Newton’s Laws

Physics 1425 lecture 6

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Newton Extended Galileo's Picture of Motion to Include Forces

Galileo said:

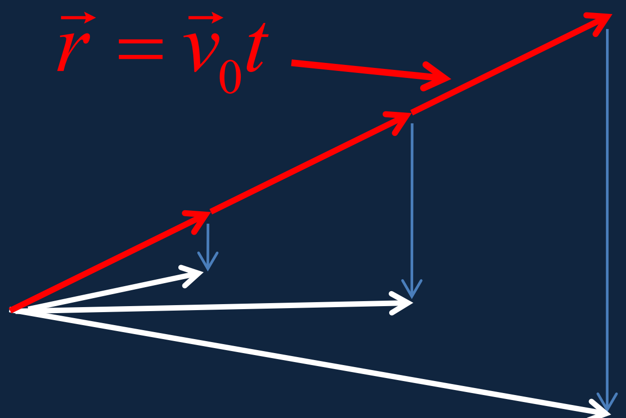
- Natural horizontal motion is at constant velocity unless a force acts: a push from behind will cause acceleration, friction will cause negative acceleration (that is, deceleration).
- Natural vertical motion is constant downward acceleration…

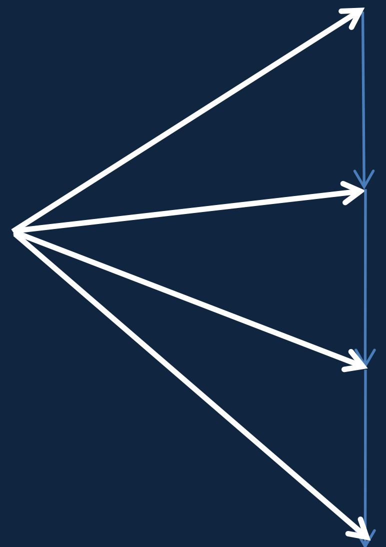
Newton Said They're the Same Thing!

- The "natural vertical motion" is at constant acceleration because there's a constant force acting – the force of gravity!
- Without that force, vertical motion would be at constant velocity.
- Look again at the path of a projectile: without gravity, it would be a straight line.

Vector Picture of Projectile Motion

$$\boxed{\vec{r} = \vec{v}_0 t - \tfrac{1}{2}\vec{g}t^2}$$





Position at 1 second intervals (notice it falls below red straight line: the *g* =0 trajectory).

Velocities and Speeds at 1 second intervals.

Newton's First Law of Motion

- Newton's First Law is that an object continues to move at constant velocity unless acted on by external forces.

- Unlike Galileo's horizontal motion law, this applies for motion in any direction.
- (This was hard to accept, because forces were considered to arise only from contact, a push or pull, and this "force of gravity" seemed magical.)

Relating Change in Velocity to Force

- This can *only* be done experimentally: Newton did many experiments.
- Care must be taken to make sure forces like friction, etc., are negligibly small.

- Take two objects made of the same material (iron, say) one twice the volume of the other, apply the same force.
- The one with twice the stuff accelerates at half the rate.

Force and Acceleration I

- Many experiments lead to the conclusion that a given force (such as a spring extended by a measured amount) accelerates an object in the direction of the force at a rate inversely proportional to the "amount of stuff" in the object.
- This amount of stuff is called the mass, or inertial mass, of the object: it measures the object's resistance to being accelerated: the object's inertia. It is denoted by *m*.

Force and Acceleration II

- It is also found that doubling the force (pulling with two identical springs, for example) doubles the acceleration.

- The bottom line is:

1. Acceleration is proportional to applied force (and of course in the same direction).
2. Acceleration is *inversely* proportional to mass.

Units for Force

- We already have a unit for mass, the kg, and acceleration, m/s^2.
- We define the magnitude of the unit force as that force which accelerates one kilogram at one meter per second per second.

- This unit force is one Newton.

Newton's Second Law

- The relation between force, mass and acceleration can now be written:

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

  where the magnitude of the force *F* is measured in Newtons, the mass is in kilograms and the acceleration is in meters per second per second.
- This is Newton's Second Law.

$\vec{F}$ Means *Total* Force!

- Newton's Second Law, $\vec{F} = m\vec{a}$ gives the acceleration of a body of mass *m* acted on by a total force $\vec{F}$.

- Air resistance and friction contribute nonzero forces, which might or might not be small.

- A car accelerating along a road is also being acted on by gravity—but that is usually cancelled out by the upward force of support from the road, called the normal force.

Inertial Frames of Reference

- Recall a frame of reference is a set of axes, like three perpendicular rulers, to measure position, plus a clock to track time, so motion can be precisely described.
- An inertial frame is one in which Newton's First Law is obeyed.
- If frame A is inertial, and frame B is moving at constant velocity relative to frame A, then frame B is also inertial.

Relative Velocity and Inertial Frames

- If a body is moving at constant velocity $\vec{v}_B$ in frame B, and frame B is moving at constant velocity $\vec{v}$ relative to frame A, then the body is moving at constant velocity $\vec{v}_A = \vec{v} + \vec{v}_B$ relative to frame A.
- For constant velocity $\vec{v}$ of frame B relative to frame A, the acceleration of a body measured in frame A equals its acceleration in frame B:

$$\frac{d\vec{v}_A}{dt} = \frac{d\vec{v}}{dt} + \frac{d\vec{v}_B}{dt} = \frac{d\vec{v}_B}{dt}$$

Relative Acceleration and Noninertial Frames

- If frame A is inertial, and frame B is accelerating with respect to frame A, then frame B is noninertial.
- Examples: inside an accelerating car; on a rotating carousel.
- A body in an accelerating car will only stay at rest relative to the car if acted on by some force (the seat, for example).

Newton's Third Law

- If two bodies interact, the force on B from A is equal in magnitude to the force on A from B, and opposite in direction :

$$\boxed{\vec{F}_{AB} = -\vec{F}_{BA}}$$

In the example shown here, the glove suffers a force exactly equal in magnitude to that felt by the face.

Action and Reaction

- Newton’s Third Law is often stated as “action equals reaction”.
- The action is body A pushing on body B.
- The reaction is the inevitable opposite force: B pushing back on A.

- Very Important! The action and the reaction *always* act on different bodies!

More Action and Reaction…

- If a car and a truck collide, the force of the truck on the car equals the force of the car on the truck…

- BUT an equal force on a smaller object will have a different result!

http://www.massachusettsinjurylawyerblog.com/car-accident.jpg

Clicker Question

If I jump upwards, I leave the ground with nonzero upward velocity—I accelerated upwards. Applying $\vec{F} = m\vec{a}$, what force caused that upwards acceleration?

A. The force of my leg muscles
B. The force of my pressure on the floor
C. The reaction force from the floor

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- Acceleration of a body can only be caused by an *outside* force acting on the body!