Newton’s Laws

Physics 1425 lecture 6
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 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/s².

• 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:

\[ \vec{F} = m\ddot{a} \]

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, \( \vec{F} = ma \), 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
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 force from the floor
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**Acceleration of a body can only be caused by an outside force acting on the body!**