Unit:

FORCES AND MOTION

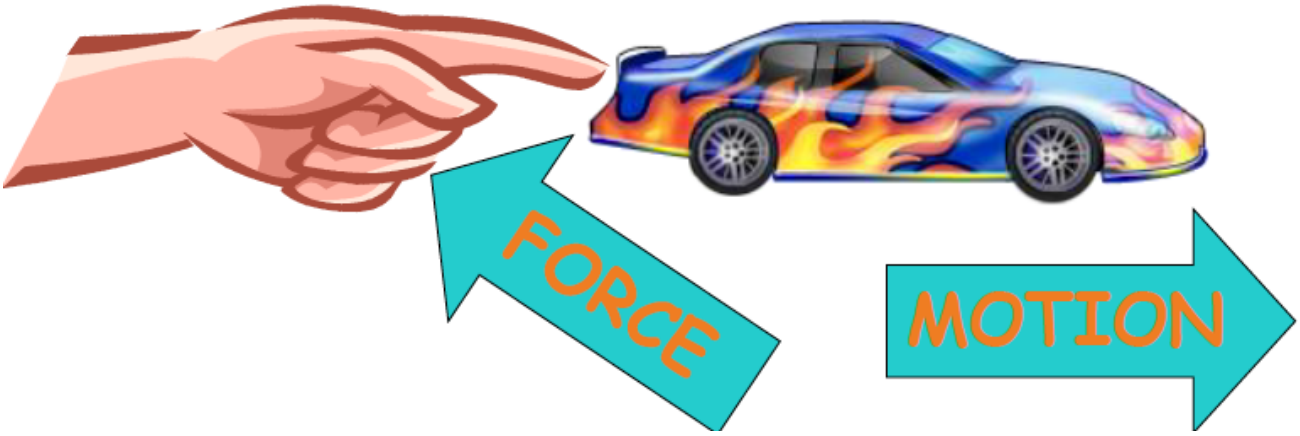
José Manuel Sánchez Hernández
Antonio José Lechuga Navarro

1. INTRODUCTION

The photograph shows the Millau Road Bridge in the South of France. At a height of 270 m, this is the highest road bridge in the world. Engineers who build bridges have a detailed understanding of forces, weight and pressure. You will meet these ideas in this chapter.

In this chapter also we study causes of motion: Why does the kitesurfer slide across the water in the way he does? The combined forces of the wind, water, and gravity accelerate him according to the principles of dynamics.

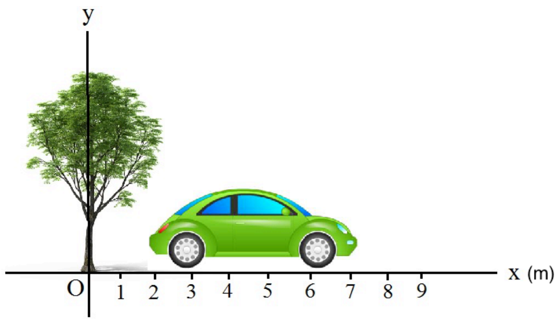
Chapter Goal: To establish a connection between force and motion.



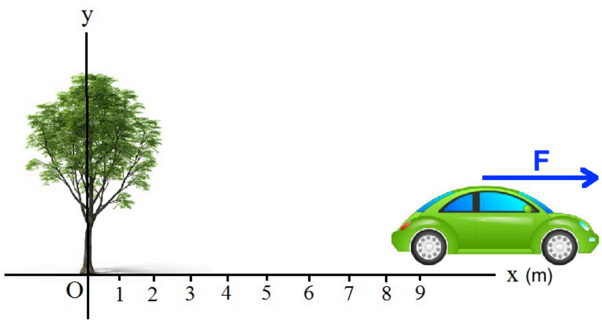
José Manuel Sánchez Hernández
Antonio José Lechuga Navarro

Furthermore, it is advisable to ditinguish between two branches of Physics, kinematics and dynamic:

- Kinematics: The study of how objects move. Motion is when an object changes position over time when compared with a reference point.



- Dynamics: The study of why objects move. What makes an object move is a force.



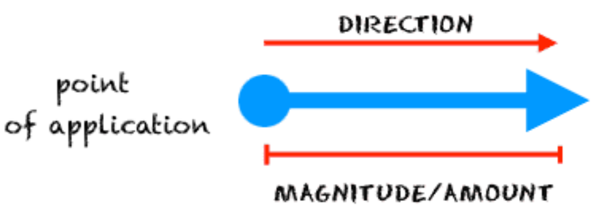
2. SCALARS AND VECTORS

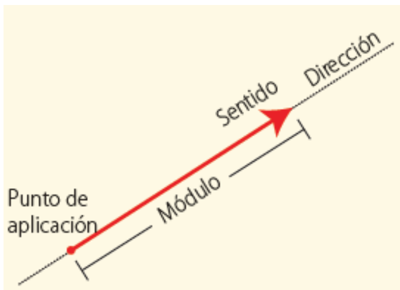
- A **scalar** quantity is one that only has a size or magnitude (no direction).
- A **vector** quantity is one that has a size and a direction.

Some examples of scalar quantities are: mass (for example, 3 kg of apples); temperature (for example, 27 °C); energy (for example, 200_joules). These quantities do not have a direction, they only have a size.

Force is an example of a vector quantity. You can push with a force of 250 N to the right or with a force of 250 N to the left. Each force has the same magnitude, but the effect is in a different direction.

A vector magnitude is symbolised by an arrow.





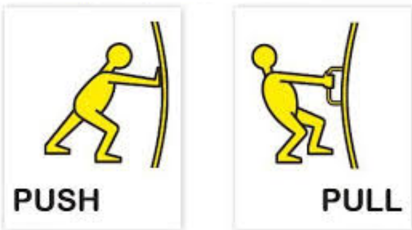
José Manuel Sánchez Hernández
Antonio José Lechuga Navarro

✓ *Activity **A1**. Which one of these is a scalar quantity and which one is a vector quantity?*

a) Sepeed
b) Velocity
c) Mass
d) Weight
e) Volume
f) Temperature
g) Acceleration
h) Force

3. WHAT IS A FORCE?

A **force** is a push or a pull. Whenever you push or pull something you are exerting a force on it. The forces that you exert can cause three things:



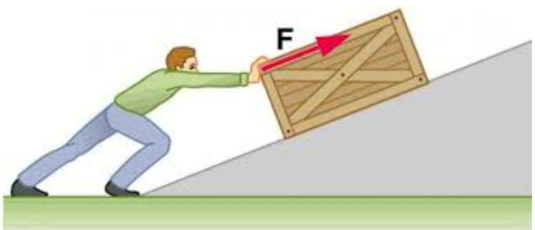
✓ You can ***change the shape*** of an object. For example, you can stretch or squash a spring and you can bend or break a ruler.

✓ You can ***change the speed*** of an object. For example, you can increase the speed of a ball when you throw it and you decrease its speed when you catch it.

✓ A force can also ***change the direction*** in which something is travelling. For example, we use a steering wheel to turn a car.

PROPERTIES OF A FORCE:

- A force is a vector quantity.
- It is represented by the symbol F.
- It is measured in the SI unit in newtons (N)



José Manuel Sánchez Hernández
Antonio José Lechuga Navarro

THE SIZES OF SOME FORCES:

The unit we use to measure force is the newton (N). Large forces may be measured in kilonewtons (kN) or meganewtons (MN). A few examples of the size of various forces are given below.

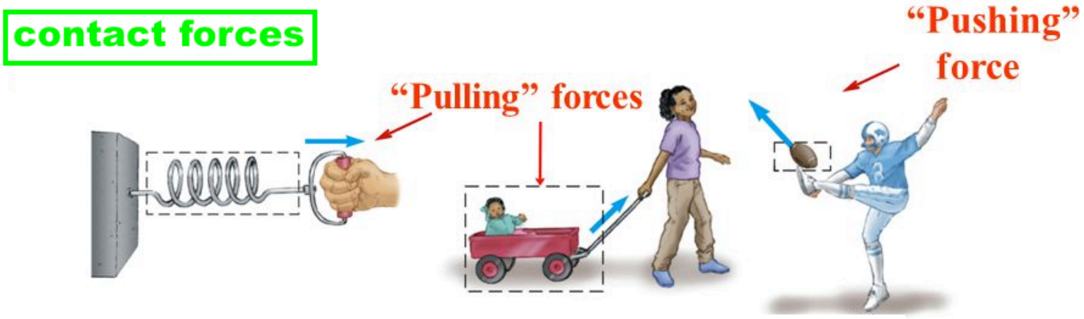
- The pull of gravity on a fly = 0.001 N
- The pull of gravity on an apple = 1 N
- The frictional force slowing a rolling football = 2 N
- The force required to squash an egg = 50 N
- The tension in a rope towing a car = 1000 N (1 kN)
- The frictional force exerted by the brakes of a car = 5000 N (5 kN)
- The push from the engines of a space rocket = 1 000 000 N (1 MN)

4. TYPES OF FORCES

Contact forces

The forces described so far are called contact forces. Your hand touches something to exert a force. Here are some further examples of contact forces:

- **Friction** is the contact force that opposes objects moving relative to each other. Friction acts between two sliding surfaces. Friction can also act to stop something beginning to move.
- **Air resistance, or drag**, is a force that acts on an object moving through the air. You can feel air resistance if you put your hand out of a car window when the car is moving. A boat experiences drag when it moves through water.
- **Tension** is the name we give to the force exerted through a rope when we pull something.
- **Normal** contact force is the force that supports an object that is resting on a surface such as a table or the floor.

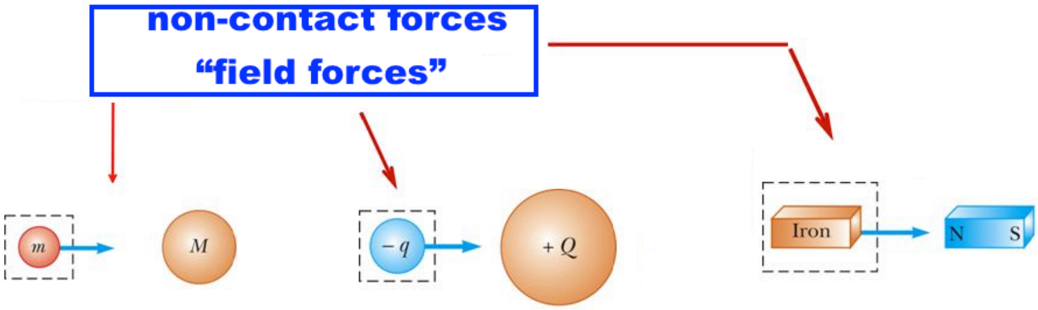


José Manuel Sánchez Hernández
Antonio José Lechuga Navarro

Non-contact forces

There are also non-contact forces. These are forces that act between objects that are physically separated. Gravitational, electrostatic and magnetic forces are examples of non-contact forces.

- **Gravity**, the Earth pulls you downwards whether you are in contact with it or not. The Sun's gravity acts over great distances to keep the Earth and other planets in orbit.
- **Electrostatic forces**, these are forces that act between charged objects. By rubbing a balloon you can charge it and stick it to the wall.
- **Magnetic forces**, a magnet can attract objects made from iron or steel towards it.



✓ *Activity **A2**. What is a contact force? Which one of the following is an example of a contact force?*

__a)__ friction __b)__ gravity __c)__ magnetic

✓ *Activity **A3**. What is a non-contact force? Which one of the following is an example of a non-contact force?*

__a)__ air resistance __b)__ electrostatic __c)__ tension

José Manuel Sánchez Hernández
Antonio José Lechuga Navarro

- ✓ *Activity **A4**. Classify the following types of forces bellow the correct picture:*

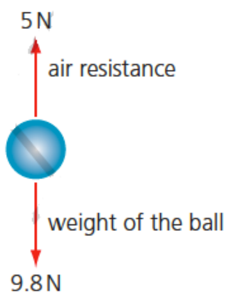
Spring force *Gravity* *Applied force* *Buoyant force*

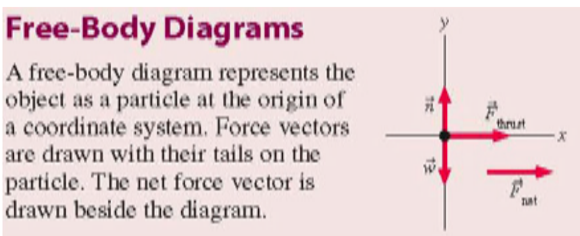
Friction force *Tension force* *Magnetic force* *Drag force*

5. FREE BODY DIAGRAM

Free body diagrams are used to show the magnitude and direction of all of the forces that act on an object.

Figure is an example of a free body diagram. Two forces act on the ball: the air resistance exerts an upward force on the ball, and the pull of gravity (the ball's weight) exerts a downwards force on it. The sum of these two forces is 10 N – 5 N = 5 N downwards, so the ball continues to spead up.





José Manuel Sánchez Hernández
Antonio José Lechuga Navarro

✓ *Activity **A5**. Draw the following free body diagrams, imagine each object or mass as a particle:*

Free Body Diagram Practice

1. A book is at rest on a tabletop. Diagram the forces acting on the book.
2. A picture is hanging from the ceiling by two ropes. Diagram the forces acting on the picture. He was not injured in the experiment.
3. An egg is free-falling from a nest in a tree. Neglect air resistance. Diagram the forces acting on the egg as it is falling.
4. A rightward force is applied to a book in order to move it across a desk with a rightward acceleration. Consider frictional forces. Neglect air resistance. Diagram the forces acting on the book.
5. A rightward force is applied to a book in order to move it across a desk at constant velocity. Consider frictional forces. Neglect air resistance. Diagram the forces acting on the book.
6. A college student rests a backpack upon his shoulder. The pack is suspended motionless by one strap from one shoulder. Diagram the vertical forces acting on the backpack.
7. A skydiver is descending with a constant velocity. Consider air resistance. Diagram the forces acting upon the skydiver.

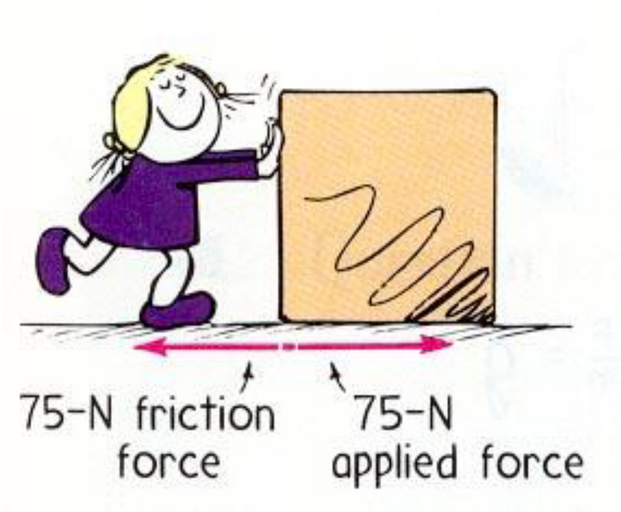
6. BALANCED AND UNBALANCED FORCES

Balanced forces are equal and opposite in direction.

A Balanced force is a force in which the net force equals zero and there is **no motion.**

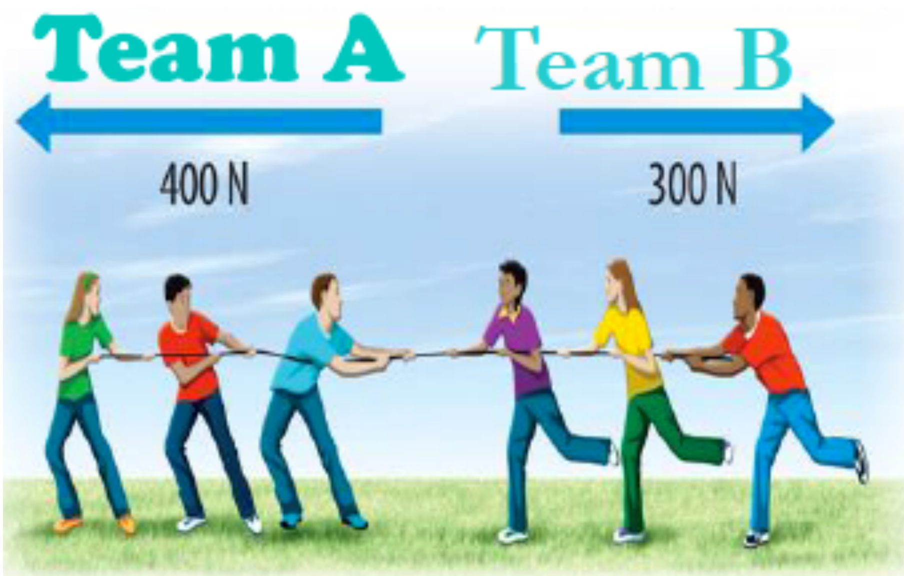
José Manuel Sánchez Hernández
Antonio José Lechuga Navarro

If all the forces are balanced, we say the object is in **EQUILIBRIUM.**

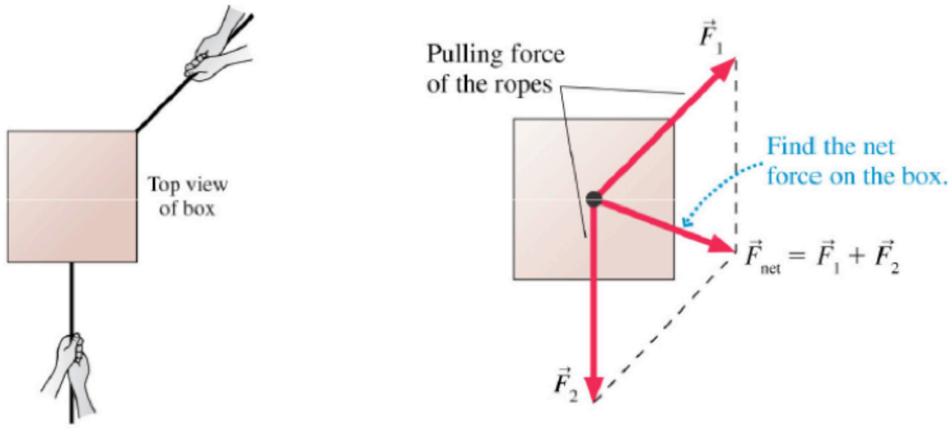


Unbalanced forces have a greater force in one direction. An unbalanced force is a force in which the net force is greater than zero ($F_{net} > 0$) causing motion.

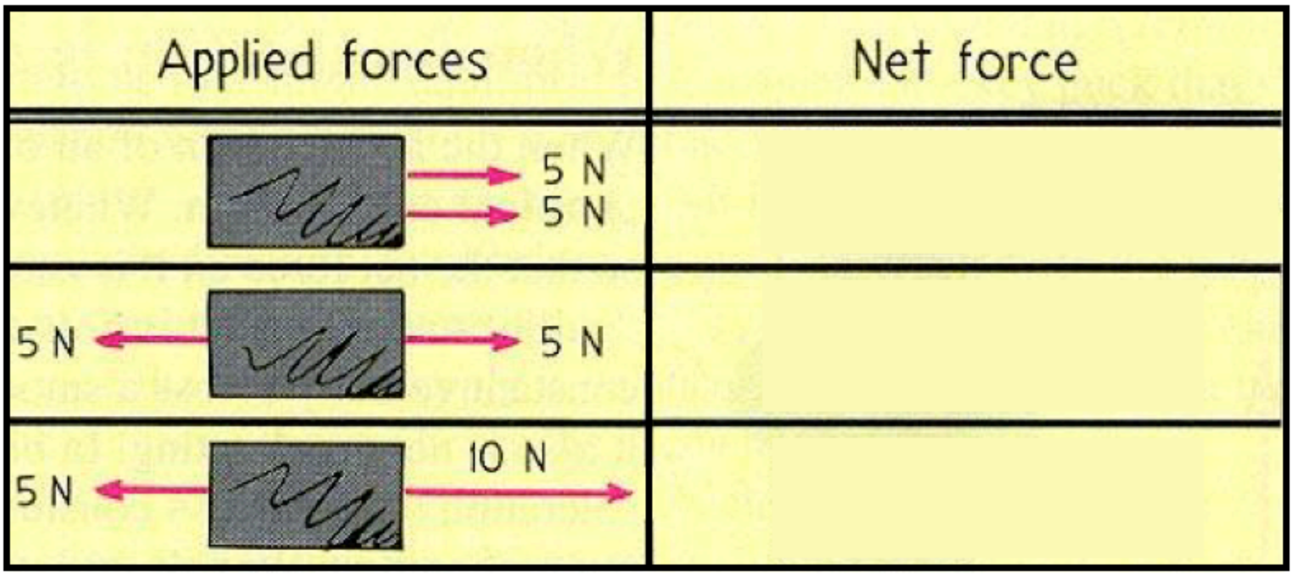
400N - 300N = 100N an **UNBALANCED** force with **MOTION** going in the direction of the greater force in this case to the left or toward team A.



A net force is the vector sum of the forces acting on an object



✓ *Activity **A6**. Fill the blanks in the below table:*



Applied forces	Net force
→ 5 N, → 5 N	
5 N ←, → 5 N	
5 N ←, → 10 N	

7. MASS AND WEIGTH

➜ we need to be careful to distinguish these terms

➜ mass is related to the amount of matter ("stuff") in an object

➜ weight is specifically the force on an object from the gravitational attraction of the Earth

Weight is the name that we give to the pull of gravity on an object. Large objects such as the Earth produce a gravitational field, which attracts masses. Smaller objects exert gravitational forces on each other, but these are too small to notice.

- ✓ Near the Earth's surface the gravitational field strength, g, is 9.8 N/kg.
- ✓ This means that each kilogram has a gravitational pull of 9.8 N.
- ✓ The weight of 1kg on the Earth's surface is 9.8 N.

To calculate weight use this equation:

$$W = m \cdot g$$

weight = mass · gravity

Where:

- weigh is in newtons, N
- mass is in kilograms, kg
- gravitational field strenght is in acceleration units m/s^2 ($g=9{,}8 m/s^2$ constant value)

Since the value of g is constant (9.8 m/s^2 near the Earth's surface) the weight of an object and the mass of an object are directly proportional.

$$\text{weight} \propto \text{mass}$$

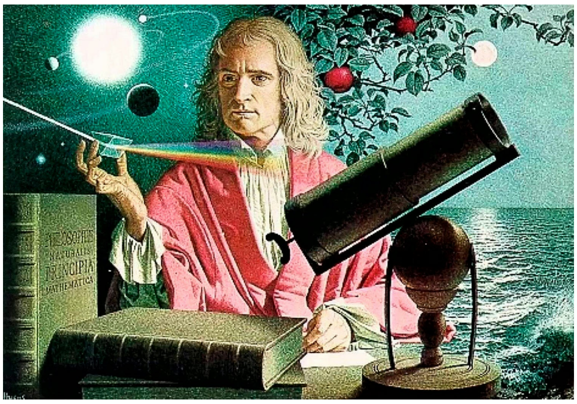
So if your mass in kilograms goes up or down, your weight in newtons will go up or down in the same proportion. The mass of an object remains the same anywhere in the Universe. The mass of an object is determined by the amount of matter in it.

However, a 50 kg mass would have a different weight on the Moon,
where the gravitational field strength is 1.6 m/s^2.

The weight of an object can be considered to act through a single point. This point is called the centre of mass of the object. The weight of an object can be measured with a spring balance, which is calibrated in newtons.

✓ *Activity* ***A7****. Click on this link and calculate the weight and the mass of the boy in each place.*

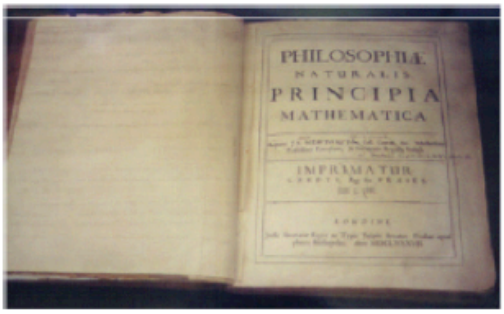
http://www.educaplus.org/game/masa-y-peso



8. LAWS OF NEWTON

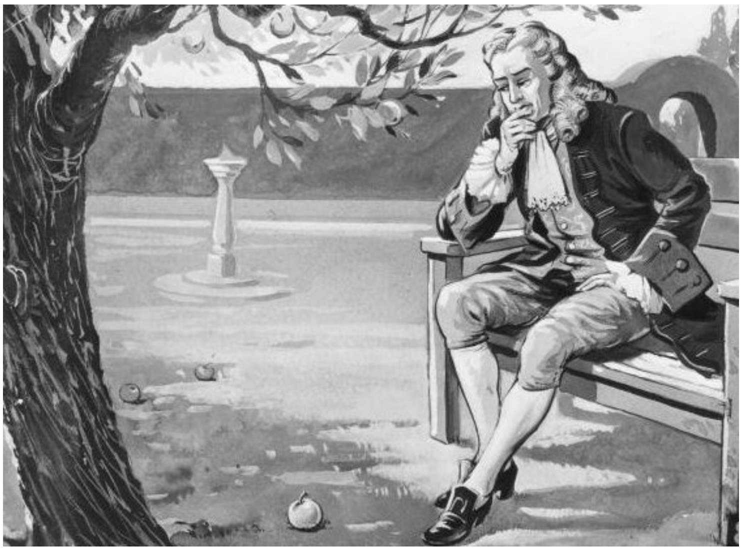
8.1 WHO WAS SIR ISAAC NEWTON?

In 1665, shortly after getting a bachelor's degree at Cambridge, Newton was forced to return to his home because of the Grat Plague. During the next 18 months he formulated most of his scientific discoveies, including: the development of his three Laws of motion, the Law of gravitation, the intion of the calculus, the dispersión of light, the building of a reflecting telescope, and so on. That short period was probably the most creative period in the history of man… and it will never be repeated!



Newton's book of 1687: the Principia Mathematica

Today, an apple tree stands on the lawn between the Great Gate and the Chapel at Trinity College, Cambridge; the rooms Newton occupied overlook the tree. The tree was grown from seeds taken from an old apple tree at Newton's birthplace, Woolsthorpe, Lincolnshire.



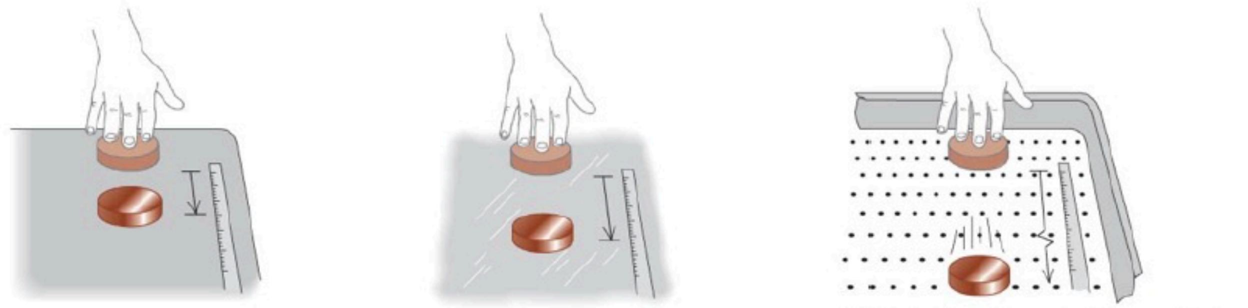
8.1 1st LAW OF NEWTON

Isaac Newton first proposed the following law of nature to attempt to describe objects in motion:

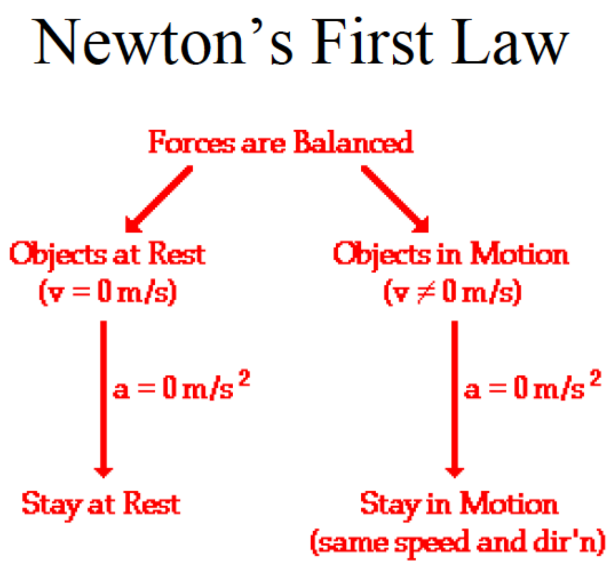
" Every object continues either at rest or in constant motion in a straight line unless it is acted upon by a net force "

the statement about objects at rest is pretty obvious, but the "constant motion" statement doesn't seem right according to our everyday observations.

Newton's First Law of Motion (Inertia Law)
An object at rest stays at rest and an object in motion stays in motion unless the object is acted on by an unbalanced force.



(a) Table: puck stops short (b) Ice: puck slides farther (c) Air-hockey table: puck slides even farther



José Manuel Sánchez Hernández
Antonio José Lechuga Navarro

CURLING & INERTIA

INERTIA AND MASS

- ✓ Inertia: the resistance an object has to a change in its state of motion.
- ✓ The more mass the more inertia
- ✓ As mass increases the more an object resists change in its motion
- ✓ Mass (kg) is the measure of inertia

8.2 2nd LAW OF NEWTON

The first law describes what happens when no force acts on an object. The second law describes the response of the object to a force being applied we know that different objects respond differently to the same magnitude of force: push a shopping trolley and push a freight train have very different responses.

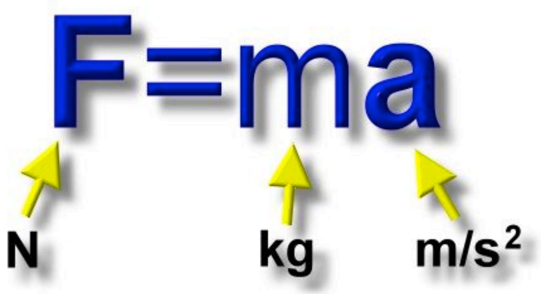
" The acceleration of an object is directly proportional to the resultant force acting on it and inversely proportional to its mass. The direction of the acceleration is the direction of the resultant force".

Newton's Second Law of Motion (Acceleration Law)
When a force acts (pushes or pulls) on an object, it changes the object's speed or direction (in other words, it makes the object accelerate). *The bigger the force, the more the object accelerates.*

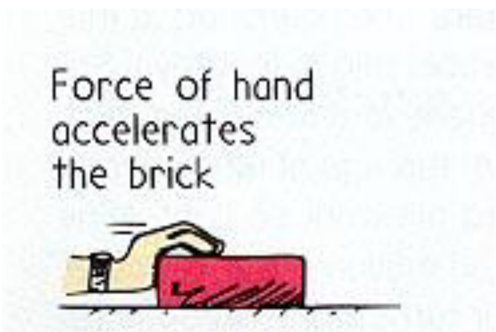
$$\sum \vec{F} = m\vec{a}$$

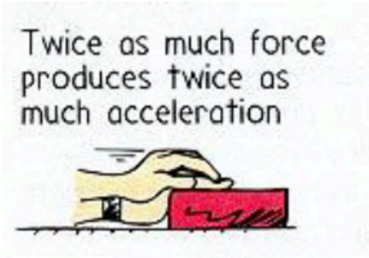
According to Newton's Second Law of Motion, the net force acting on a body equals the product of the mass and the acceleration of the body. The direction of the force is the same as that of the acceleration. In equation form:

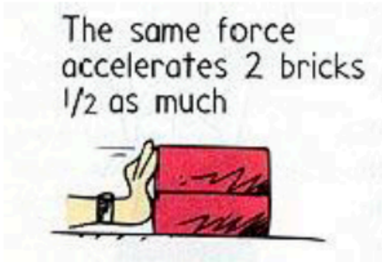
F = force
m = mass
a = acceleration

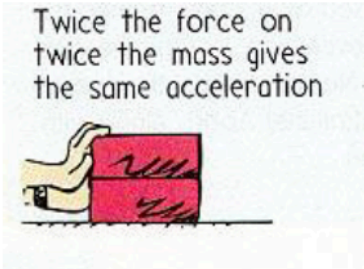


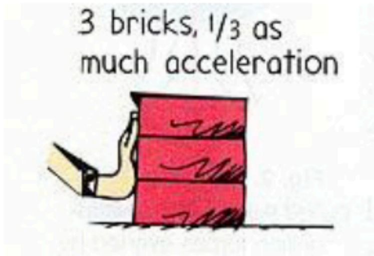
- ✓ F = forcé applied to an object (N = Newtons= kg ·m/s^2)
- ✓ m = object's mass (kg)
- ✓ a = acceleration (m/s^2)











✓ *Activity **A8**. How much horizontal net force is required to accelerate a 1000 kg car at 2 m/s^2? (Sol: 2000N)*

✓ *Activity **A9.** A net force of 10 Newtons acts on a box which has a mass of 2 kg. What will be the acceleration of the box? (Sol: 5m/s^2)*

✓ *Activity **A10.** A net force of 15 N is exerted on a fiizzy drink bottle to cause it to accelerate at a rate of 5 m/s^2. Determine the mass of the bottle. (Sol: 3kg)*

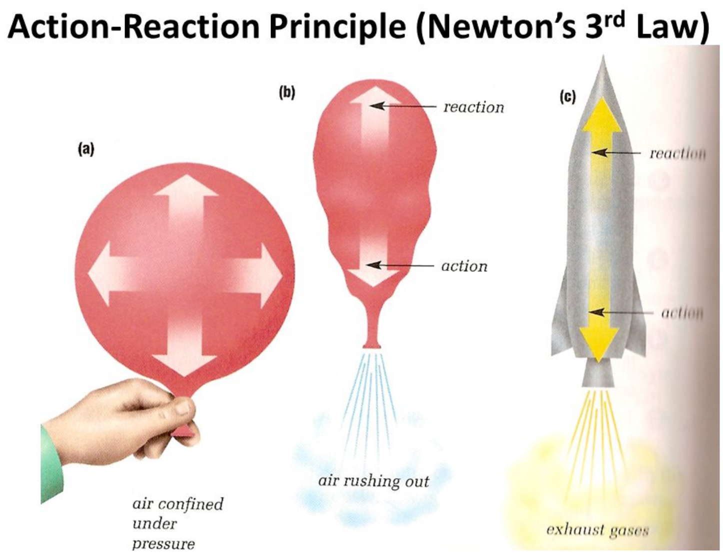
8.2 3rd LAW OF NEWTON

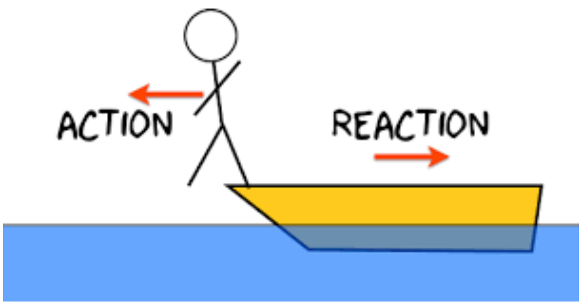
What is the third law of motion?

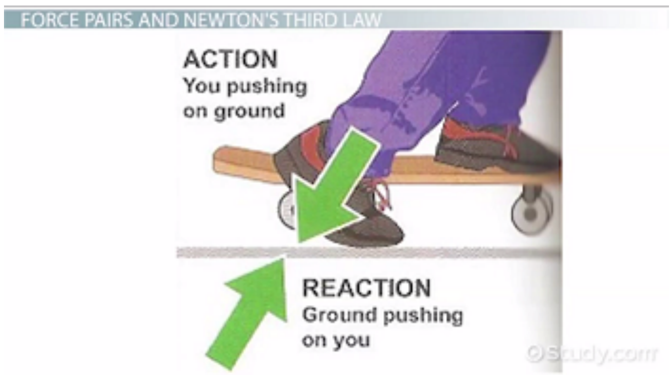
- For every action forcethere is an equal and opposite reaction force
- Two different objects and two different forces (equal but opposite)
- Forces always occur in pairs
- Also known as The Law of Force Pairs

Newton's Third Law of Motion (Action - Reaction Law)

When a force acts on an object, there’s equal force (called a reaction) acting in the opposite direction. This law is sometimes written that “actions are equal and opposite”.







José Manuel Sánchez Hernández
Antonio José Lechuga Navarro

LAWS OF NEWTON SUMMARY

José Manuel Sánchez Hernández
Antonio José Lechuga Navarro

ACTIVITIES

Activities

27. Complete the table	True	False
friction is a force that works in an opposite direction to movement of an object.		
There is always friction when an object is moving on Earth.		
Friction can only happen with large objects.		
Friction can happen with both liquids and solids.		
Friction can stop things from moving		
The Moon has no gravity		
Mass and weight have essentially the same meaning. To increase the weight of an object requires an increase in the mass of the object.		
Friction provides the force which "pushes" a car forward as it accelerates down the road. (Assume a flat road.)		
Bigger the distance between two masses lower the force between them		

28. Choose the correct one

1). A boy sits halfway down a grassy slope. What force stops him sliding down?

a. Weight b. gravity c. friction

2). On which surface will a toy sledge travel the furthest?

a. carpet b. wood c. ice

3). Rougher surfaces have ...

a. greater friction b. less friction c. same level of friction

5. If you poured oil onto a wooden surface, the friction would ...

a. be reduced b. be increased c. remain the same.

FORCE WORKSHEET

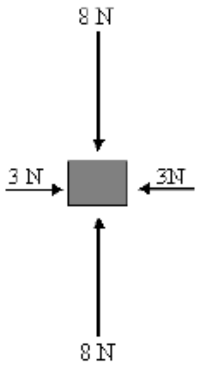
1. What is force?
2. In what unit do we measure force?
3. Analyze each vector diagram and fill in the diagram below.

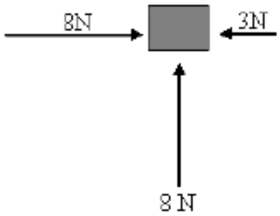
Vector Diagram	Total Force	Resultant Force	Motion Direction
5 N → ← 6N			
5 N → ← 5 N			
16 N → ← 7 N			
8N → ← 3N			
16 N → 7 N →			

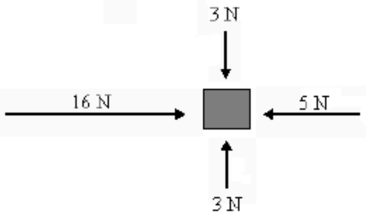
4. Describe the motion of an object that has balanced forces acting on it.
5. Describe the motion of an object that has unbalanced forces acting on it.
6. What are the unbalanced forces that cause a moving object to slow and stop?

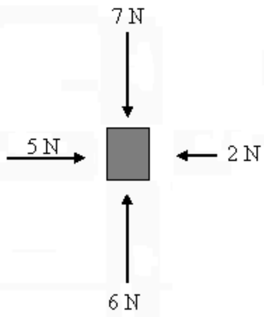
José Manuel Sánchez Hernández
Antonio José Lechuga Navarro

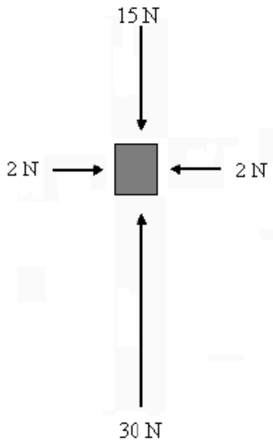
7. Draw an arrow showing which direction will each box move?

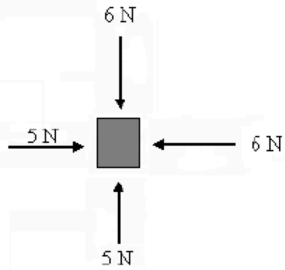


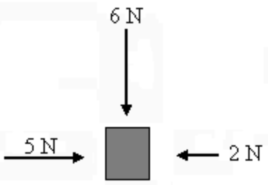


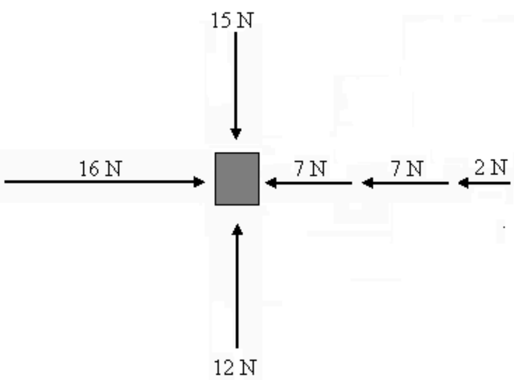






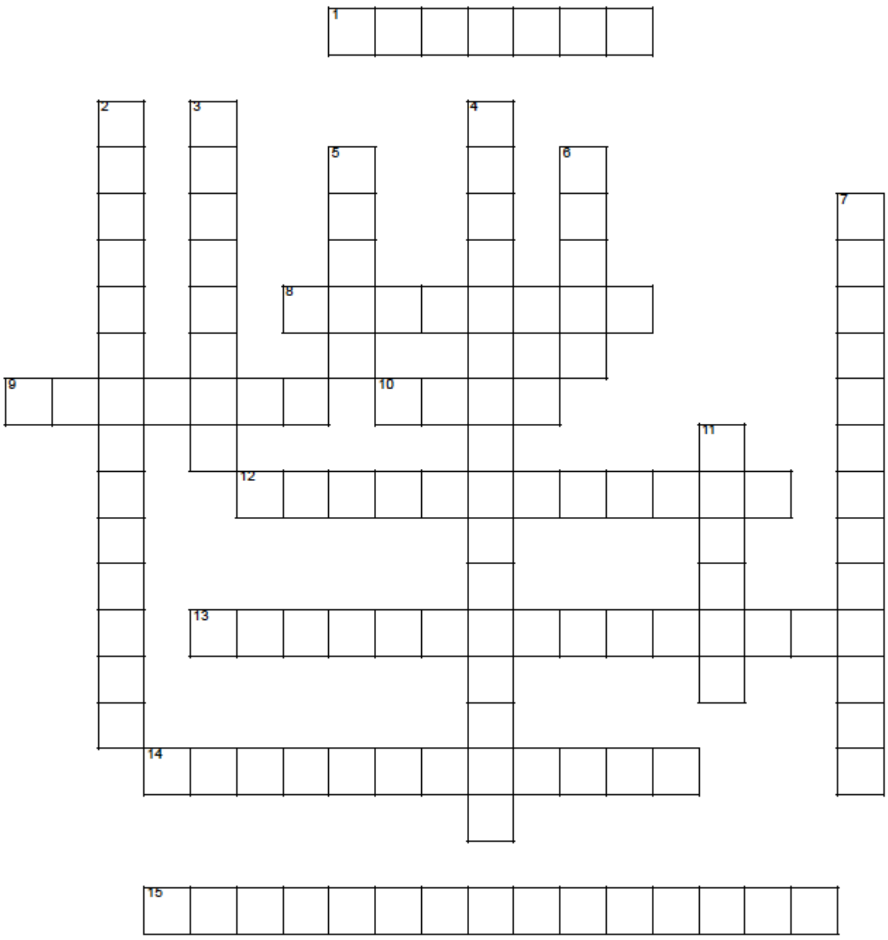






José Manuel Sánchez Hernández
Antonio José Lechuga Navarro

NEWTON'S 2nd LAW CROSSWORD PUZZLE



Across

1. The force that pulls objects toward each other

8. The overall force on an object when all individual forces acting on it are added together

9. The tendency of an object to resist change in its motion

10. The amount of matter in object

12. Slowing down

13. Force that produces a nonzero net force

14. A change of velocity

15. For every action there is an equal opposite reaction

Down

2. Equal Forces acting on an object In opposite directions

3. Speed in a given direction

4. Acceleration of an object depends upon its mass & the force acting upon it

5. The distances an object travels per unit of time

6. A push or pull

7. Energy that an object has due to its motion

11. The state in which one object's distance from another is changing

José Manuel Sánchez Hernández
Antonio José Lechuga Navarro

MASS AND WEIGHT ACTIVITIES

1. Define Mass –

2. Define Weight –

3. Describe what will happen (if anything) to mass and weight when you go to the moon.

    a. Why would this happen?

4. Find the weight of a 60 kg astronaut on earth

    a. Find the weight of the same object on a planet where the gravitational attraction has been reduced to 1/10 of the earth's pull. Show all work.

5. A backpack weighs 8.2 newtons and has a mass of 5 kg on the moon. What is the strength of gravity on the moon? (Be careful with units, remember $1N = 1\ kg \cdot m/s^2$)

José Manuel Sánchez Hernández
Antonio José Lechuga Navarro

6. A physical science test book has a mass of 2.2 kg
   a. What is the weight on the Earth?

   b. What is the weight on Mars ($g = 3.7\ m/s^2$)

   c. If the textbook weights 19.6 newtons on Venus, What is the strength of gravity on Venus?

7. Of all the planets in our solar system, Jupiter has the greatest gravitational strength.
   a. If a 0.5 kg pair of running shoes would weigh 11.55 newtons on Jupiter, what is the strength of gravity there?

   b. If he same pair of shoes weighs 0.3 newtons on Pluto, what is the strength of gravity on Pluto?

NEWTON'S 2nd LAW PROBLEMS

1. A little boy pushes a wagon with his dog in it. The mass of the dog and wagon together is 45 kg. The wagon accelerates at 0.85 m/s^2. What force is the boy pulling with?

2. A 1650 kg car accelerates at a rate of 4.0 m/s^2. How much force is the car's engine producing?

3. A 68 kg runner exerts a force of 59 N. What is the acceleration of the runner?

4. A crate is dragged across an ice covered lake. The box accelerates at 0.08 m/s^2 and is pulled by a 47 N force. What is the mass of the box?

5. 3 women push a stalled car. Each woman pushes with a 425 N force. What is the mass of the car if the car accelerates at 0.85 m/s^2?

6. A tennis ball, 0.314 kg, is accelerated at a rate of 164 m/s^2 when hit by a professional tennis player. What force does the player's tennis racket exert on the ball?

7. In an airplane crash a woman is holding an 8.18 kg baby. In the crash the woman experiences a horizontal de-acceleration of 88.2 m/s^2. How many g's is this de-acceleration? How much force must the woman exert to hold the baby in place?

8. When an F-14 airplane takes-off an aircraft carrier it is literally catapulted off the flight deck. The plane's final speed at take-off is 68.2 m/s. The F-14 starts from rest. The plane accelerates in 2 seconds and has a mass of 29,545 kg. What is the total force that gets the F-14 in the air?

9. A sports car accelerates from 0 to 60 mph, 27 m/s, in 6.3 seconds. The car exerts a force of 4106 N. What is the mass of the car?

10. A sled is pushed along an ice covered lake. It has some initial velocity before coming to a rest in 15 m. It took 23 seconds before the sled and rider come to a rest. If the rider and sled have a combined mass of 52.5 kg, what is the magnitude and direction of the stopping force? What do "we" call the stopping force?

11. A car is pulled with a force of 10,000 N. The car's mass is 1267 kg. But, the car covers 394.6 m in 15 seconds.
    (a) What is expected acceleration of the car from the 10,000 N force?
    (b) What is the actual acceleration of the car from the observed data of x and t?
    (c) What is the difference in accelerations?
    (d) What force caused this difference in acceleration?
    (e) What is the magnitude and direction of the force that caused the difference in acceleration?

José Manuel Sánchez Hernández
Antonio José Lechuga Navarro

12. A little car has a maximum acceleration of 2.57 m/s^2. What is the new maximum acceleration of the little car if it tows another car that has the same mass?

13. A boy can accelerate at 1.00 m/s^2 over a short distance. If the boy were to take an energy pill and suddenly have the ability to accelerate at 5.6 m/s^2, then how would his new energy-pill-force compare to his earlier force? If the boy's earlier force was 45 N, what is the size of his energy-pill-force?

14. A cartoon plane with four engines can accelerate at 8.9 m/s^2 when one engine is running. What is the acceleration of the plane if all four engines are running and each produces the same force?

15. While dragging a crate a workman exerts a force of 628 N. Later, the mass of the crate is increased by a factor of 3.8. If the workman exerts the same force, how does the new acceleration compare to the old acceleration?

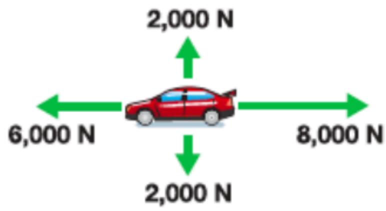
16. A rocket accelerates in a space at a rate of "1 g." The rocket exerts a force of 12,482 N. Later in flight the rocket exerts 46,458 N. What is the rockets new acceleration? What is the rocket's new acceleration in "g's?"

17. A race car exerts 19,454 N while the car travels at a constant speed of 201 mph, 91.36 m/s. What is the mass of the car?

PRACTICE EXAM

NET FORCE & NEWTON'S 1ST LAW OF MOTION

1. Describe the motion of the race car shown in the graphic to the right. Assume the car is moving forward. Is it speeding up or slowing down?



2. Find the net force on each box.

3. You weigh a bear by making him stand on four scales as shown. Draw a free-body diagram showing all the forces acting on the bear. If his weight is 1,500 newtons, what is the reading on the fourth scale?

4. A bowling ball has a mass of 6 kilograms. A tennis ball has a mass of 0.06 kilogram. How much inertia does the bowling ball have compared to the tennis ball?

5. Make a free-body diagram of someone pushing a refrigerator that shows:
   a. A net force of 100 N with the refrigerator being pushed to the right.
   b. The refrigerator in equilibrium.

NEWTON'S 2ND LAW OF MOTION

6. A 100 kg bag of sand has a weight on 100 N. When dropped its acceleration is what?

7. What is the net force required to give an automobile of mass 1600 kg an acceleration of 4.5 m/s^2?

8. What is the acceleration of a wagon of mass 20 kg if a horizontal force of 64 N is applied to it? (ignore friction)

9. What is the mass of an object that is experiencing a net force of 200 N and an acceleration of 500 m/s^2?

10. During a test crash, an air bag inflates to stop a dummy's forward motion. The dummy's mass is 75 kg. If the net force on the dummy is 825 N toward the rear of the car, what is the dummy's deceleration?

11. A bicycle takes 8.0 seconds to accelerate at a constant rate from rest to a speed of 4.0 m/s. If the mass of the bicycle and rider together is 85 kg, what is the net force acting on the bicycle? (Hint: first, calculate acceleration)

NEWTON'S 3RD LAW OF MOTION

12. For each of the following interactions, identify action and reaction forces (action-reaction pairs):
    a. A hammer hits a nail
    b. Earth's gravity pulls down on you
    c. A helicopter blade pushes air downward
    d. You step off a curb
    e. You pat your friend on the back
    f. A wave hits a rocky shore

13. Which exerts more force, the Earth pulling on the moon or the moon pulling on the Earth? Explain.

14. When a heavy football player and a light one run into each other, which player hits the other with more force? Explain. Which one is hurt more by the collision? Explain.

15. Jane has a mass of 40 kg. She pushes on a 50 kg rock with a force of 100 N. What force does the rock exert on Jane?

16. You dribble a basketball while walking on a basketball court. List and describe the pairs of action-reaction forces in this situation.

APPLY ALL OF NEWTON'S LAWS!!

17. When Jane drives to work, she always places her pocketbook on the passenger's seat. By the time she gets to work, her pocketbook has fallen on the floor in front of the passenger seat. One day, she asks you to explain why this happens in terms of physical science. What do you say?

18. You are waiting in line to use the diving board at your local pool. While watching people dive into the pool from the board, you realize that using a diving board to spring into the air before a dive is a good example of Newton's third law of motion. Explain how a diving board illustrates Newton's third law of motion.

19. You know the mass of an object and the force applied to the object to make it move. Which of Newton's laws of motion will help you calculate the acceleration of the object?

VOCABULARY

In the table below write down the keywords learned from the unit with their meaning.

key word	meaning	key word	meaning