Physics I

Lecture 9

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Review of Lesson 4

- Position & Displacement
- Average & Instantaneous Velocity
- Average & Instantaneous Acceleration
- Projectile Motion
  - Vertical & Horizontal Motion
  - Range
- Uniform Circular Motion
- Relative Motion

فصل پنجم

نیرو و قوانین نیوتون

Isaac Newton (1643 - 1727) published Principia Mathematica in 1687. In this work, he proposed three "laws" of motion:

Newton's First Law

An object subject to no external forces is at rest or moves with a constant velocity if viewed from an inertial reference frame.

If no forces act, there is no acceleration.

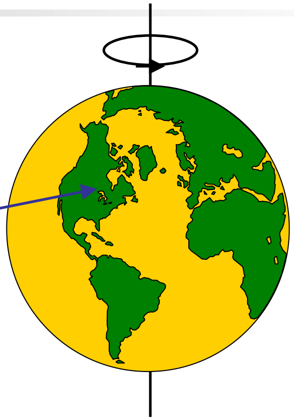
inertial reference frames

An IRF is a reference frame that is not accelerating (or rotating) with respect to the "fixed stars".

Is Urbana a good IRF?

Is Urbana accelerating?

Urbana is on the Earth.
The Earth is rotating.



What is the centripetal acceleration of Urbana?

$$a_U = \frac{v^2}{R} = \left(\frac{2\pi}{T}\right)^2 R$$

a_U = .034 m/s2 (~ 1/300 g)
Close enough to *0* that we will ignore it.
Urbana is a pretty good IRF.

T = 1 day = 8.64 x 10^4 sec,
$R \sim R_E$ = 6.4 x 10^6 meters

Mass

- What exactly is mass?
- We have some feel for this by the fact that different bodies react differently to the same force (if we have some way of consistently applying the same force)
- The more mass a body has, the less it will accelerate given the same applied force

Mass

- So we can see a ratio forming here:

$$\frac{\mathrm{m}}{\mathrm{m_o}} = \frac{a_o}{a}$$

where the force is held constant

Mass

- So back to the initial question: *What is mass?*
- Mass is something intrinsic to an object – we can only define it as a characteristic of an object that relates forces on the object to how the body reacts (accelerates) in response to those forces

Inertia and Mass

Inertia is the natural tendency of an object to remain at rest or in motion at a constant speed along a straight line.

The mass of an object is a quantitative measure of inertia.

SI Unit of mass: kilogram (kg)

Newton’s Second Law

- Everything we have been discussing so far regarding forces, masses and acceleration can be neatly summed up using Newton’s 2nd Law:

  The net force on a body is equal to the product of the body’s mass and the acceleration of the body

Newton's Second Law

- In equation form this is the famous:

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

- While this is very simple equation, we must be careful in our use of it
- We must first note that force, like acceleration, is a vector (this must be true as mass is only a scalar)

Force has units of [M]x[L / T^2] = kg m/s^2 = N (Newton)

Newton's Second Law

- Because force is a vector quantity, the usual rules apply: we can break forces down into components – one for each axis of our coordinate system
- So we have:

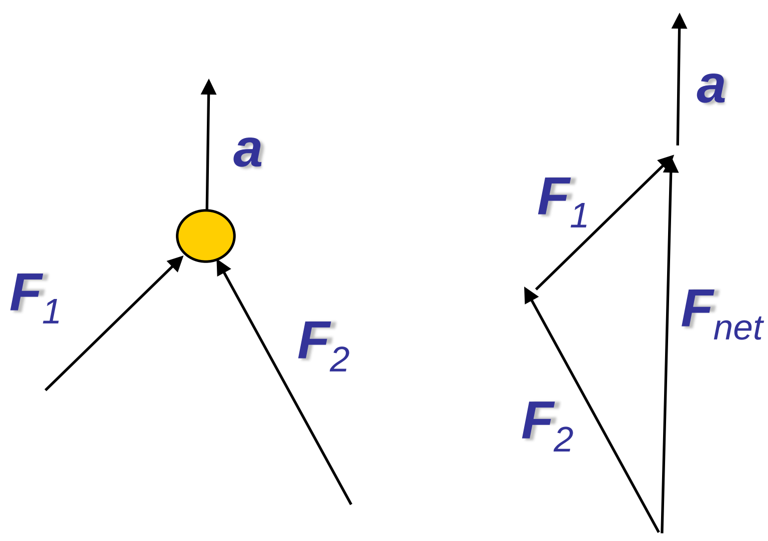
$$\vec{F}_{\mathrm{net,x}} = m\vec{a}_{\mathrm{x}},\ \vec{F}_{\mathrm{net,y}} = m\vec{a}_{\mathrm{y}},\ \vec{F}_{\mathrm{net,z}} = m\vec{a}_{\mathrm{z}}$$

What is a force?

A Force is a *push* or a *pull*.

A Force has magnitude & direction (vector).

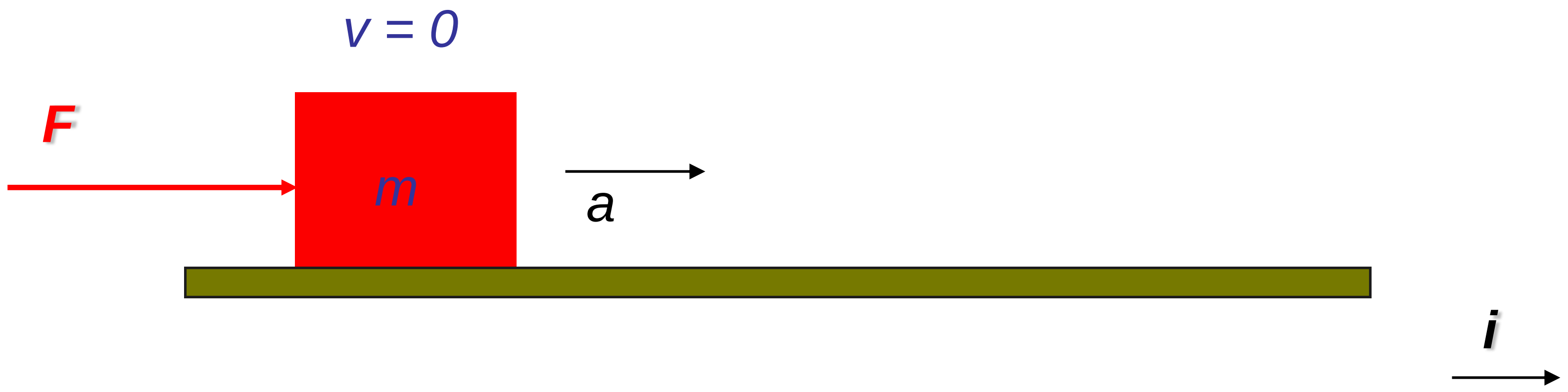
Adding forces is like adding vectors.



$$\boxed{F_{net} = ma}$$

Example: Pushing a Box on Ice.

- **A skater is pushing a heavy box (mass m = 100 kg) across a sheet of ice (horizontal & frictionless). He applies a force of 50 N in the i direction. If the box starts at rest, what is its speed v after being pushed a distance d = 10 m?**



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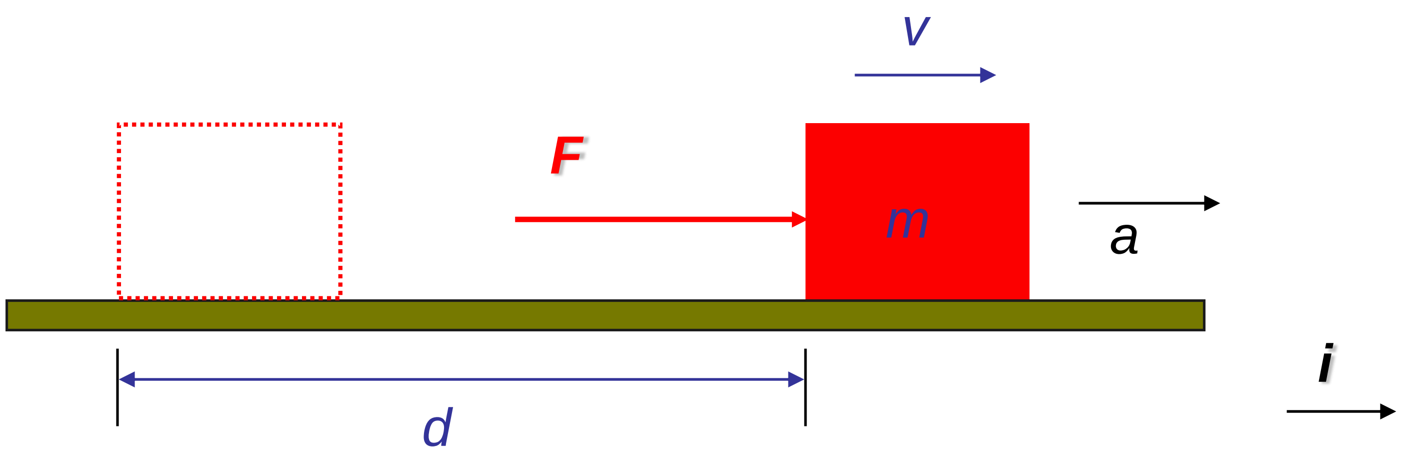


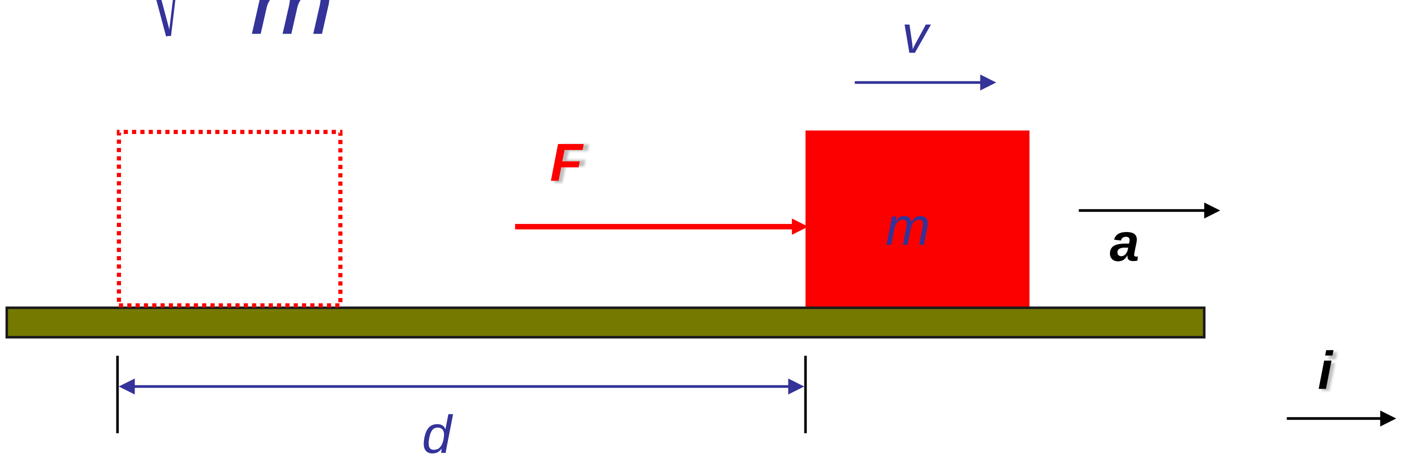
Start with $F = ma$

$a = F / m$

Recall that $v^2 - v_0^2 = 2a(x - x_0)$

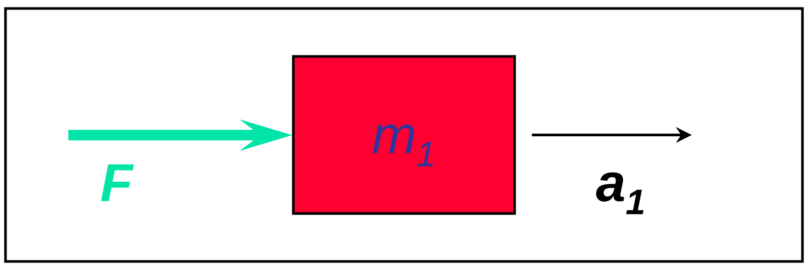
- So $v^2 = 2Fd / m$

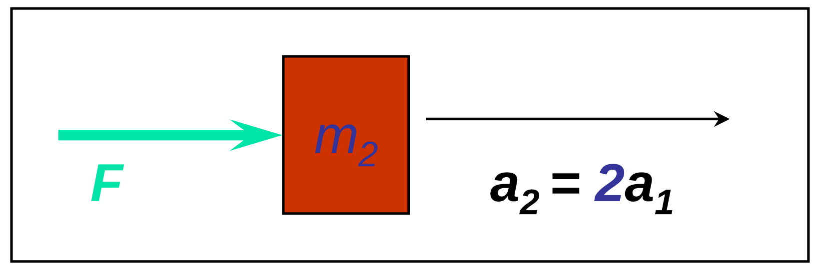
$$v = \sqrt{\frac{2Fd}{m}}$$



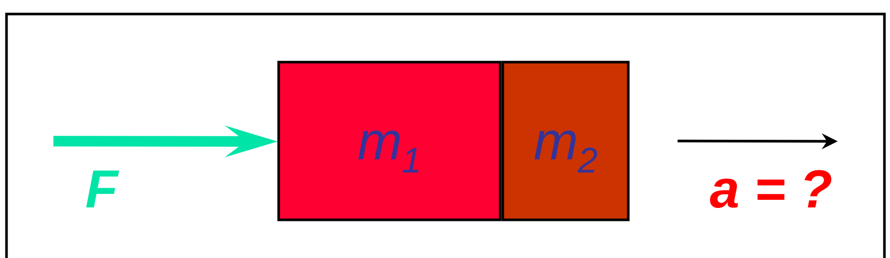
Force and acceleration

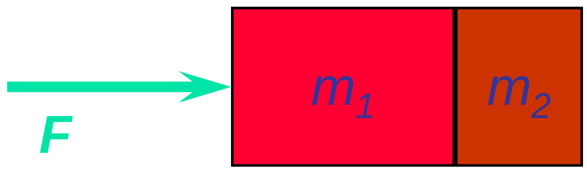
A force F acting on a mass m_1 results in an acceleration a_1. The same force acting on a different mass m_2 results in an acceleration $a_2 = 2a_1$.





If m_1 and m_2 are glued together and the same force F acts on this combination, what is the resulting acceleration?





$a = F / (m_1 + m_2)$

Since $\boldsymbol{a_2} = 2\boldsymbol{a_1}$ for the same applied force, $m_2 = (1/2)m_1$!

- $m_1 + m_2 = 3/2\ m_1$

- So $a = (2/3)F / m_1$ But $F/m_1 = a_1$

$\boxed{\mathbf{a = 2/3\ a_1}}$

Types of Forces:

In nature there are two general types of forces, fundamental and non-fundamental.

Fundamental forces:

- **Gravitational force**
- **Strong nuclear force**
- **Weak nuclear force**
- **Electromagnetic force**

Non-fundamental forces:

Pushing, Pulling, Kicking, Grabbing, etc….

These are related to the electromagnetic force. They arise from the interactions between the electrically charged particles that comprise atoms and molecules.

Fundamental Forces

Fundamental Force	Example	Particles Affected	Relative Strength
Strong nuclear	Nucleus	Nuclear	1
Electromagnetic	+, - Charges	Charged	10^{-2}
Weak nuclear	Radioactivity	Nuclear	10^{-15}
Gravitational	Your weight	All	10^{-38}

Forces

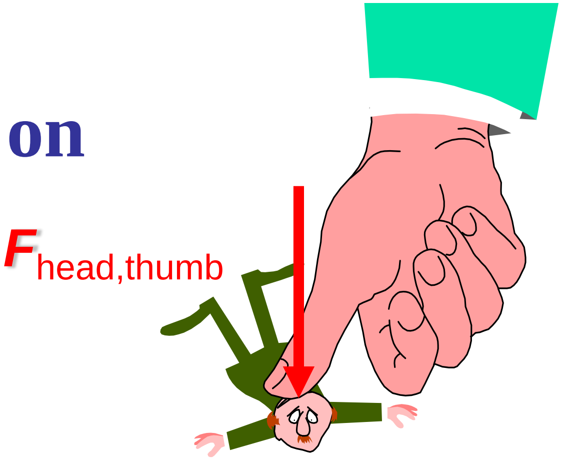
- We will consider two kinds of forces:
  - **Contact force:**
    - **This is the most familiar kind.**
      - **I push on the desk.**
      - **The ground pushes on the chair...**
  - **Action at a distance:**
    - **Gravity**
    - **Electricity**

Contact forces:

- **Objects in contact exert forces.**

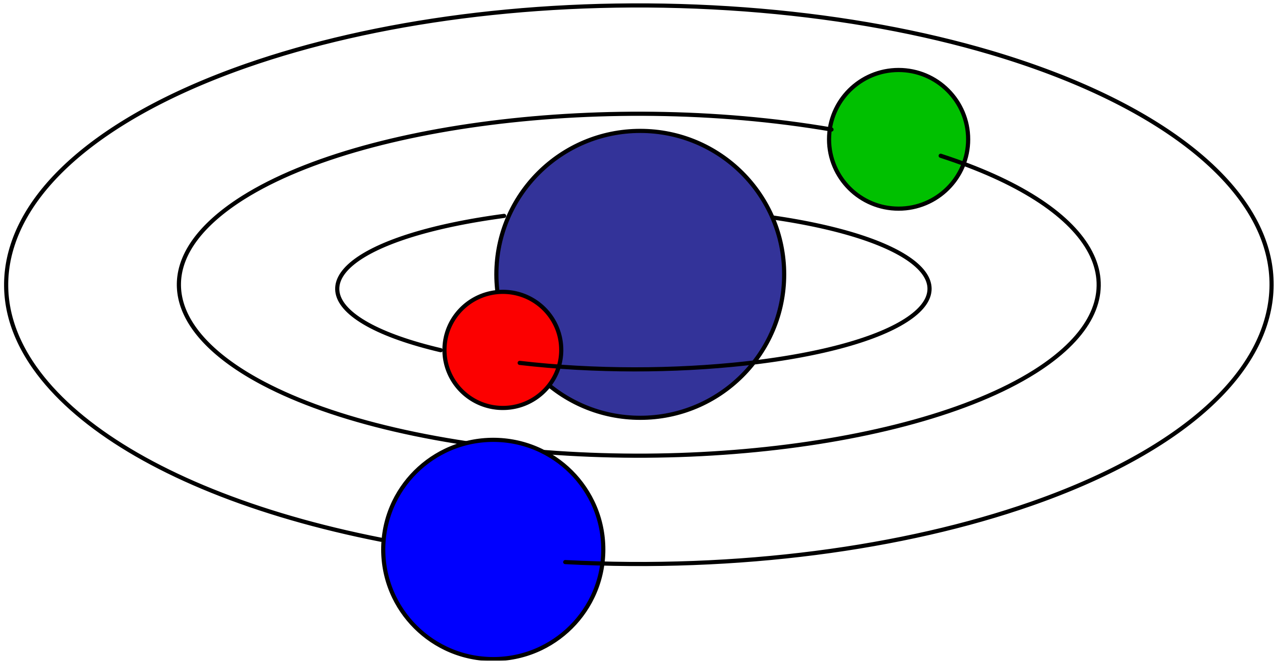
- **Convention: $\boldsymbol{F}_{a,b}$ means**
- **"the force acting on *a* due to *b*".**

- **So $\boldsymbol{F}_{head,thumb}$ means "the force on the head due to the thumb".**



Action at a distance

- Gravity:



Particular Forces (Normal Force)

- **As I am standing here on the floor, my body mass is exerting a force against the floor**
- **The floor flexes (a little) due to my presence and in turn exerts a force upwards against me – otherwise I would accelerate downwards**
- **The force exerted by the floor against me is called a *normal force* ('normal' because it is perpendicular to the surface of the floor)**

Particular Forces (Normal Force)

- Going back to the elevator example, there is of course a normal force exerted by the floor of the elevator against someone standing in the elevator
- When the elevator is accelerating, the normal force will be:

$$N = mg + ma_y$$

$$N = m(g + a_y)$$

Particular Forces (Friction)

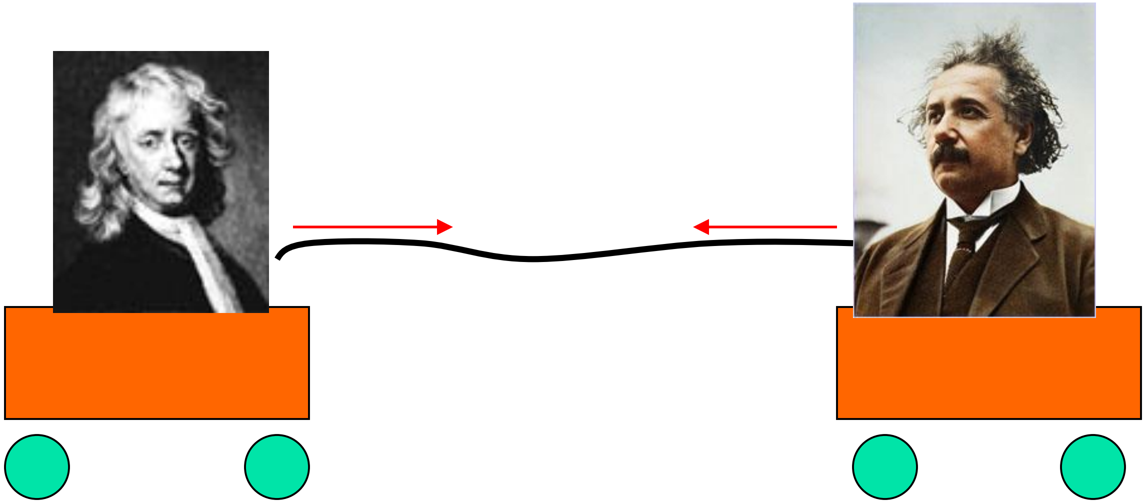
- When one object slides along the surface of another, the motion will be resisted by *friction.*
- Friction generates a force in opposition to the direction of motion.
- We often will assume frictionless surfaces to simplify things, but we will look at friction in more detail later.

Newton’s Third Law

- Two bodies interact when they exert forces on each other
- If I push against the wall I am clearly exerting a force on it – the wall is also clearly exerting a force back against me
- These forces apparently are equal – otherwise one of us (the wall or me) would be accelerated

Newton's 3rd Law

For every action (force), there is an equal and opposite reaction (opposing force).



Force *on* Newton *by* Einstein = Force *on* Einstein *by* Newton

(But their accelerations need not be the same: Newton tries to outsmart Einstein by loading his own cart with lead bricks)

Newton's Third Law

- Newton's 3rd Law states that: *When two bodies interact, the forces on the bodies from each other are always equal in magnitude and opposite in direction*
- As hard as I push on the wall, the wall will push back just as hard (in the opposite direction)

Newton's Third Law

- In vector notation, we have:

$$\vec{F}_{\mathrm{Me,\,Wall}} = -\vec{F}_{\mathrm{Wall,\,Me}}$$

- This is called a *third-law force pair*
- We will always have a third-law force pair whenever two bodies interact