass leads to less acceleration $\rightarrow a \propto 1/m$

conclude that: $a \propto F/m$

How Things Work, Sec. 1.1, Pg 22

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Newton's Second Law

2

Σ F = ma

Acceleration is **proportional** to the net force applied

The constant of **proportionality** is the mass.
(Definition of mass can be thought of as $m = F/a$)

Remember from Newton's 1st Law

- mass is a measure of **inertia**
- an object's "**resistance**" to acceleration

The **mass** of an object is an intrinsic property

- it is independent of external influences
- mass is **different** from **weight**

How Things Work, Sec. 1.1, Pg 22

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ConceptTest 2

Forces

A steady force applied to a 2 kg mass causes it to accelerate at 4 m/s². If the same force is applied to a 4 kg mass, what is the resulting acceleration?

1. 1 m/s²
2. 2 m/s²
3. 4 m/s²
4. 8 m/s²
5. 16 m/s²

PHYS 11: Chap. 4, Pg 24

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ConcepTest 2 Forces

A steady force applied to an object causes it to accelerate at 4 m/s^2 . What is the acceleration of the object if the force is doubled and the mass is doubled?

1. 1 m/s^2
2. 2 m/s^2
3. 4 m/s^2
4. 8 m/s^2
5. 16 m/s^2

0 of 5

PHYS 11: Chap. 4, Pg 20

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ConcepTest 2 Forces

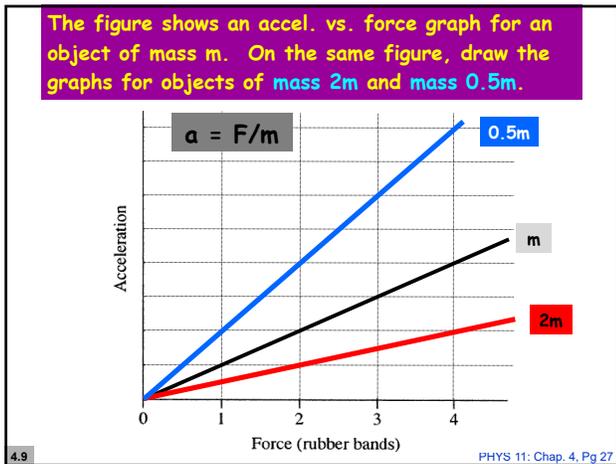
A steady force applied to an object causes it to accelerate at 4 m/s^2 . What is the acceleration of the object if the force is doubled and the mass is halved?

1. 1 m/s^2
2. 2 m/s^2
3. 4 m/s^2
4. 8 m/s^2
5. 16 m/s^2

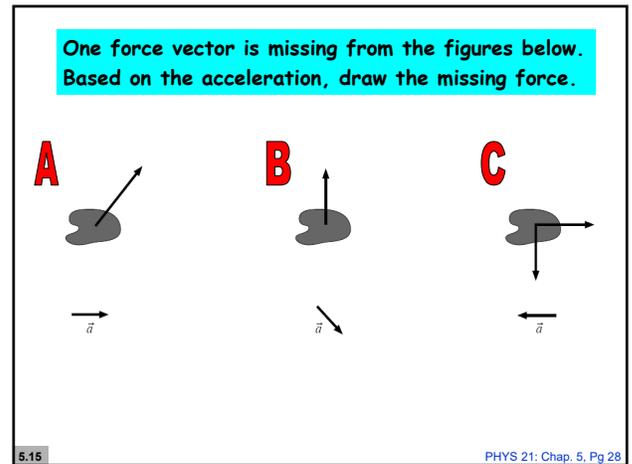
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PHYS 11: Chap. 4, Pg 20

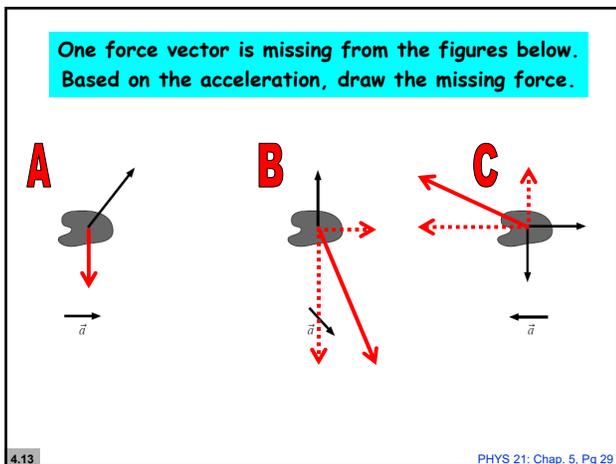
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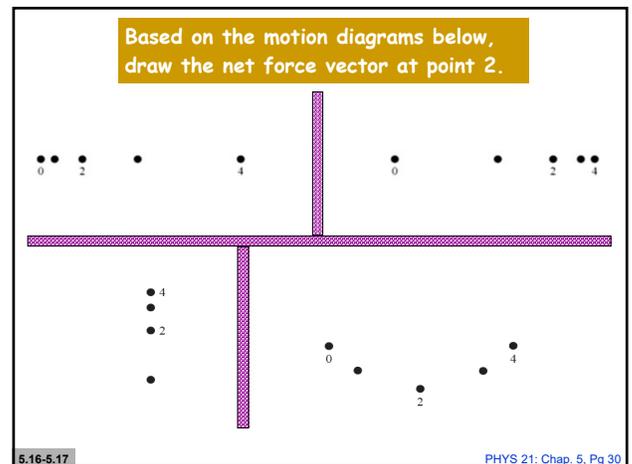
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Based on the motion diagrams below, draw the net force vector at point 2.

4.15 PHYS 21: Chap. 5, Pg 31

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Free-Body Diagrams

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Draw a free-body diagram for each case. Be sure to show the **net force** on the object also.

- 1) An elevator suspended by a cable is descending at constant velocity
- 2) A car on a very slippery icy road is sliding headfirst into a snowbank, where it gently comes to rest with no one injured.
- 3) A compressed spring is pushing a block across a rough horizontal table at a steadily increasing speed.
- 4) A brick is falling from the roof of a three-story building.

5.3-5.6 PHYS 21: Chap. 5, Pg 33

33

Draw a free-body diagram for each case. Be sure to show the **net force** on the object also.

- 1) An elevator suspended by a cable is descending at constant velocity.
- 2) A car on a very slippery icy road is sliding headfirst into a snowbank, where it gently comes to rest with no one injured.
- 3) A compressed spring is pushing a block across a rough horizontal table at a steadily increasing speed.

$\vec{a} = 0 \Rightarrow \vec{F}_{net} = 0$

 $\vec{F}_{net} = 0$

$\alpha \neq 0 \Rightarrow \vec{F}_{net} \neq 0$

4.4-4.6

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Blocks A and B are connected by a string passing over a pulley. Block B is falling and dragging block A across a rough surface. Draw a free-body diagram for each block.

4.22 PHYS 21: Chap. 5, Pg 35

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Blocks A and B are connected by a string passing over a pulley. Block B is falling and dragging block A across a rough surface. Draw a free-body diagram for each block.

4.22 PHYS 21: Chap. 5, Pg 36

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Blocks A and B are connected by a string passing over a pulley. Block B is falling and pulling block A up. Draw a free-body diagram for each block.

4.22 PHYS 21: Chap. 5, Pg 37

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Blocks A and B are connected by a string passing over a pulley. Block B is falling and pulling block A up. Draw a free-body diagram for each block.

4.22 PHYS 21: Chap. 5, Pg 38

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Draw separate free-body diagrams for these cases.

PHYS 21: Chap. 5, Pg 39

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Draw a free-body diagram for each case. Be sure to show the net force on the object also.

- 1) A heavy crate is being lowered straight down at constant speed by a steel cable.
- 2) A boy is pushing a box across the floor at a steadily increasing speed.
- 3) A bicycle is coasting down a hill and speeding up. Friction is negligible, but air resistance is not.
- 4) You've slammed on the car brakes while going down a hill, and you are skidding to a halt.

5.24-5.27 PHYS 21: Chap. 5, Pg 40

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Draw a free-body diagram for each case. Be sure to show the net force on the object also.

- 1) A heavy crate is being lowered straight down at constant speed by a steel cable.

$\vec{a} = 0 \Rightarrow \vec{F}_{net} = 0$

- 2) A boy is pushing a box across the floor at a steadily increasing speed.

$a \neq 0 \Rightarrow F_{net} \neq 0$

4.17-4.20

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Draw a free-body diagram for each case. Be sure to show the net force on the object also.

- 3) A bicycle is speeding up as it goes down a hill. Friction is negligible, but air resistance is not.

- 4) You've slammed on the car brakes while going down a hill, and you are skidding to a halt.

4.17-4.20

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Write a short description of a real object to which these free-body diagrams correspond.

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Draw a free-body diagram for each case. Be sure to show the **net force** on the object also.

- 1) An elevator, suspended by a cable, has just left the 10th floor and is speeding up as it descends.
- 2) A jet plane is speeding down the runway during takeoff. Air resistance is not negligible.
- 3) You've just kicked a rock on the sidewalk and it is now sliding along the concrete.
- 4) A styrofoam ball has just been shot straight up. Air resistance is not negligible.

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Draw a free-body diagram for each case. Be sure to show the **net force** on the object also.

- 1) A spring-loaded gun shoots a plastic ball. The trigger has just been pulled and the ball is starting to move down the horizontal barrel.
- 2) A person on a bridge throws a rock straight down toward the water. The rock has just been released.
- 3) A gymnast has just landed on a trampoline. She is still moving downward as the trampoline stretches.
- 4) A rocket is being launched straight up. Air resistance is not negligible.

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Write a description to match the free-body diagrams. Show the direction of the acceleration of the object.

4.31-4.32

PHYS 21: Chap. 5, Pg 46

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