Dynamics

Forces and Newton's Laws

Dynamics

I. Newton's 3 Laws of Motion
   - inertia, force, mass, weight
   - interaction & nature of force

II. Normal Force

III. Compression, Tension, Sections

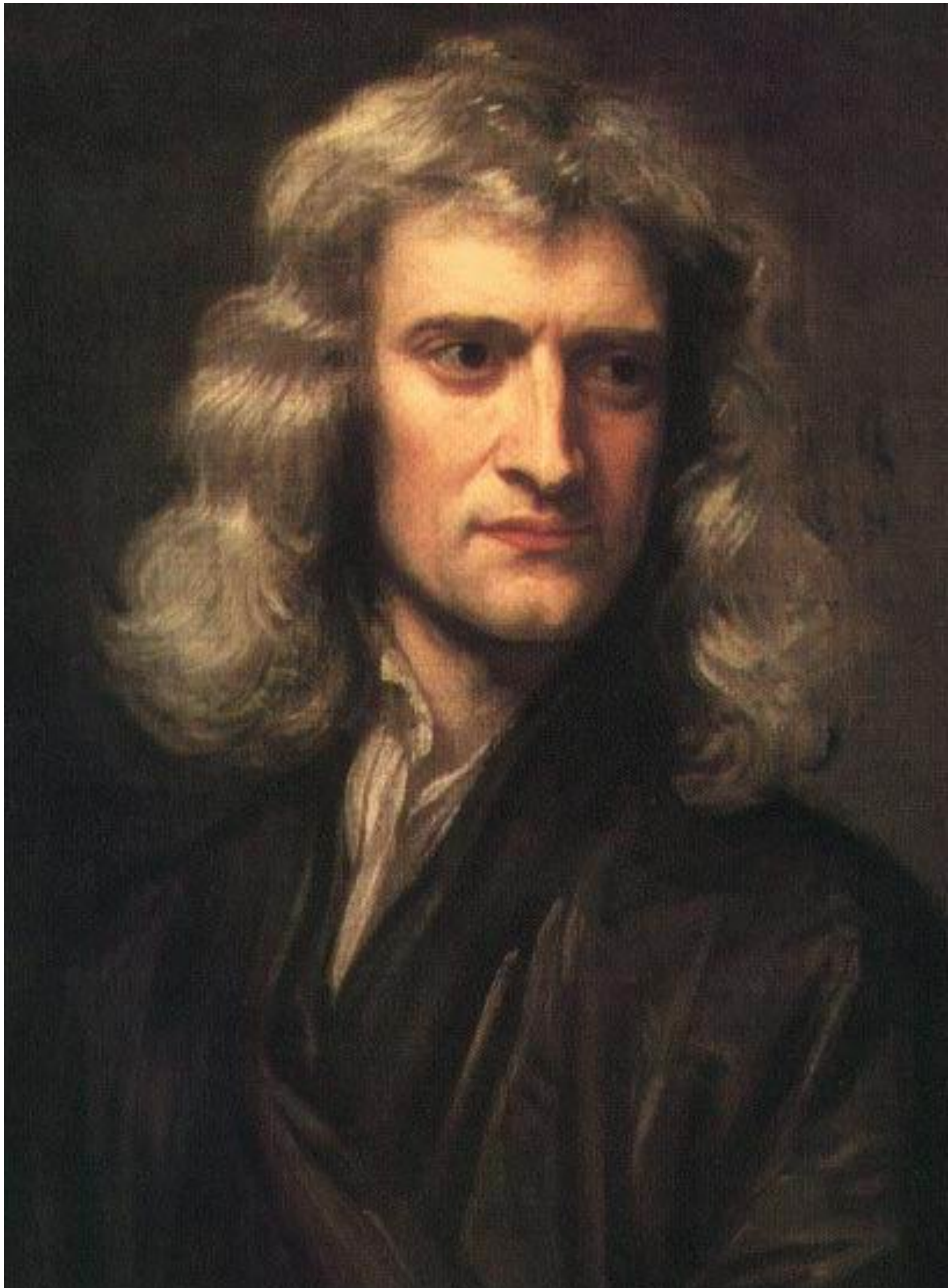
IV. Pulleys and Systems

V. Friction (between solids)

VI. Air Resistance

VII. Inclines, ramps, etc.

	The student will be able to:	HW:
1	State Newton's 1st and 2nd Laws of Motion and apply these laws to physical situations in order to determine what forces act on an object and to explain the object's resulting behavior. Define and apply the concept of inertia and inertial frame of reference.	1 – 7
2	Recognize and state the proper SI unit of force and give its equivalence in fundamental units and use the relation $\mathbf{F}_{net} = m\mathbf{a}$ to solve problems.	8 – 10
3	Recognize the difference between weight and mass and convert from one to the other.	11 – 14
4	State and utilize Newton's 3rd Law to solve related problems.	15 – 18
5	Understand and utilize the concept of the normal force to solve related problems.	19, 20
6	Define and apply the concepts of compression and tension and use the method of sections to solve for these.	21 – 26
7	Solve force problems involving pulleys, including those involving multiple objects and systems of equations (such as Atwood's machine).	27 – 31
8	Understand and utilize the relation between friction force, normal force, and coefficient of friction for both cases: static and kinetic.	32 – 37
9	Solve problems involving air resistance in which friction is assumed directly proportional to velocity; define and apply the concept of terminal velocity.	38 – 39
10	Apply force components to objects on an incline and solve related problems.	40 – 44



Isaac Newton
(1643 – 1727 AD)

In 1687 Newton published the ***Philosophiæ Naturalis Principia Mathematica*** or simply "the ***Prinicipia***" in which he established **three laws of motion** and the law of universal gravitation.

This is the basis for classical physics!

Newton's 1st Law of Motion

If the net force on an object is zero the object continues in its initial state of rest or motion with a constant velocity.

This establishes the concept of *inertia*.

Inertia is the tendency of an object to maintain its state of motion.

Inertia is *not a force*, but rather a *property* of all matter. Force is not a requirement for motion!

Newton's 2^{nd} Law of Motion

The effect of an applied force is to cause an object to accelerate in the direction of the force. The acceleration is directly proportional to the force and inversely proportional to the mass of the object.

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

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

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

The word "net" is extremely important! If there is more than one force acting on an object the net force is equal to the *vector sum* of all force acting on the object!

$$\Sigma \vec{F} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \ldots$$

An object "responds" to anything and everything that "pushes" or "pulls" it.

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

$$\Sigma F_x = ma_x \qquad \Sigma F_y = ma_y$$

As is often the case in physics, it may be useful to resolve this formula into *x* and *y* components.

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

What is mass?

Mass is a measure of the quantity of matter within an object. (How many protons, neutrons, electrons, etc…)

Mass is a measure of *inertia*! The more the mass of an object, the greater its tendency to maintain its state of motion (it *accelerates less*).

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

Units of force:

The SI unit of force is the **newton**. One newton is the amount of force necessary to accelerate one kilogram at one meter per second per second.

$$N = kg \cdot \frac{m}{s^2}$$

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

Units of force:

Another unit of force is the **pound**. One pound is the amount of force necessary to accelerate one slug at one foot per second per second.

$$lbf = slug \cdot \frac{ft}{s^2}$$

Newton's 3^{rd} Law

The Nature of Force

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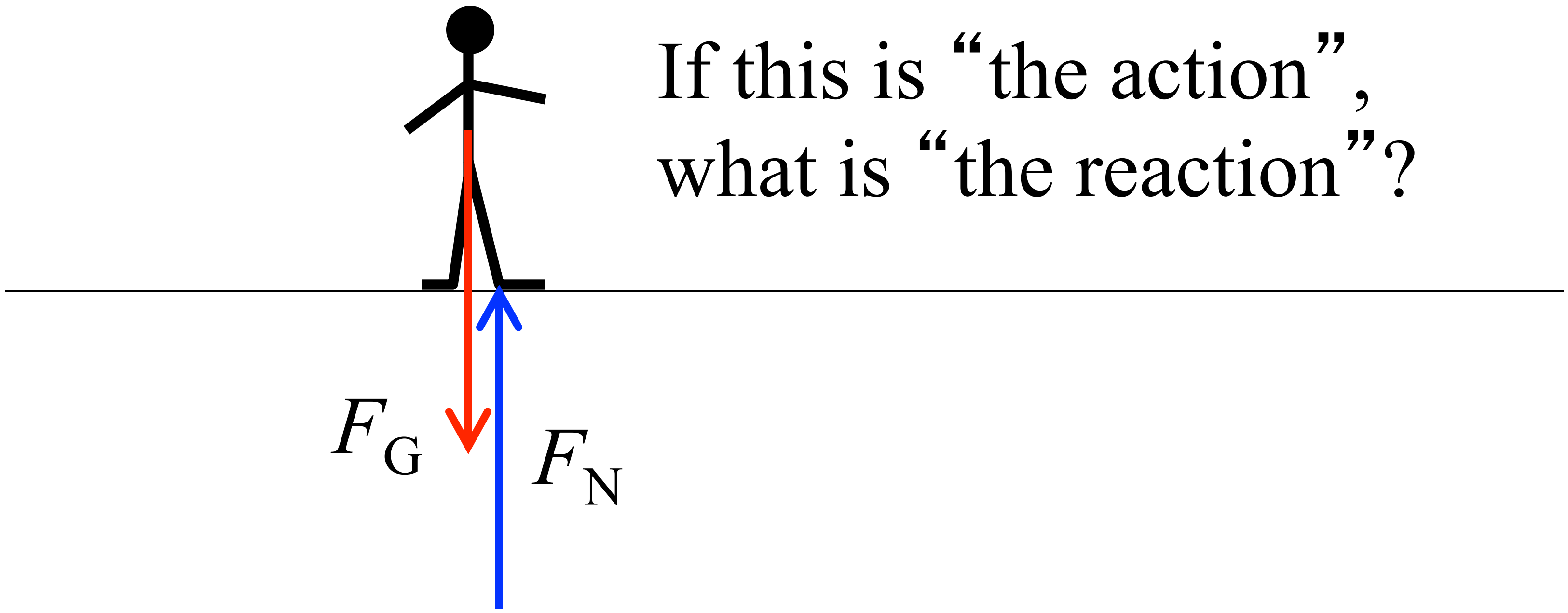
Newton's 3rd Law of Motion

Forces always occur in *pairs*. If object *A* exerts a force on object *B*, then object *B* exerts a force on object *A* that is equal in magnitude and opposite in direction.

Popularly known as: "equal and opposite action and reaction".

All forces arise in pairs as a result of an *interaction* of two objects. The equal and opposite forces (of each pair) act on two separate objects.

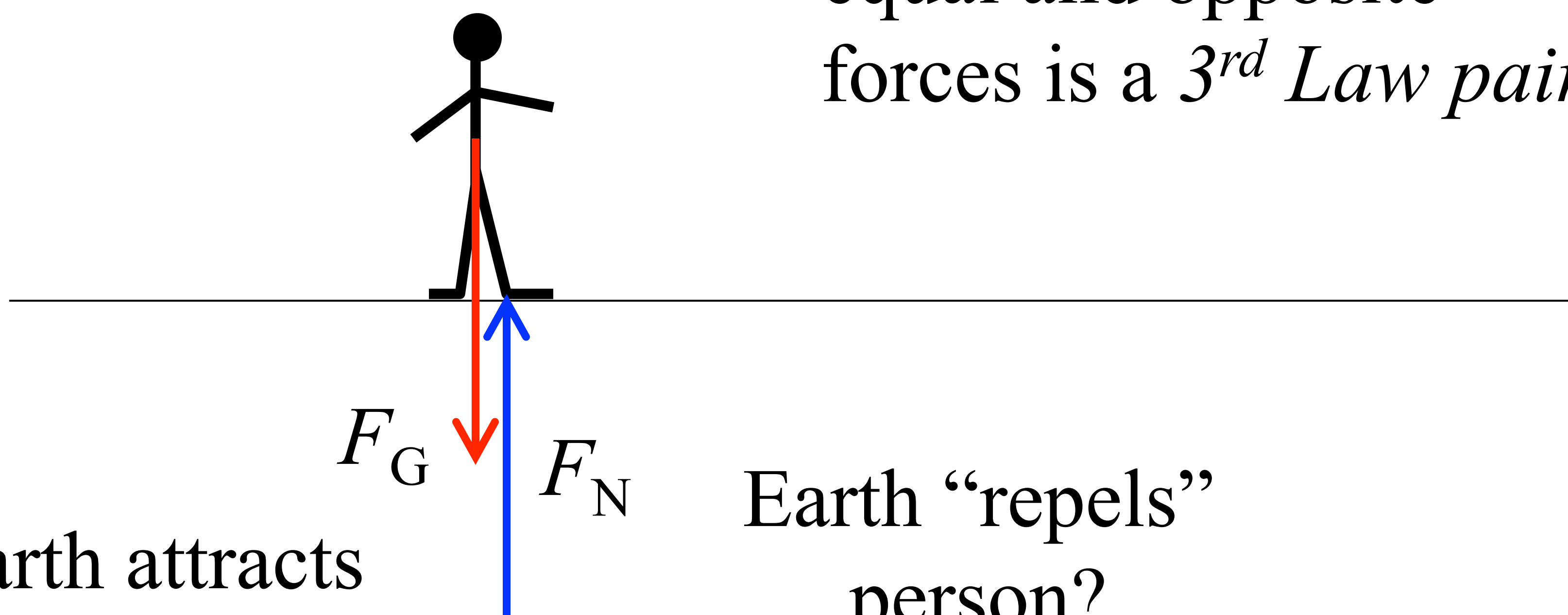
What forces are there when a person stands at rest on the ground?



If this is "the action", what is "the reaction"?

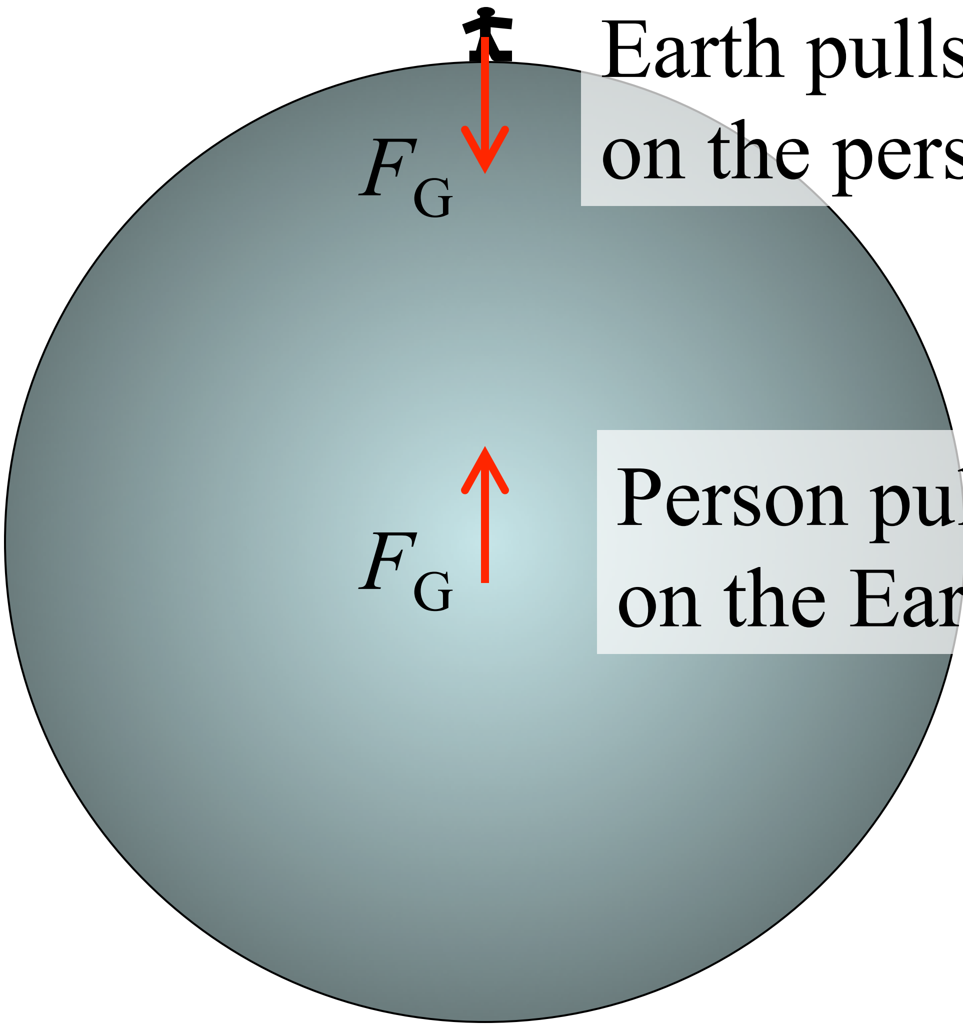
Is this a 3rd Law “action-reaction” pair?

No! Not *every* pair of equal and opposite forces is a *3rd Law pair*!



Earth “repels” person?

Earth attracts person.



Earth pulls down on the person.

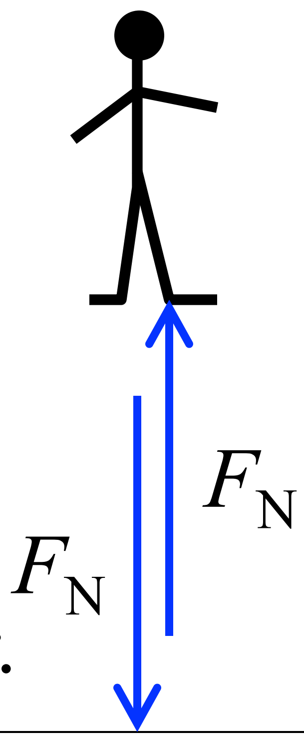
Person pulls up on the Earth!

a 3rd Law pair of forces

These two forces must <u>*always*</u> be equal and opposite as long as and whenever the person interacts with Earth!

a 3rd Law action/reaction pair of forces!

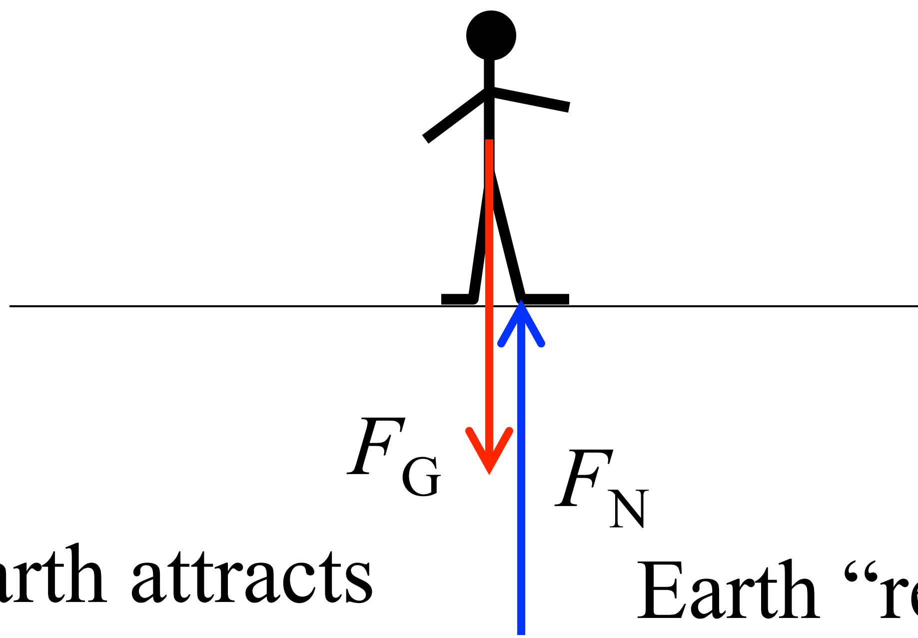
These two forces must ***always*** be equal and opposite as long as and whenever atoms in the feet of the person interact with atoms in the floor!



Floor pushes up on feet.

Feet push down on floor.

Not *every* pair of opposing forces is a *3rd Law pair*! The two forces shown here *might* be equal and opposite, but *only* if the person is not accelerating up or down. If the person *does* accelerate up or down (or if there are other forces) these two forces can and will be different in magnitude!



not a 3rd Law pair of forces

Inertial and Noninertial Frames

When is force *really* force?

Inertial Frames of Reference

- In an inertial frame of reference an object at rest stays at rest, an object in motion maintains a constant velocity.
- Put another way, objects are observed to follow Newton's 1st Law of Motion.
- Any object that accelerates is responding to a force, such as gravity.
- Examples: The Earth is taken to be an inertial frame of reference. A subway car in motion at constant velocity

Inertial Frames of Reference – Examples:

Earth is taken to be an inertial frame of reference. Relative to Earth, objects follow Newton's 1st and 2nd Laws of Motion to a very high degree of accuracy.

A train car moving at constant velocity is also an inertial frame. A ball at rest on the floor of the car will remain at rest relative to the car. A ball rolling at constant speed across the floor will continue at that speed and in the same direction. Thus, the ball illustrates inertia as expected in this moving frame of reference. Also, a ball that is dropped in the train car accelerates in the direction of an actual force interaction – gravitation between the ball and the Earth. For *any* observed acceleration occurring in this frame of reference there is a real force interaction that is responsible.

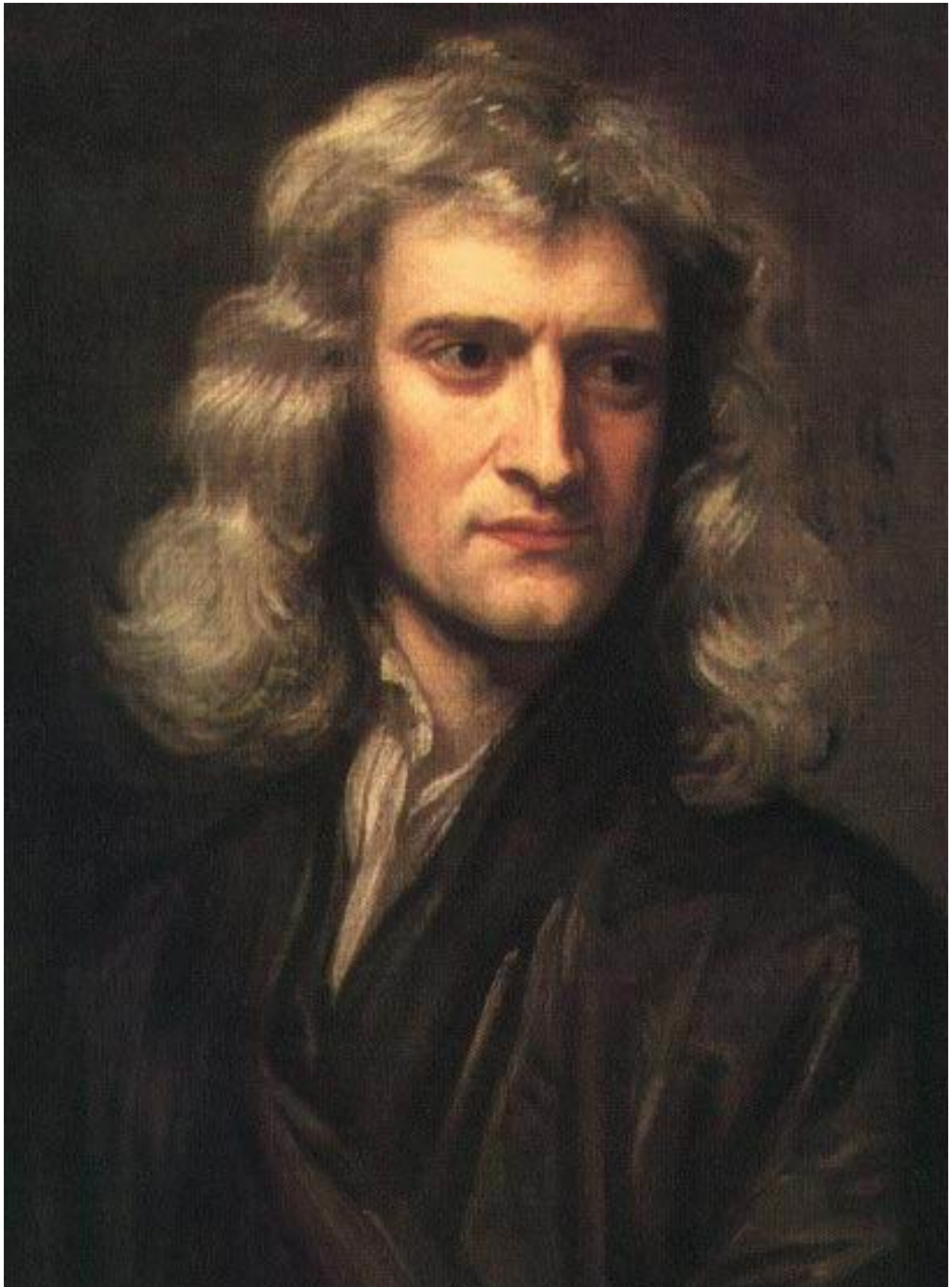
Noninertial Frames of Reference

- In an noninertial frame of reference an object at rest does *not* stay at rest, an object in motion does *not* maintain constant velocity.
- Put another way, objects are observed to *contradict* Newton's 1st Law of Motion.
- There are observed accelerations for which there is no actual force. (2nd Law *also* contradicted!)
- Scientists and engineers sometimes choose to treat this effect as a "fictional force" (a pseudo-force). It might be called an "inertial force".

Noninertial Frames of Reference – Examples:

A train car that accelerates is a noninertial frame. A ball initially at rest on the floor of the car will not remain at rest relative to the car. A ball rolling across the floor will not continue at the same speed and/or same direction. Thus, the ball does not illustrate the property of inertia as expected in this moving and accelerating frame of reference. Instead the ball will appear to accelerate and there will be no actual force interaction that can explain this. Also, a ball that is dropped in the train car will not fall straight down and instead follow a curved path – accelerating horizontally in this frame, again with no actual force interaction responsible.

Technically, the Earth is *also* a noninertial frame, but this is usually disregarded. The surface of the Earth is constantly accelerating and this is responsible for the coriolis effect or “coriolis force”. There is also a slight “centrifugal force” effect due to the rotation of the Earth – these are pseudo-forces for which there are no actual “action and reaction” pairs.



Isaac Newton

"I do not know what I may appear to the world, but to myself I seem to have been only like a boy playing on the sea-shore, and diverting myself in now and then finding a smoother pebble or a prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me."