

Pre-AP Physics Notes on Forces and Newton's Laws of Motion - Ch 4

Galileo mathematically described "how" things move with his "kinematics formulas" (studied in Ch. 2 and 3). Even with his version of a law of inertia, "Galileo's kinematics" could not explain why things move and behave the way they do. Newton was born within a year of Galileo's death and grew up to take Galileo's work and build upon it.

Newton's Laws of Motion make up what is called "Newtonian Mechanics" or "Newtonian Dynamics" and they describe why things move the way they do. This is what you learn in about in Ch. 4.

I. All changes in motion are caused by an unbalanced or "net" force

A. There are only three fundamental forces currently identified in nature.

They are the:

1. **Electro-weak force** - includes all of the following interactions or forces:
 - the electromagnetic force between electrically charged (positive or negative) objects
 - the force between magnetic objects (with North and South Poles), and
 - the force present in the nucleus of atoms that controls radioactive decay.
2. **Nuclear Strong force** - the force that binds the parts of the atomic nucleus together
3. **Gravitational force** - the force present between all material objects (objects that have mass)

When you look at that list you might wonder why there are no everyday Newtonian "pushes or pulls" listed. The word fundamental is important and means "primary" or "most basic" in this case. An ordinary push or mechanical force is not a fundamental force. The reason for this is because a mechanical push or pull is **actually an electromagnetic force**.

B. We can still define a force in physics **very simplistically** as: a push or a pull on an object. Here are some other quick facts:

note—forces do not always make things move - it takes a NET force to CHANGE an object's state of motion (it could make it start moving or stop moving or change direction.

- the SI Unit of force is a Newton (N) Weight is a force...the force due to gravity! 1 Newton is **almost the same WEIGHT** as $\frac{1}{4}$ lb.
- Many forces can easily be measured with a **spring scale** or other type of force sensor
- **Contact forces** - forces that are the result of physical contact between two objects
- **Field forces** - does not involve contact between objects; e.g., gravity, electrostatic, magnetic
- **Free-Body diagram** or "**force diagram**" - diagram depicting all the **forces** acting on a single object

II. Newton's Laws of Motion

You will need to know all of Newton's Laws by their number, name, and description and will need to recognize and describe examples of each law.

1. A. Newton's First Law - "Law of Inertia" $[\Sigma F=0]$ **Net Force = zero!**

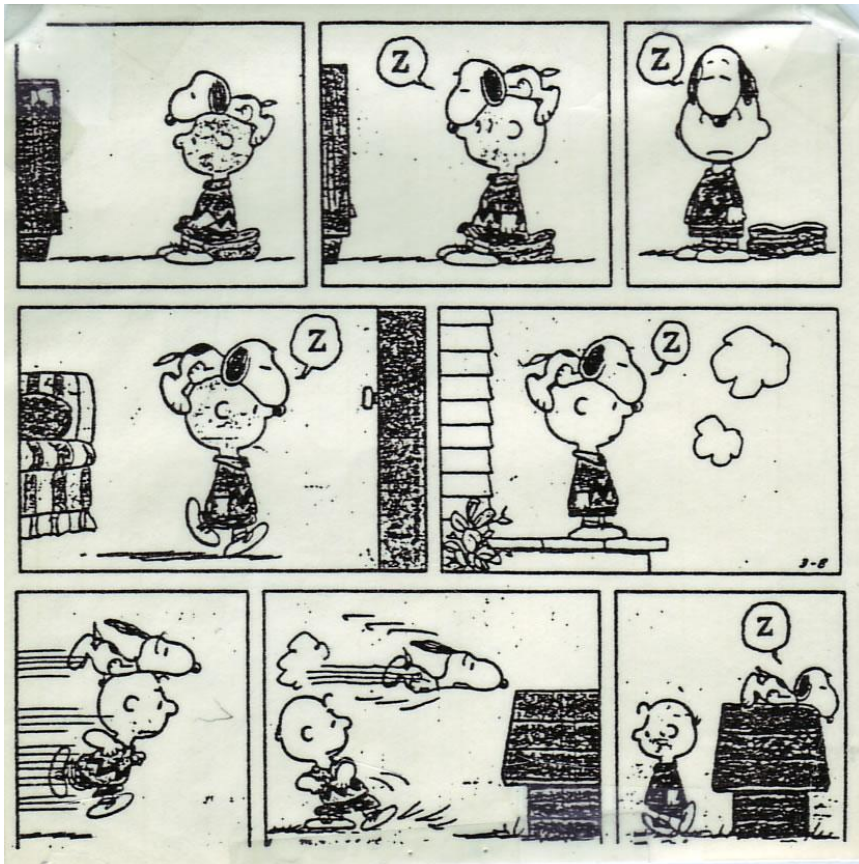
Object can remain still OR object could remain in CONSTANT velocity! This does **NOT necessarily** mean that there are no forces acting on the object! Any forces present are balanced and the object is at equilibrium.

An object in motion will stay in constant motion and an object at rest will stay at rest unless acted upon by an **unbalanced (or net) force**. "**Constant**" motion is motion in a straight line at constant speed = constant velocity. The law of inertia says that objects with mass also have inertia and this property makes them tend to **maintain their current state of motion**.

Mass is a way of measuring inertia and just measures the amount of matter in the object. Mass is a fundamental property of matter and does not change with a change in location.

Questions:

1. Which has greater mass - a kg of feathers or a kg of lead?
Which of those two would weigh more on Earth?
Which of those would have a greater volume?
Which has more inertia?
2. What force keeps a cannonball moving once it has been shot from the cannon?



B. Newton's Second Law - "Law of Force and Acceleration" [$\Sigma F=ma$]

When a net force is exerted on an object, the object will accelerate in the same direction as the net force. The amount of the acceleration will be directly proportional to the amount of the net force and will be inversely proportional to the amount of the objects mass.

The equation (in words) is: **Net Force = mass times acceleration**

The NET Force (in N) is equal to the object's mass (in kg) times the resulting acceleration in m/s^2

In symbols it is:

$$\Sigma F = ma \quad \text{where } \Sigma F \text{ and } a \text{ are vectors}$$

Weight is a measure of the force of gravity on an object. Weight, unlike mass, is not an inherent property of matter. Weight (N) is dependent on the force of gravity which varies with location. Mass (kg) is a property describing the amount of matter in an object which does not change with location. Remember that

- **Weight is a force** and that "**g**" is an **Acceleration**. From the units of mass and acceleration you can see that the units for force are $kg \cdot m/s^2 = N$ (Newton). 1 Newton is a little less than $\frac{1}{4}$ lb.

So, the formula to calculate weight is just a special case of using $F=ma$ because $W=mg$

$$g_e = G \frac{M_e}{R_e^2}$$

$$W = mg$$

$$g_e = 9.8 \text{ m/s}^2$$

Example 1 -

What is the weight of a 2.5 kg mass on Earth?

Example 2 -

What net force is required to bring a 1500-kg truck to rest from a speed of 100km/h (27.8 m/s) within a distance of 55 m?

Question: Why is the acceleration due to gravity the same for a heavy and a light ball?

C. Newton's Third Law - the law of action and reaction. [$F_{1,2} = - F_{2,1}$] This is read as ... Force on object 1 due to object 2 is equal and opposite to the Force on object 2 due to object 1. Often stated, "For every action there is an equal and opposite reaction."

- Whenever an object exerts a force on a second object, the second object exerts an equal and opposite force on the first object. This interaction is simultaneous.

For every action or force there is an equal and opposite reaction force. Another way to state Newton's third law is "**Forces always occur as pairs**".

These equal and opposite forces are called "action-reaction pairs". These action reaction pairs are often misidentified by students.

Question: If you push horizontally on a block of wood moving it across a straight level surface at constant velocity, can you say that the force of friction on the block is the reaction to the force of your hand on the block?

Answer: NO... Even though the force of friction would indeed be equal and opposite to the force of your hand, these forces are acting on the SAME object, so they are not action-reaction pairs.

The reaction force to the force of your hand on the block is the force of the block on your hand. It is the exact same force on the other object and it is always equal in magnitude and oppositely directed.

- These "force pairs" **always act on different objects** and are always simultaneous! - **NO time delay!** If object "a" acts on object "b", then the reverse is also true...that object "b" also acts on object "a" with an equal force. If "A" forces "B", then "B" forces "A" equally. The forces are opposite and equal - **BUT the resulting accelerations will depend on the masses of the objects involved as stated in Newton's Second Law.**

Question: If you push harder on the block causing it to accelerate, then must the force of your hand on the block be greater than the force of the block on your hand?

Answer: Again, **NO**. Those two forces (action-reaction pair) are **always** equal (the block would push back as much harder on your hand as your hand pushed on it). The reason the block accelerates is because the force of your hand is greater on the block than friction is that is acting on the block.

A third way of saying the law of action and reaction is to say - "You can't touch without being touched".

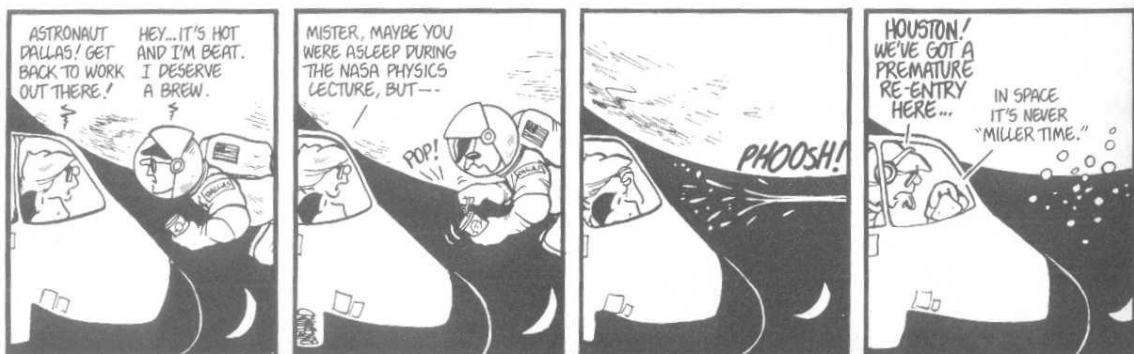
More Questions:

1. A rock falls to Earth. If the pull of the Earth on the rock is the action force, identify the reaction to this force. Is it: a. the force of air resistance acting on the rock, b. the pull of the rock on the earth?, c. the rock accelerating to earth?, or d. the force on the rock when it hits the earth?
2. Which of the forces in #1 is greater?

2. Why does a gun recoil?

3. A bug is hit and splatters on a windshield. Which encounters the greater force the car or the bug? The greater acceleration?

Rocket Propulsion



4. How can a rocket accelerate in outer space when the exhaust gases have no air to push against?

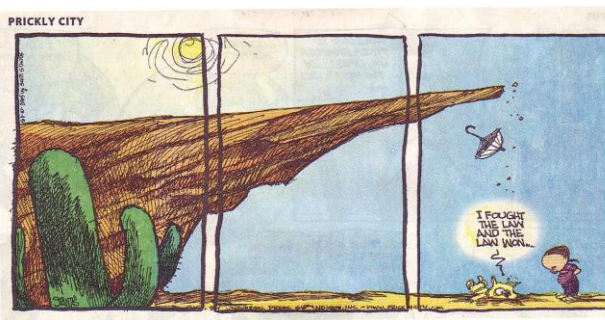
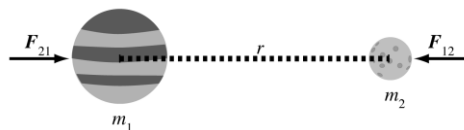
Newton's Law of Universal Gravitation

off the mark by Mark Parisi
www.offthemark.com



- Every particle in the universe exerts an attractive force on every other particle. The magnitude of the force is proportional to the product of the two masses and inversely proportional to the square of the distance between the two objects (inverse square law).

$$F = G \frac{m_1 m_2}{r^2}$$



III. Problem Solving and Working with Forces: ALWAYS DRAW A Force or "Free Body" DIAGRAM. A free body diagram shows all the external forces acting on an object (see examples below of boxes on inclined planes).

1. Forces are vector quantities - THEY ALWAYS have a direction and are represented by arrows.

2. Forces always occur in pairs - action/reaction pairs and act on different objects, BUT when drawing a free-body diagram we are interested only in the forces acting on the ONE object.

3. All real-life objects on Earth have forces acting on them. The only time when an object can exist with virtually no forces acting on it - is when the object is FAR out in space away from any stars or planets. The object would be truly weightless - but still have the same mass as always.

4. The net force (often called the ΣF or the resultant force) is found by adding together all of the forces acting on an object as vectors! Keep in mind the direction of the force may be negative or positive.

5. If the net force is zero, the object **CAN NOT** be accelerating ... **BUT the object CAN** be moving with a constant velocity or remaining still.

6. If there is a net force of some amount, then there **must** be acceleration involved and that acceleration will be in the same direction as the net force. If there is acceleration, you **must be able to identify** the unbalanced or net force!!

IV. Free-body Diagrams or Force Diagrams

When analyzing a force problem, **the first step** is to identify all of the forces acting on an object and to draw a "free-body" or "force" diagram and label all the external forces on the object.

Some common forces you will analyze on free-body diagrams

1. **Gravitational Force or Weight (F_g or W or mg)—measure of force of gravity ($W=mg$)**
Weight, unlike mass, is not an inherent property of matter; weight is dependent on the force of gravity, which varies from location to location; mass is a measure of the quantity of matter
2. **Normal force (F_N or N)**—the one component of the force that a surface exerts on an object with which it is in contact; "normal" means perpendicular
3. **Tension (F_T or T)** - a force applied by means of a rope, cable, string, chain, etc. Tension always acts along the direction of the rope, etc.
4. **Friction (F_f)** - force between two surfaces which are in contact with each other. Friction acts parallel to the surfaces and resists or opposes any relative motion
 - a. **Static friction (F_s)** — friction force that opposes the start of motion. Static friction is the resistive force between two surfaces which are not moving relative to each other, but would be moving if there were no friction.
 - b. **Kinetic friction (F_k)**— friction force between surfaces in relative motion. Kinetic friction is typically less than static friction for the same two surfaces in contact.
 - c. The frictional force is directly proportional to the normal force $f \propto N$
The constant that makes the proportionality into an equation is represented by the Greek letter μ (mu).

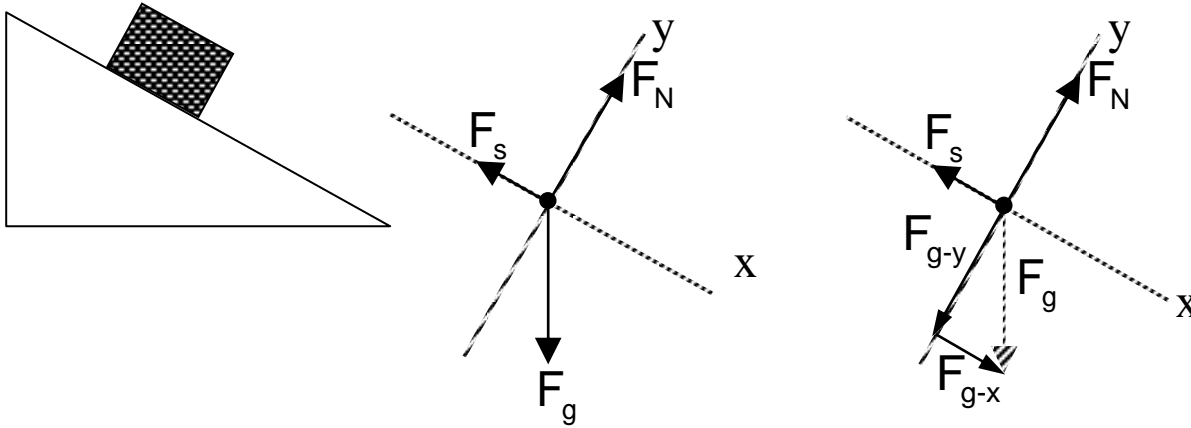
$$F_s \leq \mu_s N \quad F_k = \mu_k N \quad \text{where } F_s \text{ is the static frictional force and } F_k \text{ is the kinetic}$$

μ is the coefficient of friction which is a ratio of the frictional force to the normal force. Its value depends upon the nature of the surfaces in contact. The larger the value of μ , the "stickier" the two surfaces are to each other. **Note the less than or equal to sign for static friction.** The static frictional force will only be as large as necessary to keep the object in equilibrium. The equation would only **be equal at the maximum frictional force** Note the less than or equal to sign for static friction. The static frictional force will only be a large as necessary to keep the object in equilibrium. The equation would only be equal at the maximum frictional force which would be the value just before the object moves.

- d. **Coefficient of friction (μ)**—ratio of the frictional force to the normal force; μ is a constant that depends upon the nature of the surfaces in contact; the larger the value of μ , the "stickier" the two surfaces are to each other $F_f = \mu F_N$

The purpose of drawing the free-body diagram is to easily see the relationship among the forces. In the case shown below, there are **three external forces acting on the box (see first vector diagram)**:

- (1) Force of static friction F_f or F_s up the incline (always resisting motion),
- (2) Force of gravity (F_g) or weight = mg downward **toward the center of the Earth**, and
- (3) The Normal force - the support of the plane's surface pushing up on the box (F_N) called the normal force since it always acts **perpendicular to surface**.



- We draw the x-axis parallel to the inclined surface which gives the \mathbf{F}_g vector a horizontal and vertical component as shown.
- Since the object is at rest, friction must be equal to the horizontal component of gravity $\mathbf{mg} \sin\theta$ and the normal force \mathbf{F}_N would be equal to the vertical component of gravity $\mathbf{mg} \cos\theta$.
- If the box were accelerating down the incline then $\mathbf{mg} \sin\theta$ would be larger than the force of friction and we would apply Newton's 2nd law.

Steps for solving challenging force problems

1. Draw a free-body diagram analyzing all forces on the object under analysis
2. Determine whether or not the object is at equilibrium $\sum \mathbf{F} = 0$ or $F_{\text{net}} = 0$ for equilibrium and $\sum \mathbf{F} = m\mathbf{a}$ or $F_{\text{net}} = m\mathbf{a}$ for accelerations]

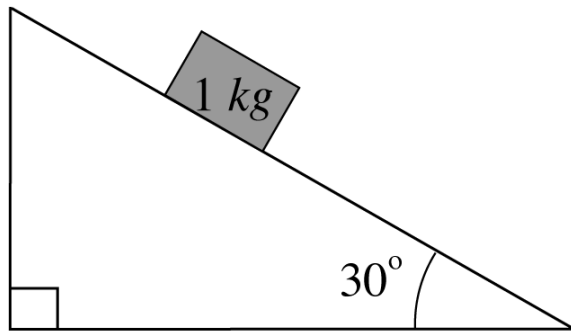
Set up as many equations as necessary to solve for all unknown variables

Example 3. A 24 kg crate is moving at a constant velocity along a horizontal floor because of a 75 N horizontal force pushing it along.

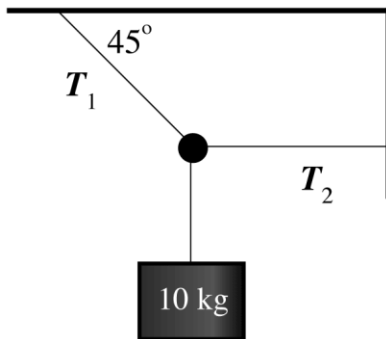
- a. How much is the force of friction acting on the crate as it moves?
- b. Find the coefficient of kinetic or sliding friction between the crate and the floor.

Example 4. A student moves a box of books by attaching a rope to the box and pulling with a force of 90.0 N at an angle of 30.0° . The box of books has a mass of 20.0 kg, and the coefficient of kinetic friction between the bottom of the box and sidewalk is 0.200. Find the acceleration of the box.

Example 5. The Inclined plane. A force of 8.50 N is required to slide a 1 kg box up a 30.0° inclined plane with a constant velocity. Calculate the coefficient of friction between the trunk and plane.



Example 6: Tension in cables. Find the tension in each cable in the diagram below.



BART'S LAWS

We hold these truths to be self-evident.
Do not try to avoid these laws,
for they refuse to be avoided.

BART'S FIRST LAW OF MOTION:
A body at rest remains at rest until a parental body comes over and tells it to mow the lawn. If that body continues to remain at rest despite the urgings of the parental body, see Bart's Second Law of Motion.

Body at rest
Parental body

BART'S SECOND LAW OF MOTION:
The acceleration produced by an unbalanced force acting on a body is directly proportional to the mass of the force plus whether or not the force is carrying a weapon plus how loud the force is screaming.

Unbalanced Force
Scream
Body
Acceleration

BART'S UNIVERSAL LAW OF MOTION:
What goes up must come down, man.

Velocity
Force

BART'S THIRD LAW OF MOTION:
When one body exerts a force upon another body, the second body exerts an equal force upon the first body, and these forces are opposite in direction (i.e., for every action there is an equal and opposite reaction).

Action
Reaction
Gravity

1471
Count Dracula born.

1492
Columbus gets lost and discovers America.

1559
Montezuma's Revenge invented.

1586
Francis Bacon invents the salty breakfast treat named for him.

1630
The Three Musketeers invent the swashbuckle to hold up their pants.

1650
Pirates rule the seven seas.

1687
Newton invents gravity, so people don't have to tie themselves to their beds when they go to sleep at night.

87