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!

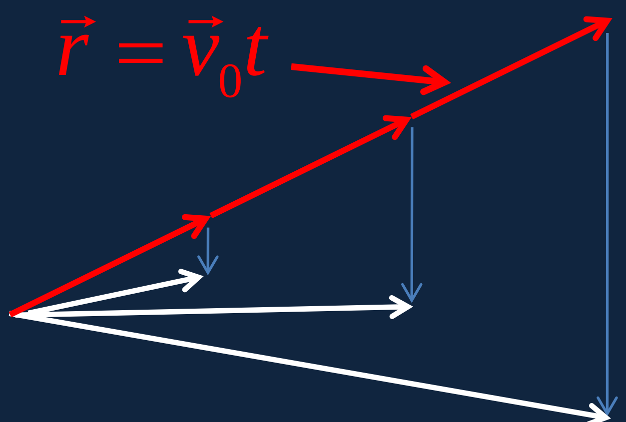
- The “natural vertical motion” is at constant acceleration because there’s a constant force acting – the force of gravity!

- Without that force, vertical motion would be at constant velocity.

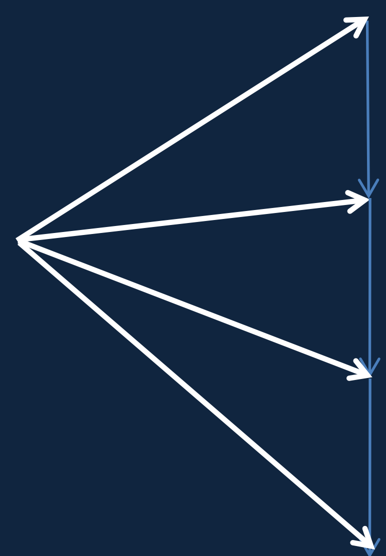
- Look again at the path of a projectile: without gravity, it would be a straight line.

Vector Picture of Projectile Motion

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



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, 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.

ConcepTest 4.1a Newton’s First Law I

A book is lying at rest on a table. The book will remain there at rest because:

1) there is a net force but the book has too much inertia
2) there are no forces acting on it at all
3) it does move, but too slowly to be seen
4) there is no net force on the book
5) there is a net force, but the book is too heavy to move

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There are forces acting on the book, but the only forces acting are in the *y*-direction. Gravity acts downward, but the table exerts an upward force that is equally strong, so the two forces cancel, **leaving no net force**.

ConcepTest 4.1b Newton's First Law II

A hockey puck slides on ice at constant velocity. What is the *net* force acting on the puck?

1) more than its weight
2) equal to its weight
3) less than its weight but more than zero
4) depends on the speed of the puck
5) zero

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The puck is moving at a constant velocity, and therefore it is not accelerating. Thus, there must be no net force acting on the puck.

Follow-up: Are there any forces acting on the puck? What are they?

ConcepTest 4.2a Cart on Track I

Consider a cart on a horizontal frictionless table. Once the cart has been given a push and released, what will happen to the cart?

1) slowly come to a stop
2) continue with constant acceleration
3) continue with decreasing acceleration
4) continue with constant velocity
5) immediately come to a stop

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After the cart is released, there is no longer a force in the x-direction. ***This does not mean that the cart stops moving!!*** It simply means that the cart will ***continue moving with the same velocity*** it had at the moment of release. The initial push got the cart moving, but that force is not needed to *keep* the cart in motion.

ConcepTest 4.2b Cart on Track II

We just decided that the cart continues with **constant velocity**. What would have to be done in order to have the cart continue with constant acceleration?

1) push the cart harder before release
2) push the cart longer before release
3) push the cart continuously
4) change the mass of the cart
5) it is impossible to do that

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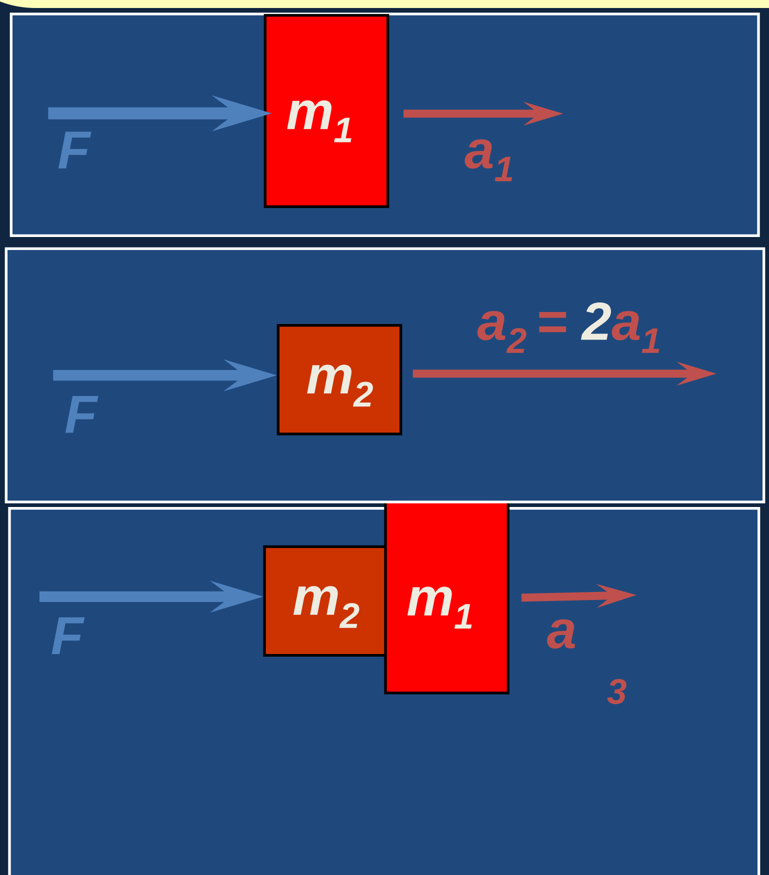
In order to achieve a non-zero acceleration, it is necessary to **maintain the applied force**. The only way to do this would be to **continue pushing** the cart as it moves down the track. This will lead us to a discussion of Newton's Second Law.

ConcepTest 4.6 Force and Two Masses

A force F acts on mass m_1 giving acceleration a_1. The same force acts on a different mass m_2 giving acceleration $a_2 = 2a_1$. If m_1 and m_2 are glued together and the same force F acts on this combination, what is the resulting acceleration?

1) $\frac{3}{4}\,a_1$
2) $\frac{3}{2}\,a_1$
3) $\frac{1}{2}\,a_1$
4) $\frac{4}{3}\,a_1$
5) $\frac{2}{3}\,a_1$



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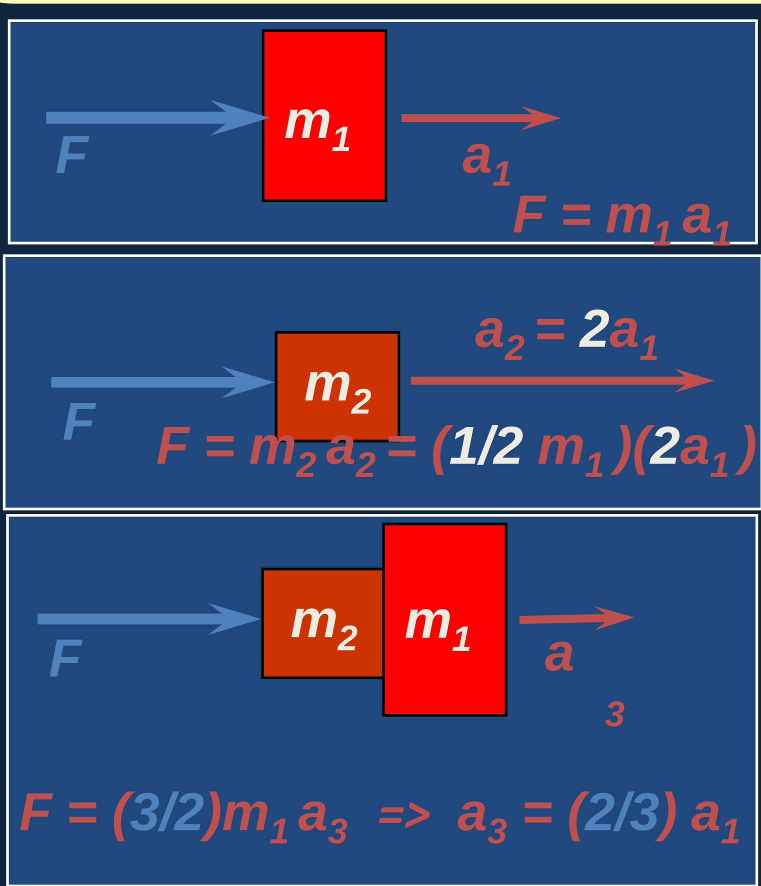

Mass m_2 must be $(\frac{1}{2}m_1)$ because its acceleration was $2a_1$ with the same force. Adding the two masses together gives $(\frac{3}{2})m_1$, leading to an acceleration of $(\frac{2}{3})a_1$ for the **same applied force**.

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.

http://startswithabang.com/?p=1718

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!

Problem from Book

- A 0.140-kg baseball traveling 35.0 m/s strikes the catcher's mitt, which, in bringing the ball to rest, recoils backward 11.0 cm. What was the average force applied by the ball on the glove?

Problem from Book

- An exceptional standing jump would raise a person 0.80 m off the ground. To do this, what force must a 68-kg person exert against the ground? Assume the person crouches a distance of 0.20 m prior to jumping, and thus the upward force has this distance to act over before he leaves the ground.