Physics

Forces and Newton's Laws

- Dynamics
    1. Forces
    2. How and why do objects move?
- Newton’s 3 laws of motion

What causes acceleration?

Introduce a new concept:

FORCE

Dynamics is the study of forces and the *resulting* motion.

Ancient View

- Objects tend to stop if they are in motion
- Force is required to keep something moving

Modern View

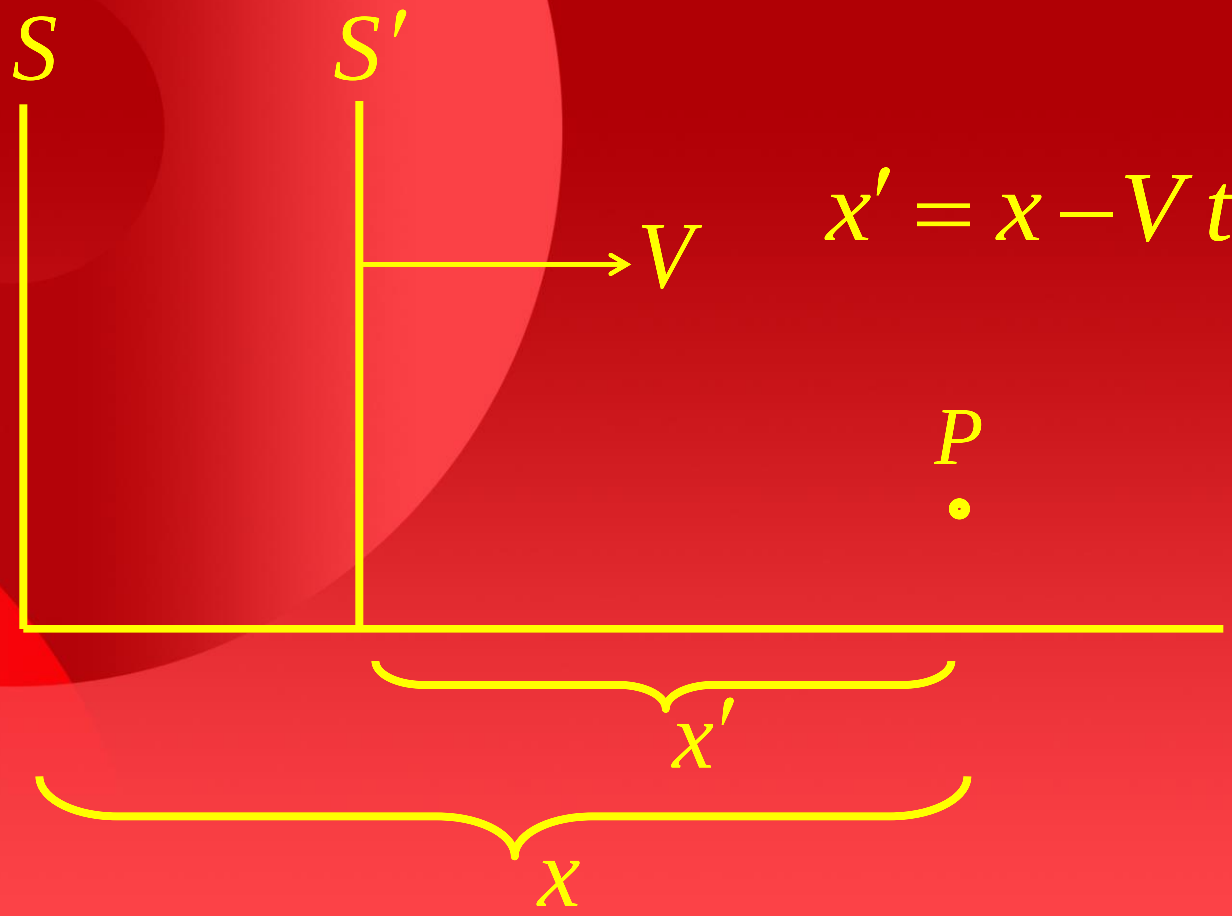
- Objects tend to remain in their initial state
- Force is required to *change* motion

Isaac Newton (1643–1727) wrote *Principia Mathematica* in 1687 and proposed three “laws” of motion.

NEWTONS FIRST LAW

An object will remain at rest or move with constant velocity unless acted upon by a net external force.

FRAMES OF REFERENCE



$$x' = x - Vt$$

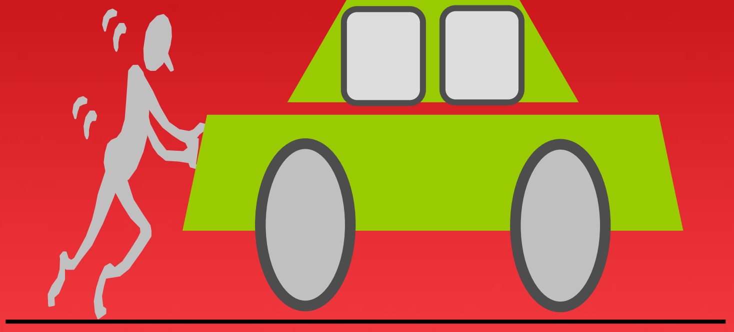
- A non-accelerating frame is called an inertial frame
- Newton's first law holds only in inertial frames
- In an accelerating frame we experience apparent forces.

How much does a body resist?

The resistance depends on mass. The more massive an object, the more resistant it will be to changing its state of motion.

Easy to push

Hard to push



Inertia: resistance to change in motion *i.e.* resistance to acceleration

→ Mass is a measure of inertia

Is mass the same as:

size?	NO
density?	NO
weight ?	NO

more force leads to more acceleration

$$\Rightarrow \quad a \propto F$$

more mass leads to less acceleration

$$\Rightarrow \quad a \propto \frac{1}{m}$$

conclude that: $a \propto \dfrac{F}{m}$

Newton's Second Law

$$F = ma \quad (\text{or } a = F/m)$$

where $F = F_1 + F_2 + F_3 + \cdots$

Definition of mass is: $m = F/a$

But you need an independent way of measuring force!

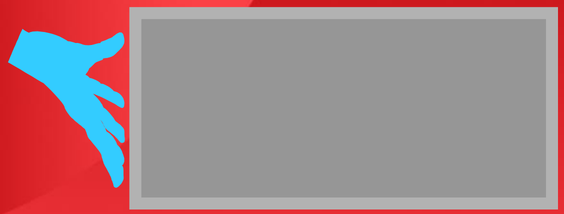
How?

Force is a vector
(magnitude and direction)

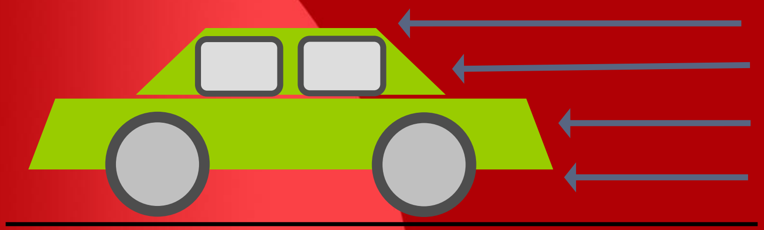
The direction of acceleration is in direction of the force!

Contact forces

objects in contact exert forces on each other

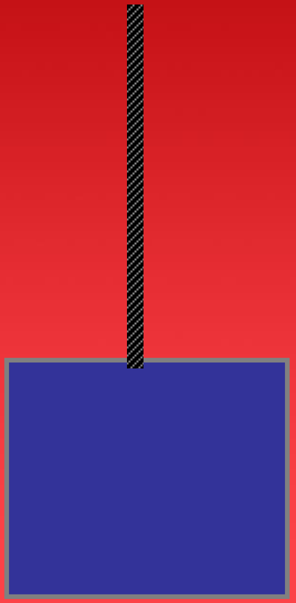


» you push on a box



» air pushes on a car (air resistance)

» tension in a rope



- Force has dimensions of

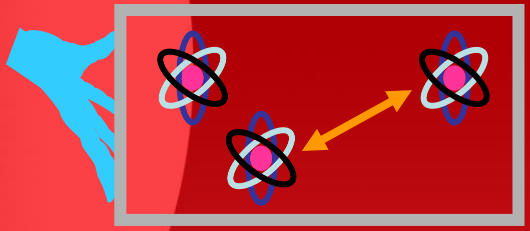
  [mass] $\times$ [acceleration]

  $= M\,L\,T^{-2}$

- In the MKS system the unit of force is the Newton. It has the symbol N where:

  1 N = 1 **kg·m/s^2**

- Only external forces are considered in the Second Law



- Internal force: Forces between atoms in block
- External force: Hand pushing on block

$$F = F_1 + F_2 + F_3 \cdots + F_N$$

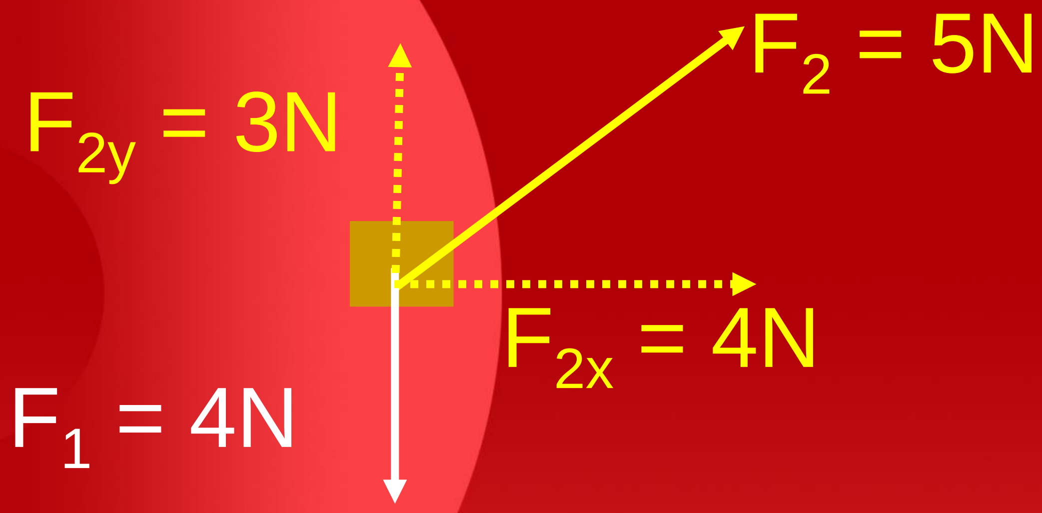
$$= \sum_{i=1}^{N} F_i \quad \text{(Greek "Sigma")}$$

is the TOTAL force.

Forces can added in two ways:

(1) Graphically (arrows)

(2) Algebraically (components)



$$\Sigma F_x = F_{2x} = 4\text{ N}$$

$$\Sigma F_y = F_{2y} - F_1 = -1\text{ N}$$

$$|\Sigma F| = \sqrt{\Sigma F_x{}^2 + \Sigma F_y{}^2}$$
$$= \sqrt{17}\text{ N}$$

Weight

Force of attraction between an object and an astronomical body (Earth, Moon, etc.)

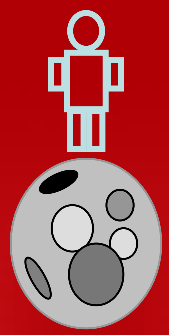
Weight = Force of gravity:

$$F = m\,a$$

$$W = m\,g$$

Weight (like any force) is a vector.

Units: Newtons (N)



Same mass

Different weight

m = 100 kg

W = 160 N

m = 100 kg

W = 980 N

Insert astronaut clip

NEWTONS THIRD LAW

For every action there is an equal and opposite reaction.

Is boxing glove A hitting glove B, or is glove B hitting glove A?

The gloves hit each other

For the boxing gloves:

Action: A pushes on B

Reaction: B pushes on A

Action and Reaction forces:

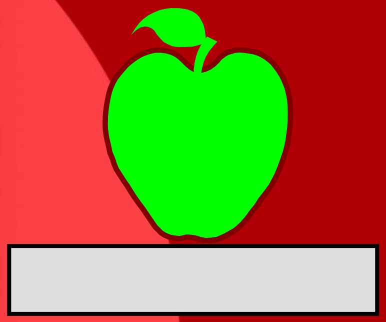
- Are in opposite directions
- Have the same magnitude

$$F_{A \text{ on } B} = -F_{B \text{ on } A}$$

Action and Reaction forces:

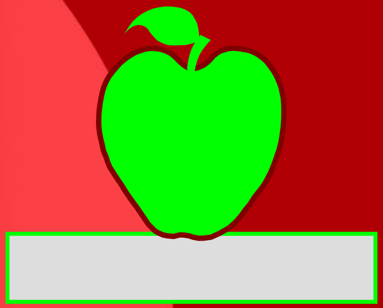
- act on different objects

$$F_{A\ on\ B} = -F_{B\ on\ A}$$



Action: force of the Earth on the apple (gravity)

Reaction: NOT force of the table on the apple BUT force of the apple on the Earth

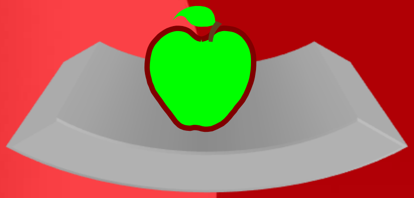


The table *does* exert a force on the apple.

The reaction force is: the apple exerts a force on the table.

How can a table exert a force on an apple?

No apple, no force

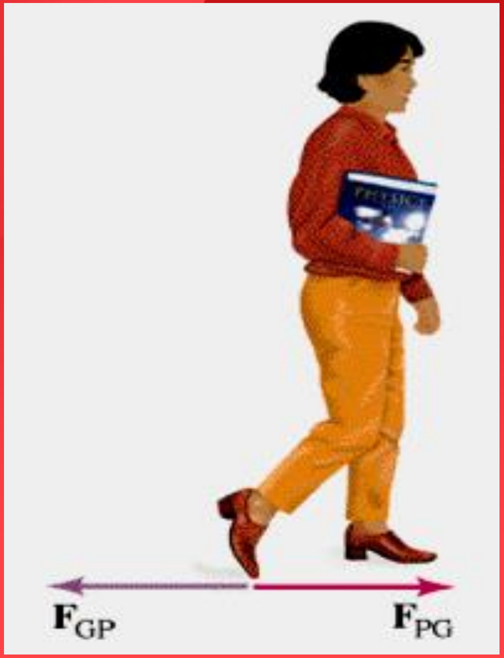


With the apple, the table bends ever so slightly so there is a force upward (like a diving board)

How come this physics student can walk?

You push your foot backwards against the ground -- but you want to walk forwards! Why do you push backwards?

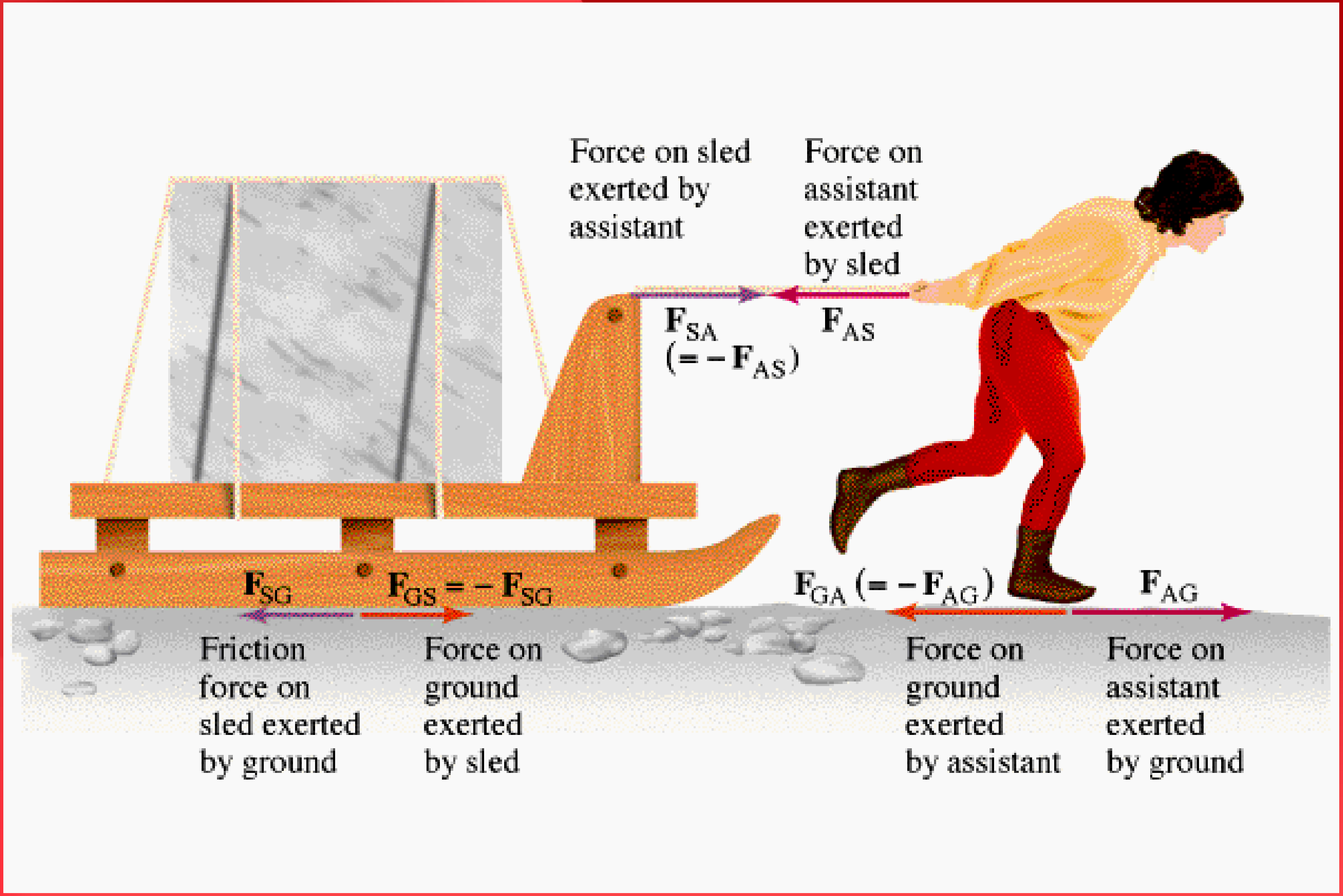
<u>Newton to the rescue</u>! The ground pushes forward on your foot -- this is how you walk!



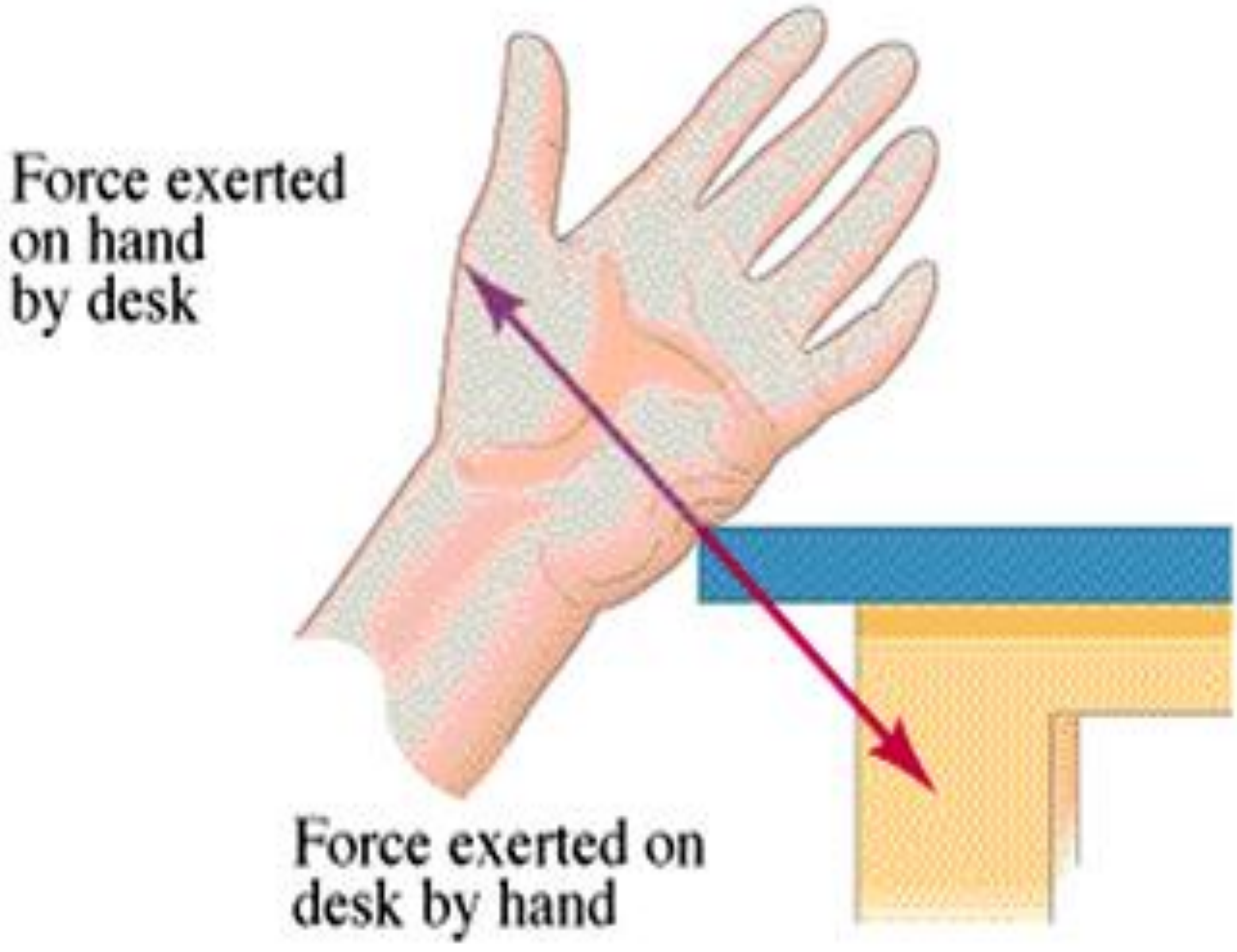
- That's Newton's 3rd law: *you kick something -- it kicks you right back!*

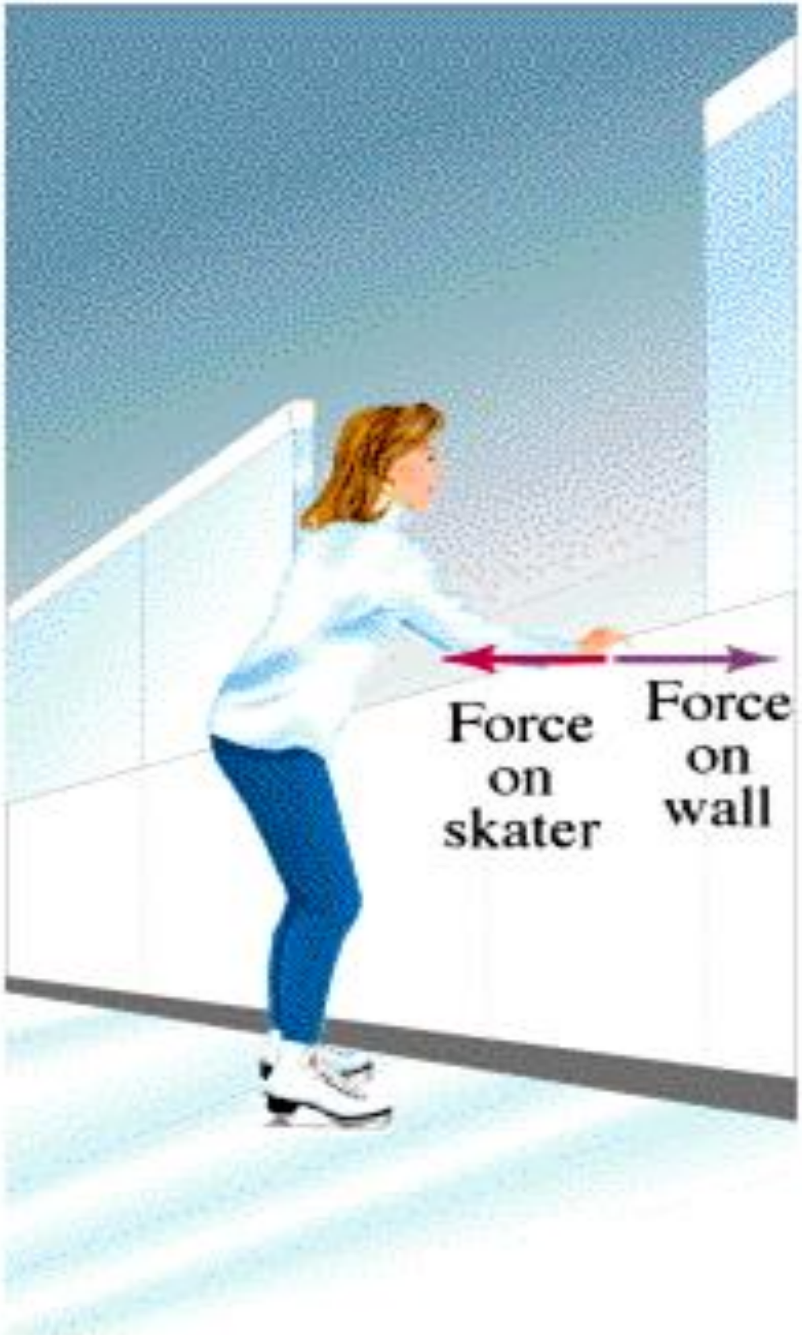
Or:

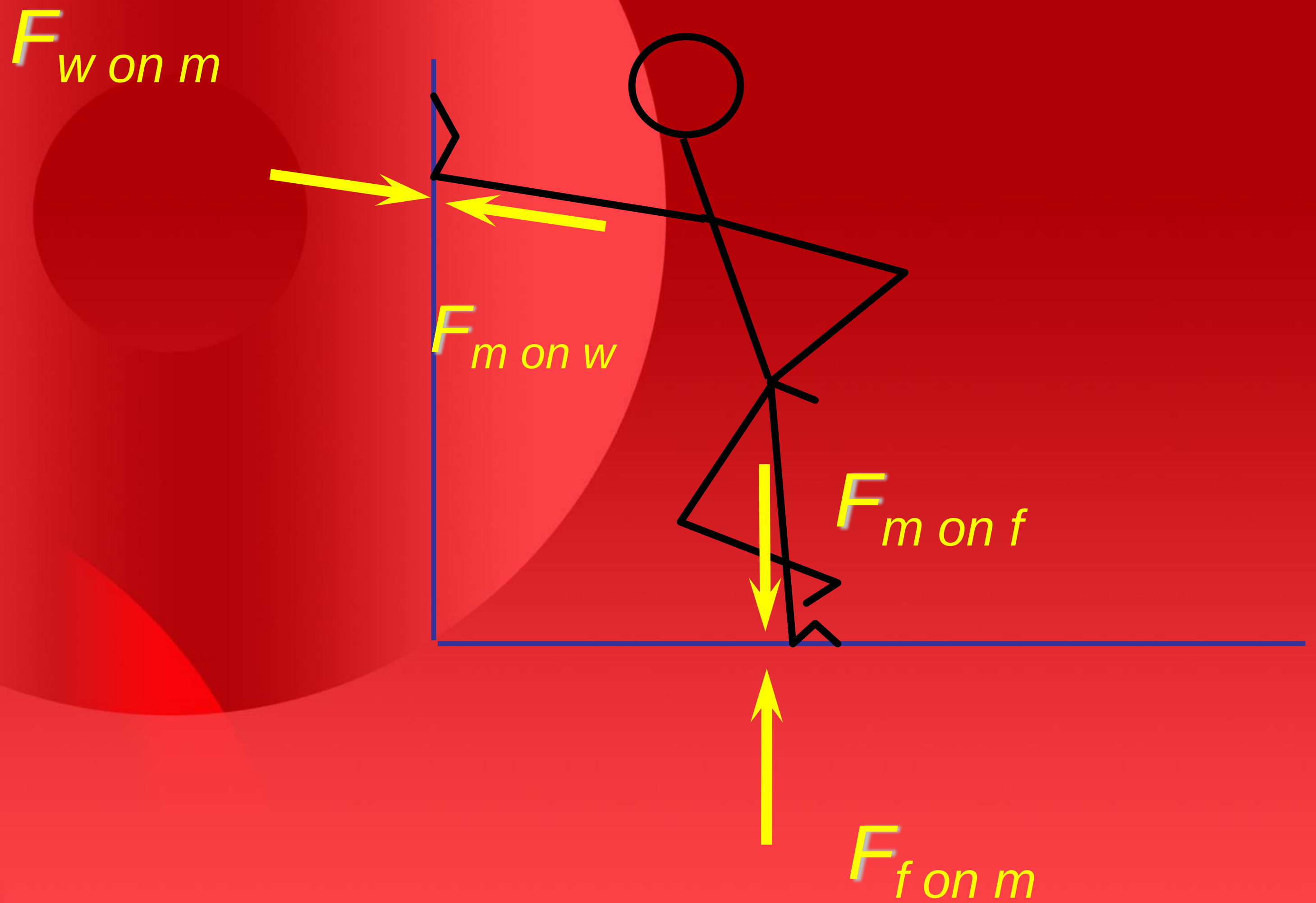
Whenever one object exerts a force on a second, the second exerts an equal and opposite force on the first.



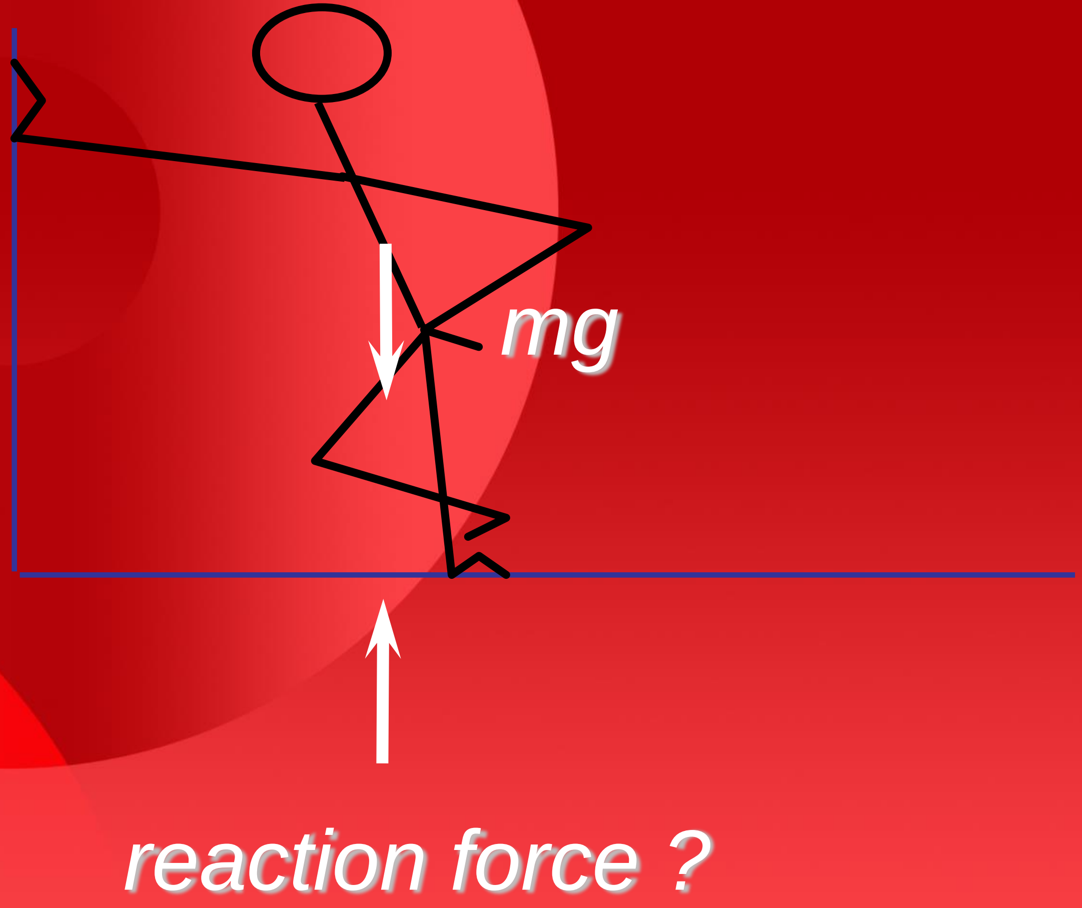
Force on sled exerted by assistant
Force on assistant exerted by sled
$\mathbf{F}_{SA}$ $(= -\mathbf{F}_{AS})$
$\mathbf{F}_{AS}$
$\mathbf{F}_{SG}$
$\mathbf{F}_{GS} = -\mathbf{F}_{SG}$
$\mathbf{F}_{GA}$ $(= -\mathbf{F}_{AG})$
$\mathbf{F}_{AG}$
Friction force on sled exerted by ground
Force on ground exerted by sled
Force on ground exerted by assistant
Force on assistant exerted by ground


Force exerted
on hand
by desk
Force exerted on
desk by hand


Force
on
skater
Force
on
wall



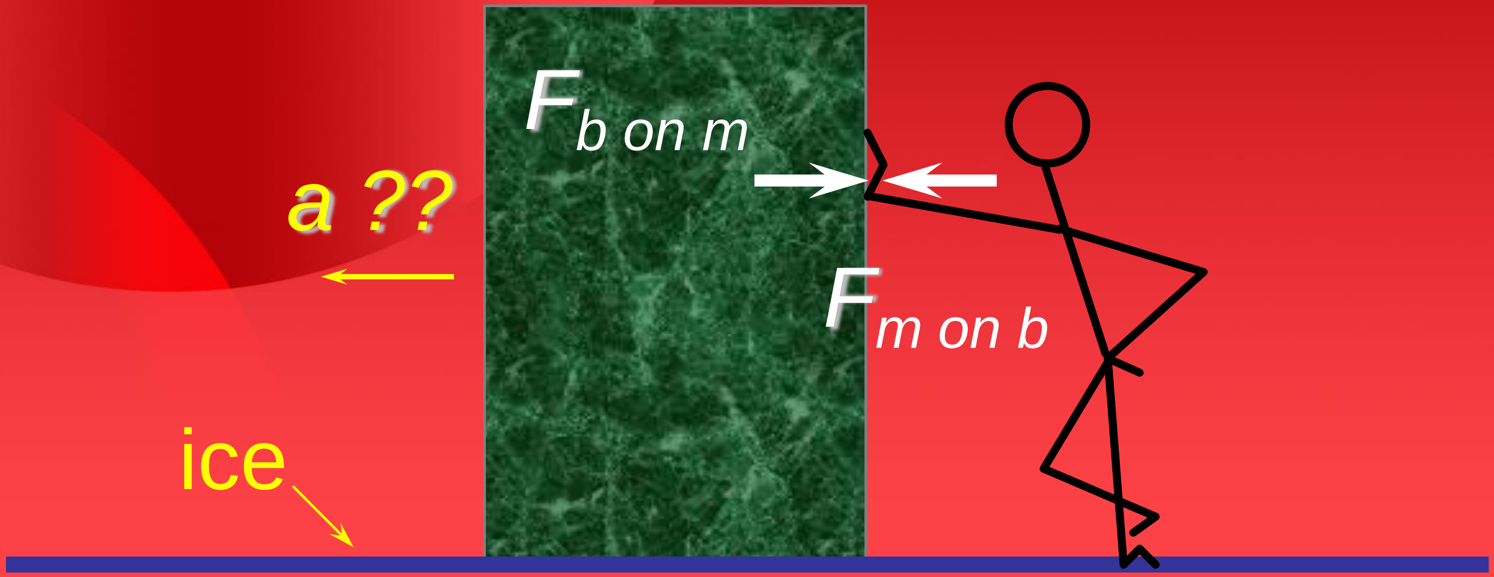
$F_{w\ on\ m}$
$F_{m\ on\ w}$
$F_{m\ on\ f}$
$F_{f\ on\ m}$



mg
reaction force ?

Since $F_{b\ on\ m} = -F_{m\ on\ b}$

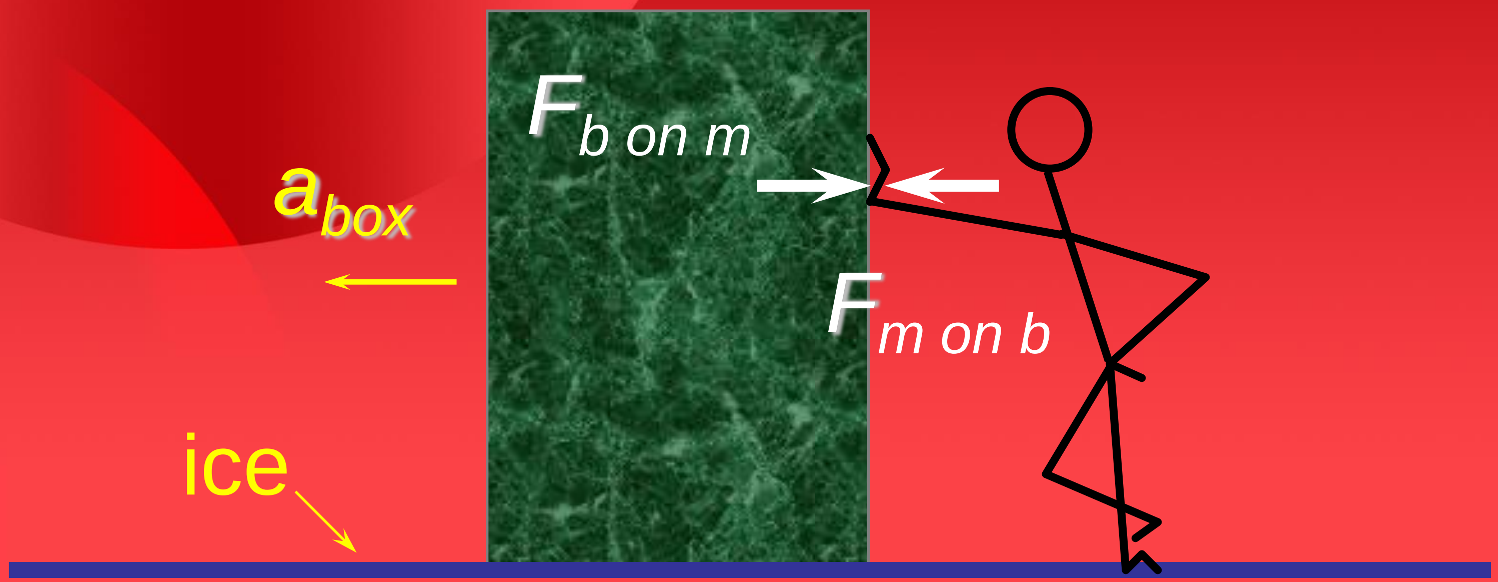
then why isn't $F_{net} = 0$ and $\mathbf{a} = 0$?



Consider *only the box* as the system !

Free Body Diagram: isolate the force on the object !!

$$F_{\text{on box}} = F_{m\ on\ b} = m\, a_{box}$$



CLAIM: If something is moving, there must be a net force on it.

FALSE. A body moving at constant velocity has no net force on it. An accelerating body must have a net force on it.

CLAIM: All equal and opposite forces are action-reaction pairs.

<u>FALSE.</u> The weight of a book sitting on a tabletop and the normal force of the table acting on the book are equal and opposite, but they are not an action-reaction pair!

CLAIM: If there is a force on an object, it must be accelerating.

FALSE. Only a *net* force on the object leads to acceleration.