Forces: Chapter 4 and 5

Definition of Dynamics

Dynamics is the study of why an object moves.

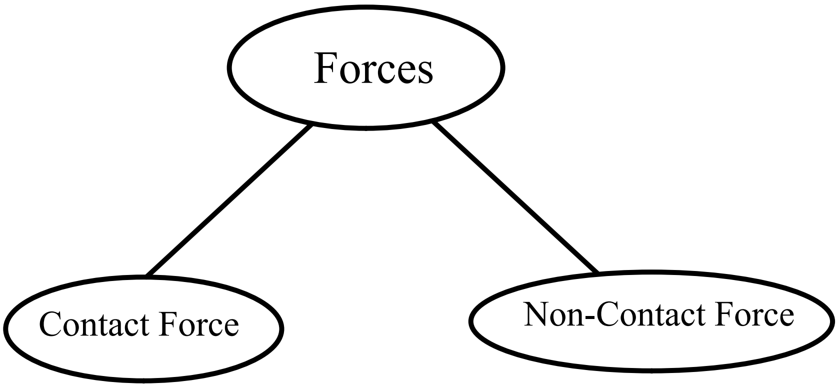
In order to understand why objects move, we must first study forces.

Forces

A ***force*** is defined as a push or a pull.

Forces are vector quantities - they have magnitude and direction.

In the last unit, the sum of all the forces acting on an object was referred to as the resultant force. ***Net force***, $\vec{\mathbf{F}}_{net}$, is another term used for the vector sum of forces.



Contact Force

- a force exerted by an object in direct contact with another object

<u>Examples</u>

friction
tension
normal force
applied force

Non-Contact Force

- a force that acts over a distance

<u>Examples</u>

force of gravity
magnetic force
electric force

Types of Forces

An object can experience many different forces simultaneously. Some of the more common forces are listed below.

$\vec{F}_g$: gravitational force (force of *gravity*)

- this is an attractive force that acts over a distance between masses

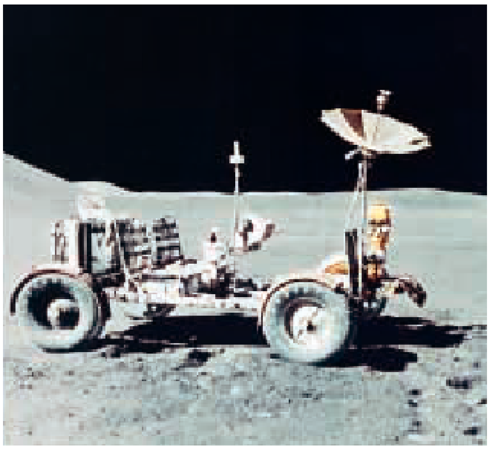
NOTE: Weight is the force of gravity acting on an object.

$$\vec{F}_g = m\vec{g}$$

Fg -> Force of gravity or weight (N)
m -> mass (kg)
g -> acceleration due to gravity (m/s^2)

PRACTICE PROBLEMS

1. Find the weight of a 2.3 kg bowling ball on Earth.
2. You have a weight of 652.58 N[down] while standing on a spring scale on Earth near the equator.
   (a) Calculate your mass.
   (b) Determine your weight on Earth near the North Pole.
   (c) Determine your weight on the International Space Station. Why would this value be impossible to verify experimentally?
3. The lunar roving vehicle (LRV) pictured here has a mass of 209 kg regardless of where it is, but its weight is much less on the surface of the Moon than on Earth. Calculate the LRV's weight on Earth and on the Moon.
4. A 1.00 kg mass is used to determine the acceleration due to gravity of a distant, city-sized asteroid. Calculate the acceleration due to gravity if the mass has a weight of 3.25×10^{-2} N[down] on the surface of the asteroid.



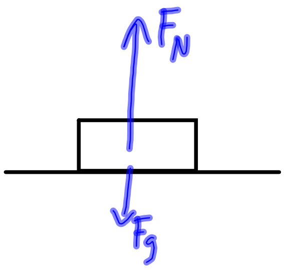
$\vec{F}_a$: an ***applied*** force

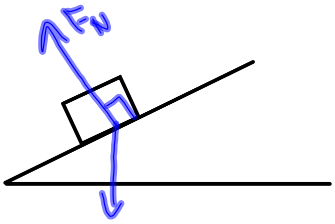
- a push or pull you exert on an object

$\vec{F}_N$: the ***normal*** force

- a force that acts perpendicular to the surface on which an object rests

NOTE: "normal" means perpendicular





$\vec{F}_f$: the force of ***friction***

- a force that opposes an object's motion

<u>static frictional force</u> (F_{fs}) - exists when you start to move an object from rest

<u>kinetic frictional force</u> (F_{fk}) - exists while an object is in motion

$$F_f = \mu F_N$$

F_f -> force of friction (N)
μ -> coefficient of friction
F_N -> normal force (N)

140 MHR • Unit 2 Dynamics

Table 4.5 Coefficients of Friction

Surfaces	Coefficient of Static Friction μ_s	Coefficient of Kinetic Friction μ_k
rubber on dry solid surfaces	1 – 4	1
rubber on dry concrete	1.00	0.80
rubber on wet concrete	0.70	0.50
glass on glass	0.94	0.40
steel on steel (unlubricated)	0.74	0.57
steel on steel (lubricated)	0.15	0.06
wood on wood	0.40	0.20
ice on ice	0.10	0.03
Teflon™ on steel in air	0.04	0.04
lubricated ball bearings	< 0.01	< 0.01
synovial joint in humans	0.01	0.003

F_T : ***tension***

- the force that acts along a rope, wire, string, etc.

Free-Body Diagrams

"***Physics is all about simplification***."

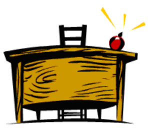
A ***free-body diagram*** (FBD) is a picture that shows ALL the forces acting on an object.

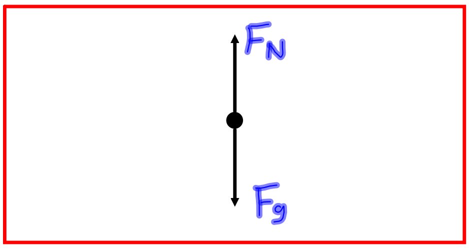
For the sake of simplicity, an object is usually represented by a dot and only the forces acting on the object are included on the diagram. The forces are represented by arrows.

> *When drawing FBDs, put the tail of the force vectors on the object, with the arrow pointing away from the object. NEVER draw a force vector pointing toward an object.*

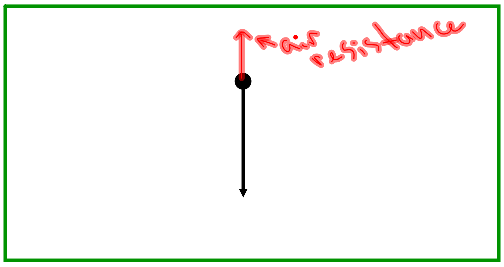
Examples:

An ***apple*** rests on a desk.

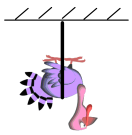


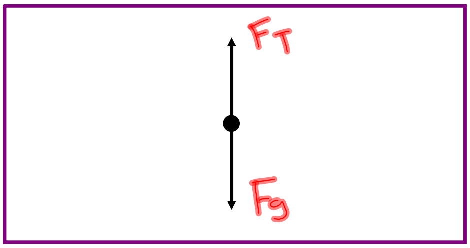


A ***flower pot*** falls in the absence of air resistance.



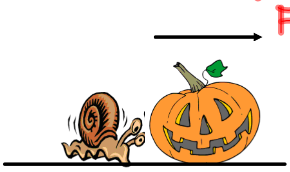
A ***turkey*** is hung from the ceiling of a classroom.

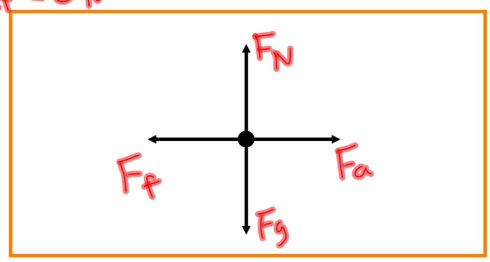




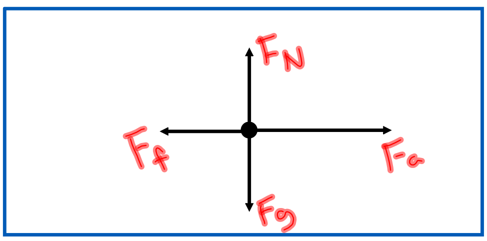
A snail pushes a ***pumpkin*** across the floor at constant speed.

Fnet = 0 N





A *car* speeds up while traveling on a dirt road.



Motion and Forces

When the net force on an object is zero, it is in a state of ***equilibrium***. This means that the object is either at ***rest*** or moving at a ***constant velocity***. ***It cannot be accelerating***.

What determines an object's motion?   ***Why, the value of the net force of course!***

Equilibrium : $\vec{F}_{net} = 0N$ * Very important

- object at rest
- object moving at constant velocity

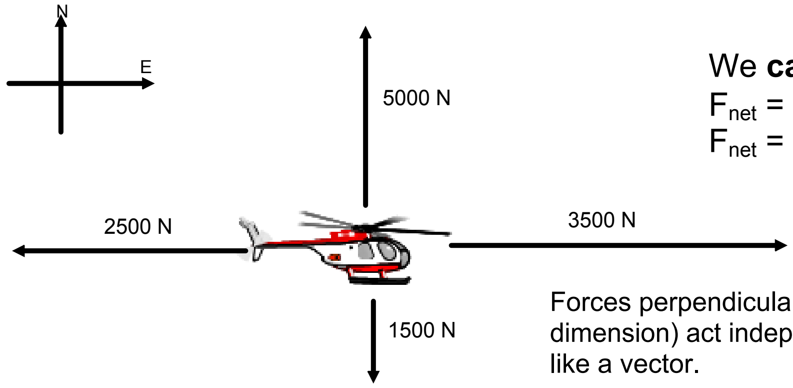
If the net force does not equal zero, the object will accelerate at a constant rate!

NOTE   The object will accelerate in the direction of the net force.

Net Force

The *__net force__* is the vector sum of all the forces acting on an object. Only forces acting in the same dimension (i.e. left and right or up and down) can be mathematically added (or subtracted).

Consider the four forces acting on the object below:



We **cannot** say the net force is:
F_{net} = 5000 - 1500 + 3500 - 2500
F_{net} = 4500 N

Forces perpendicular to each other (or in a different dimension) act independently on an object and must be added like a vector.

We can talk about the net force in each dimension:

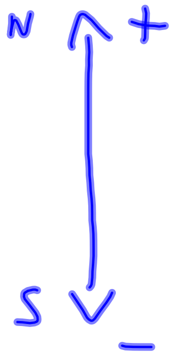
F_{net} [East] = 3500 N - 2500 N
F_{net} [E] = 1000 N

F_{net} [North] = 5000 N - 1500 N
F_{net} [N] = 3500 N

To find the actual net force on the object we would need to do a scale diagram with the vectors or a calculation (grade 12).

Often to identify which direction we are focusing on we use the subscripts x and y. Like in your math class, x - horizontal direction and y - vertical direction. Directions are all in the way your set up your problem for analysis - your frame of reference.

The force of gravity on a ball is 10 N. An upward wind acts with 14 N. What is the net force on the ball?



$$F_{net} = F_g + F_{wind}$$

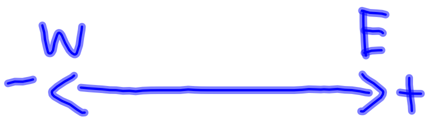
$$F_{net} = -10\,N + 14\,N$$

$$F_{net} = 4\,N \text{ (up)}$$

The force applied to a car from the gas is 1575 N [E]. Air resistance acts with 1230 N [W]. What is the net force on the car?

$$F_{net} = F_a + F_{air}$$

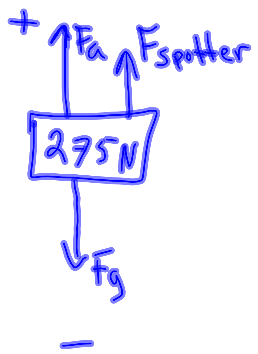
$$= 1575 - 1230$$



$$F_{net} = 345\,N$$

•

A person tries to bench press 275 N but can only lift 252 [N]. How much weight must a spotter support?



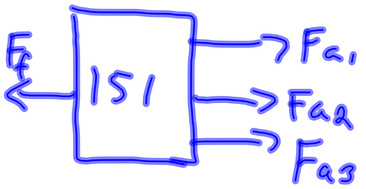
$F_{net} = F_a + F_{sp} + F_g$

$F_{net} = 0N$ (just enough to overcome gravity)

$0 = 252 + F_{sp} - 275$

$23N = F_{sp}$

Two people are supplying forces on a 151 kg box sitting on the floor. One person pushes with 144 N [E] and the other pulls with 175 N [E]. What force would a third person need to apply to start the box moving if μ_s=0.33?



$F_{net} = 0N$ (just enough to overcome friction)

$F_{net} = F_{a1} + F_{a2} + F_{a3} + F_f$

$F_{a1} = 144\text{ N}$, $F_{a2} = 175\text{ N}$, $F_{a3} = ?$, $F_f = ?$

$F_f = \mu F_N$ → Normal Force = Force gravity, mg

$F_f = \mu mg = (0.33)(151)(9.81)$

$F_f = 489\text{ N}$

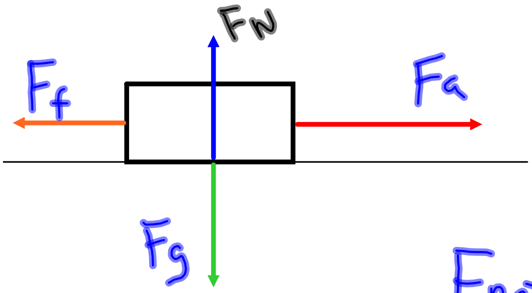
So, use the Fnet relation:

$0 = 144 + 175 + F_{a3} - 489$

$170\text{ N} = F_{a3}$

* Answer is positive so the direction is East.

<u>NOTE</u>: The net force equation is applied to different dimensions independently.



A horizontal force of 85 N is required to pull a child in a sled at constant speed over dry snow to overcome the force of friction. The child and sled have a combined mass of 52 kg. Calculate the coefficient of kinetic friction between the sled and the snow. (0.17)

$$F_{net} = F_a + F_f \quad , F_{net} = 0$$

$$F_f = \mu F_N$$

Find F_f:

$$0 = 85 + F_f \rightarrow -85 = F_f$$

Find F_N:

$$F_N = F_g = mg$$

$$F_N = (52)(9.81) = 510 \text{ N}$$

<u>Find μ</u>

$$F_f = \mu F_N$$

$$85 = \mu(510) \Rightarrow \mu = 0.17$$

Always use magnitudes (positive) numbers with this formula.

1. A 62 kg crate is pulled at a constant velocity with an applied force of 337 N.

a. Calculate the force of friction.

b. Calculate the normal force on the crate.

c. Calculate the coefficient of kinetic friction.

a) $F_{net} = 0\,N$ (constant velocity)

$F_{net} = F_a + F_f$ (only two forces acting in that direction)

$0 = 337 + F_f$

$-337\,N = F_f$

b) $F_N = F_g = mg$

$F_N = (62\,kg)(9.81\,m/s^2)$

$F_N = 608\,N$

c) $F_f = \mu F_N$ ← always use + numbers

$\mu = \frac{F_f}{F_N} = \frac{337}{608}$

$\mu = 0.55$

2. A box has a weight of 625 N and is being pulled with a net force of 12 N. The coefficient of kinetic friction is 0.23.

a. What is the mass of the box?

b. What is the force of friction?

c. What is the applied force?

a) $F_g = mg$

$625 = m(9.81)$

$63.7\ Kg = m$

b) $F_f = \mu F_N$

$F_N = F_g$

So, $F_f = (0.23)(625)$

$F_f = 144N$

↑ This is the magnitude of the force.

c) $F_{net} = F_a + F_f$

$12 = F_a - 144$

↑ F_f always opposite motion of object.

$156\ N = F_a$

3. A box is being pulled across the floor at a constant velocity with an applied force of 284 N. The coefficient of kinetic friction is 0.11.

a. What is the force of friction?

b. What is the force of gravity on the box?

c. What is the mass of the box?

a) $F_{net} = 0\ N$ $\quad F_{net} = F_a + F_f$

$0 = 284 + F_f$

$-284\ N = F_f$

b) $F_g = ?$ remember $F_g = F_N$

So $F_f = \mu F_g$

$284 = (0.11) F_g \rightarrow F_g = 2580\ N$

c) $m = ?$

$F_g = mg$

$2580\ N = m(9.81)$

$263\ Kg = m$

Force Practice:
Worksheets #1 & #2

Motion Equations

$$v_{avg} = \frac{d}{t}$$

$$d = v_0 t + \frac{1}{2} a t^2$$

$$v_{avg} = \frac{v_f + v_0}{2}$$

$$v_f^2 = v_0^2 + 2ad$$

$$a = \frac{v_f - v_0}{t}$$

d = displacement

a = acceleration

t = time

v_0 = Initial velocity (speed)

v_f = Final velocity (speed)

Chapter 5 - Newton's Laws (Page 152)

Isaac Newton

(1642-1727)

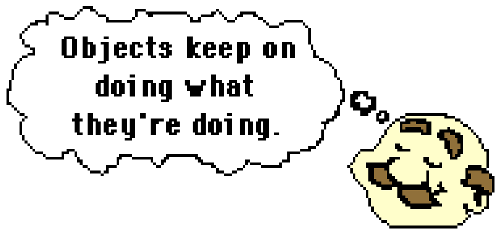
Frames of Reference

1. inertial -> frame of reference in which Newton's laws are valid
   -> frame of reference is at rest or has uniform motion

2. non-inertial -> frame of reference in which Newton's laws are not valid
   -> frame of reference is accelerating uniformly

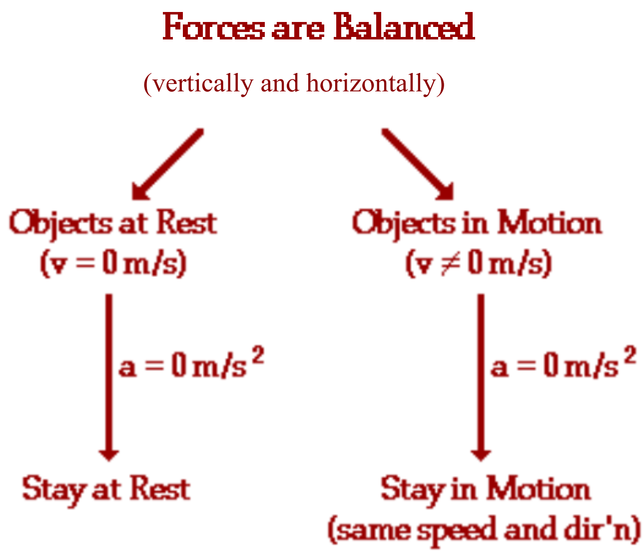
Newton's First Law of Motion (The Law of Inertia)

An object at rest tends to stay at rest and an object in motion tends to stay in motion with the same speed and in the same direction unless acted upon by an unbalanced force.



The two parts of this law are summarized in the following diagram.

$$F_{net} = 0 \text{ N}$$



Newton's Second Law of Motion Pg 160

Newton's second law can be formally stated as:

The acceleration of an object produced by a net force is:

- directly proportional to the magnitude of the net force

$$a \propto F_{net}$$

$\propto$ -> proportional to

- inversely proportional to the mass of the object

$$a \propto \frac{1}{m}$$

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

$$\boxed{\vec{F}_{net} = m\vec{a}}$$ ← Starting point for force problems involving acceleration.

$\vec{F}_{net}$ -> net force (N)
m -> mass (kg)
$\vec{a}$ -> acceleration (m/s^2)

Remember: The acceleration of an object has the same direction as the net force acting on the object.

Sample Problems

An object is accelerating at 2.0 m/s^2 east.

1. If the net force is tripled, what is the object's new acceleration?

$a = \frac{F}{m}$, if $F \times 3$ then $a \times 3$

so $a = 6.0\ m/s^2$

2. If the net force is halved, what is the object's new acceleration?

$F \div 2$ so $a \div 2$

$a = 1.0\ m/s^2$

3. If the net force is tripled and the mass is quadrupled, what is the object's new acceleration?

$a = \frac{F}{m}$

$\frac{F \times 3}{m \times 4}$ so $a \times \frac{3}{4}$ $a = 1.5\ m/s^2$

What is the acceleration of a 12 kg cart under a constant force of 88 N?

$a = \frac{F}{m}$

$a = \frac{88 N}{12 Kg}$

$a = 7.3 m/s^2$

A force of 1200 N accelerates an object at 21 m/s^2. What is the mass of the object?

$F = ma$

$m = \frac{F}{a}$

$m = \frac{1200 N}{21 m/s^2} = 57 Kg$

What average force is required to accelerate a 33 kg mass at 4.6 m/s^2?

$F = ma$

$F_{avg} = (33 Kg)(4.6 m/s^2)$

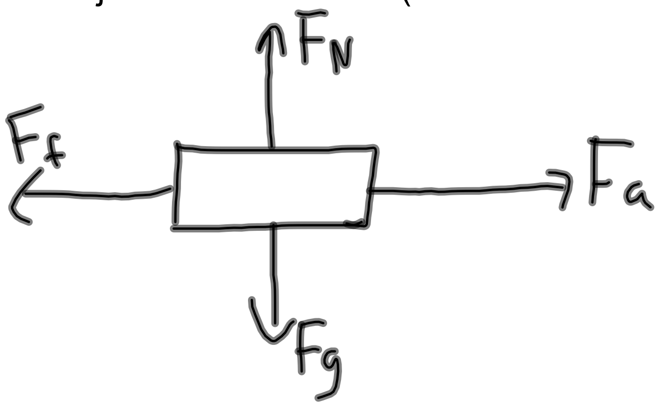
$F_{avg} = 152 N$

An applied force of 50 N is used to accelerate an object to the right across a frictional surface. The object encounters 10 N of friction. The weight of the object is 80 N.

(a) Calculate the objects mass. (8.2 kg)

(b) Calculate the net force. (40 N to the right)

(c) Calculate the object's acceleration. (4.9 m/s^2 to the right)



(a) $F_g = 80\ N = mg$

$80 = m(9.81)$

$m = 8.2\ kg$

(b) $F_{net} = F_a + F_f$

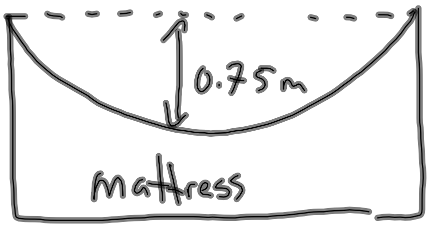
$F_{net} = 50 - 10$

$F_{net} = 40\ N$

(c) $F = ma$

$a = \frac{F}{m} = \frac{40}{8.2} = 4.9\ m/s^2$

A 2.5 kg object falls on an air mattress. Just as it hit it was traveling 19 m/s. The air mattress depressed 0.75 m before coming to a stop. What was the average force stopping the object?



Choose coordinate system up ↑ +, down ↓ −

Known variables:

$m = 2.5\ kg$

$v_0 = -19\ m/s$ (downward)

$v_f = 0\ m/s$ (stopped)

$d = -0.75\ m$ (downward)

$g = -9.81\ m/s^2$

Want:

$F_{avg} = ?$

$F_{avg} = ma$

Calculate "a" first

*check motion formulas: $v_f^2 = v_0^2 + 2ad$

Solving for acceleration:

$(0)^2 = (-19)^2 + 2a(-0.75)$

$0 = 361 - 1.5a$

$-361 = -1.5a$

$241\ m/s^2 = a$

extreme acceleration, person probably died :(

↑ positive (directed upwards) answer

$F_{avg} = ma$

$F_{avg} = (2.5)(241)$

$F_{avg} = 603\ N$

positive (upwards)

Newton's Third Law of Motion

"***For every action there is an equal and opposite reaction***."

"***Forces come in equal and opposite reaction pairs***."

If object A exerts a force on object B, then object B will exert an equal but opposite force on object A.

Examples

If I push down on the Earth, the Earth pushes up on me.

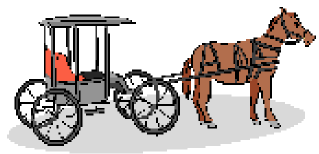
If a hockey stick applies a force to the puck, the puck applies the same amount of force back on the stick.

One of the most important conceptual questions of physics is:

"***If each action force causes an equal but opposite reaction force, then how can anything ever accelerate***?

Horse and Cart Scenario

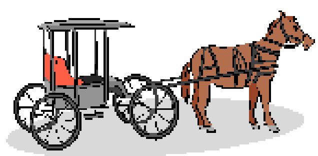
force of cart on horse ← force of horse on cart →



Each force acts on a different body.
The forces don't cancel each other.

a-r pair

force of cart on horse ← force of horse on cart →



force of ground on horse → force of horse on ground ←

a-r pair

Practice Questions:
Pg 163 #s 1 - 3.
Pg 168 #s 4 - 8.
Pg 170 #s 9 - 10, 13.
Pg 186 #s 21 - 23.

Newton's Laws
Handouts #1 & #2