

# Newton's Laws

Physics 1425 lecture 6

# Newton Extended Galileo's Picture of Motion to Include Forces

Galileo said:

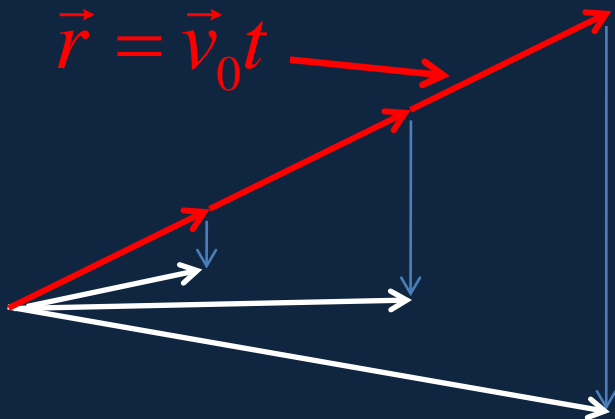
- Natural horizontal motion is at constant velocity unless a force acts: a push from behind will cause acceleration, friction will cause negative acceleration (that is, deceleration).
- Natural vertical motion is constant downward acceleration...

# Newton Said They're the Same Thing!

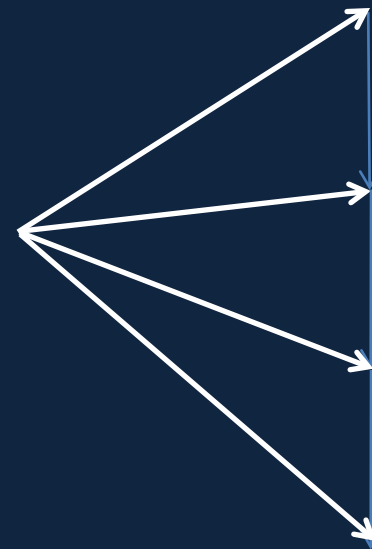
- The “natural vertical motion” is at constant acceleration **because there's a constant force acting** – the force of **gravity**!
- Without that force, **vertical motion would be at constant velocity.**
- Look again at the **path of a projectile**: without gravity, it would be a straight line.

# Vector Picture of Projectile Motion

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



**Position** at 1 second intervals (notice it **falls below 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,  $\text{m/s}^2$ .
- 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:

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

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 :

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

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>


[And here's another example, with masses about equal ...](#)

## 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!