Newton's Laws of Motion

Unit: Forces in One Dimension

NGSS Standards/MA Curriculum Frameworks (2016): HS-PS2-10(MA), HS-PS2-1

AP® Physics 1 Learning Objectives/Essential Knowledge (2024): 2.3.A, 2.3.A.1, 2.3.A.2, 2.3.A.32 2.3.A.3.i, 2.3.A.3.ii, 2.3.A.3.iii, 2.3.A.3.iv, 2.4.A, 2.4.A.1, 2.4.A.2, 2.4.A.3, 2.4.A.4, 2.4.A.5, 2.5.A, 2.5.A.1, 2.5.A.2, 2.5.A.3

Mastery Objective(s): (Students will be able to…)

- Define and give examples of Newton's laws of motion.

Success Criteria:

- Examples illustrate the selected law appropriately.

Language Objectives:

- Explain each of Newton's laws in plain English and give illustrative examples.

Tier 2 Vocabulary: at rest, opposite, action, reaction, inert

Labs, Activities & Demonstrations:

- Mass with string above & below
- Tablecloth with dishes (or equivalent)
- "Levitating" globe.
- Fan cart
- Fire extinguisher & skateboard
- Forces on two masses hanging (via pulleys) from the same rope

Notes:

force: a push or pull on an object.

In the MKS system, force is measured in newtons, named after Sir Isaac Newton:

$$1\,\text{N} \equiv 1\,\frac{\text{kg}\cdot\text{m}}{\text{s}^2} \approx 3.6\,\text{oz}$$
$$4.45\,\text{N} \approx 1\,\text{lb.}$$

net force: the amount of force that remains in effect after the effects of opposing forces cancel.

Mathematically, the net force is the result of combining (adding) all of the forces on an object. (Remember that in one dimension, we use positive and negative numbers to indicate direction, which means forces in opposite directions need to have opposite signs.)

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

(The mathematical symbol Σ means "sum", which means "There are probably several of the thing after the Σ sign. Add them all up.")

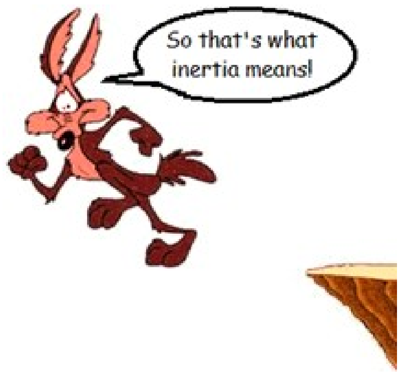
Use this space for summary and/or additional notes:

Newton's First Law: (the law of inertia) Everything keeps doing what it was doing unless a net force acts to change it. "An object at rest remains at rest, unless acted upon by a net force. An object in motion remains in motion at a constant velocity, unless acted upon by a net force."

No net force ↔ no change in motion (no acceleration).

If there is no net force on an object (the forces are "balanced"), the object's velocity will remain the same (*i.e.,* if it is moving, it will keep moving with the same velocity and if it is at rest, it will remain at rest).

If an object's motion is not changing (there is no acceleration) , then there must be no net force on it, which means all of the forces on it must cancel.



For example, a brick sitting on the floor will stay at rest on the floor forever unless an outside force moves it. Wile E. Coyote, on the other hand, remains in motion…

Inertia (resistance to change) is a property of mass. Everything with mass has inertia, regardless of the existence of the force of gravity. The more mass an object has, the more inertia it has.

Inertia can be measured in a zero-gravity environment using an inertial balance, which is just a spring attached to an apparatus to hold the object. Inertial balances are described in more detail in the section on *Springs*, starting on page 532.

translational equilibrium: A situation in which Newton's First Law applies, *i.e.,* when there is no net force on a system and its motion (velocity) does not change.

Use this space for summary and/or additional notes:

Newton's Second Law: Forces cause a change in velocity (acceleration). "A net force, $\vec{F}$, acting on an object causes the object to accelerate in the direction of the net force."

unbalanced forces: when not all of the effects of the forces on an object cancel, resulting in a net force on the object.

Net force ↔ change in motion (acceleration).

If there is a net force on an object (*i.e.,* there are unbalanced forces), the object's motion must change (accelerate), and if an object's motion has changed, there must have been a net force on it.

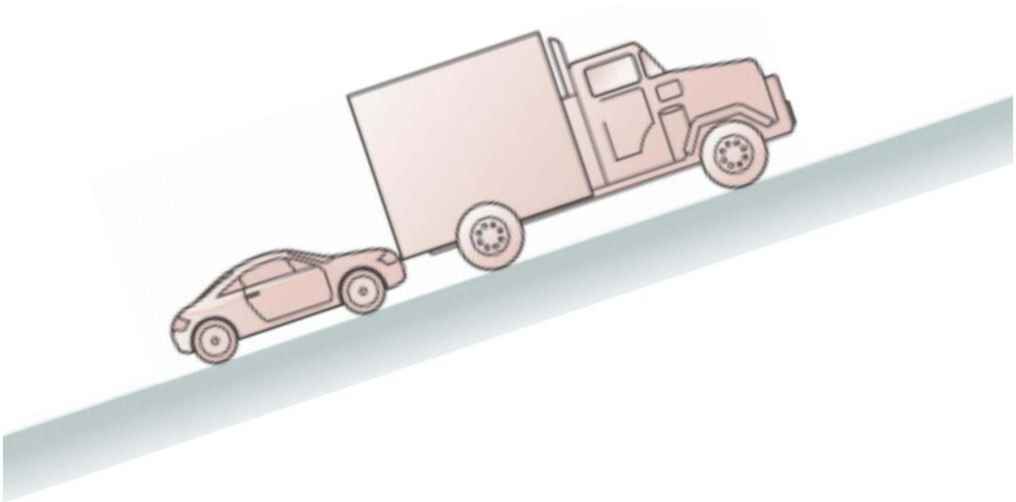
In equation form:

$$\vec{a} = \frac{\vec{F}_{\text{net}}}{m} = \frac{\sum \vec{F}}{m} \quad \text{or} \quad \sum \vec{F} = \vec{F}_{net} = m\vec{a}$$

This equation represents one of the most important relationships in physics.

Newton's Third Law: Every force produces an equal and opposite reaction force of the same type. The first object exerts a force on the second, which causes the second object to exert the same force back on the first. "For every action, there is an equal and opposite reaction."

For example, suppose a car is pushing a truck up a hill. If the car exerts a force of 100 000 N on the truck as it pushes, then the truck (which is being pulled down the hill by gravity) exerts a force of 100 000 N on the car.



This is often written as:

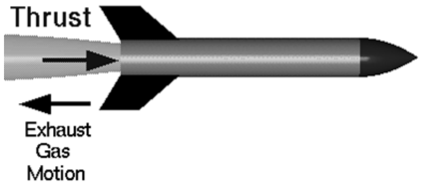
$$\vec{F}_{A \text{ on } B} = \vec{F}_{B \text{ on } A}$$

which means that the force that object *A* exerts on object *B* is equal to the force that object *B* exerts on object *A*.

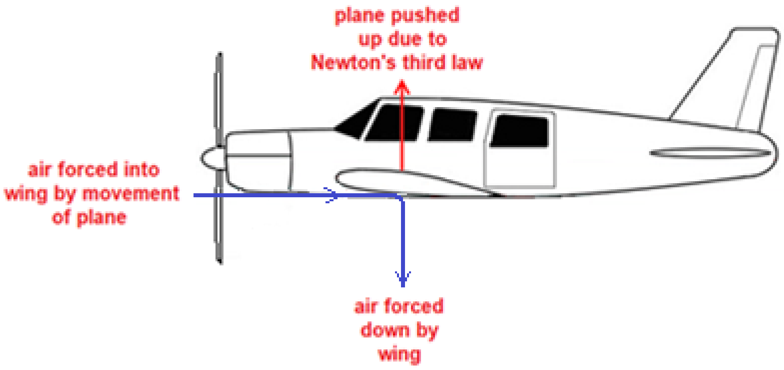
Use this space for summary and/or additional notes:

Some examples of Newton's Third Law:

- When you pull on a rope (the action force), the rope also pulls on you (the reaction force).
- Burning fuel in a rocket causes exhaust gases to escape from the back of the rocket. The force from the gases exiting the rocket (the action) causes an equal and opposite thrust force to the rocket (the reaction), which propels the rocket forward.



- The wings of an airplane are angled (the "angle of attack"), which deflects air downwards as the plane moves forward. The wing pushing the air down (the action) causes the air to push the wing (and therefore the plane) up (the reaction). This reaction force is called "lift".



- If you punch a hole in a wall and break your hand, your hand applied a force to the wall (the action). This caused a force from the wall, which broke your hand (the reaction). This may seem obvious, although you will find that someone who has just broken his hand by punching a wall is unlikely to be receptive to a physics lesson!

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Systems

system: a specific object or set of objects considered together as a way to understand, model or predict the behaviors of those objects.

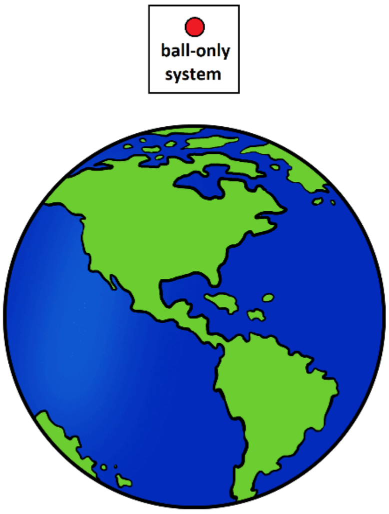
surroundings: the objects that are not part of the system.

The system may be considered as a group or unit. According to Newton's Second Law, ***a net force on an object in a system caused by an object outside of the system will cause the entire system to accelerate as if the system were a single object.***

According to Newton's Third Law, forces between objects that are both in the same system may affect each other, but their effects cancel with respect to the system as a whole. This means that ***forces within a system do not affect the motion of the system.***

For example, gravity is the force of attraction between two objects because of their mass. If a student drops a ball off the roof of the school, the Earth attracts the ball and the ball attracts the Earth. (Because the Earth has a lot more mass than the ball, the ball moves much farther toward the Earth than the Earth moves toward the ball.)

- **Ball-Only System**: If the system under consideration is only the ball, then the gravity field of the Earth exerts a net force on the ball, causing the ball to move.



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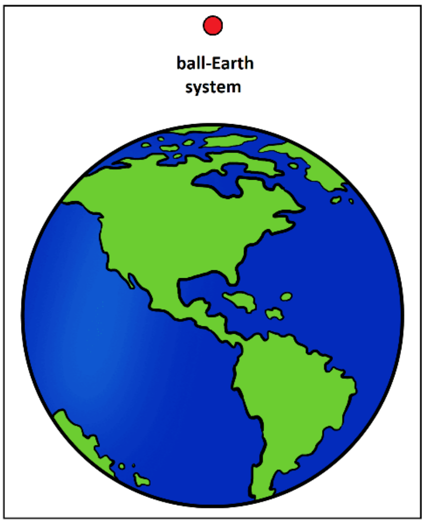
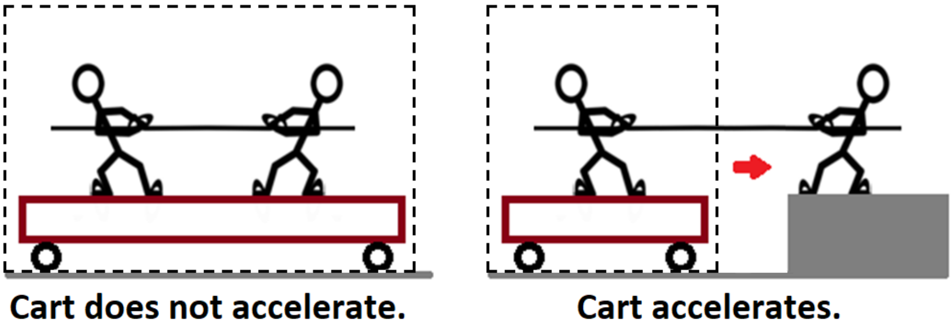
* **Ball-Earth System**: If the system is the ball and the Earth, the force exerted by the Earth on the ball is equal to the force exerted by the ball on the Earth. Because the forces are equal in strength but in opposite directions ("equal and opposite"), their effects cancel, which means there is no net force on the system. (Yes, there are forces within the system, but that's not the same thing.) This is why, for example, if all 7.5 billion people on the Earth jumped at once, an observer on the moon would not be able to detect the Earth moving.



A demonstration of this concept is to have two students standing on a cart (a platform with wheels), playing "tug of war" with a rope. In the student-rope-student-cart system, the forces of the students pulling on the rope are all within the system. There is no net force (from outside of the system) on the cart, which means the cart does not move. However, if one student moves off the cart (outside of the system), then the student outside of the system can exert an external net force on the student-cart system, which causes the system (the student and cart) to accelerate.



One of the important implications of this concept is that ***an object cannot apply a net force to itself***. This means that "pulling yourself up by your bootstraps" is impossible according to the laws of physics.

Later, in the section on potential energy on page 447, we will see that potential energy is a property of systems, and that a single isolated object cannot have potential energy.

Use this space for summary and/or additional notes: