Dynamics

Objective: Learning about the affect of forces on motion – "Dynamics"

- Kinematics –'How'
- Dynamics –'Why' (Forces)

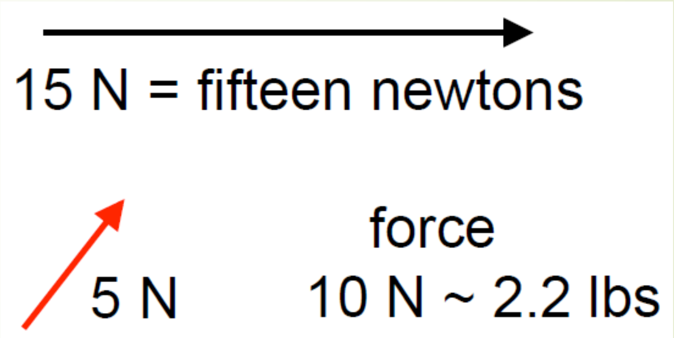
Key concepts:

- Mass and inertia
- Force
- Free-body diagram
- Newton's laws of motion
- Newton's laws of gravitation

Concept of Force

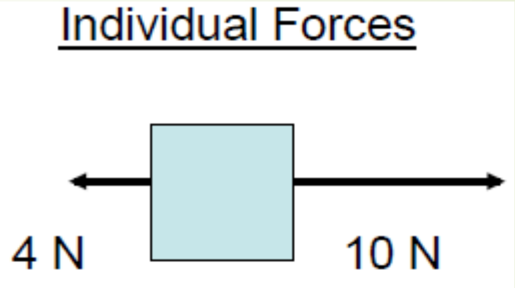
A ***force*** is a push or a pull acting on an object. A force is a vector!

- ***Contact forces*** arise from physical contact, and are due to a stretch or compression at the point of contact.
- ***Action-at-a-distance forces*** do not require contact and include gravity and forces due to charged particles

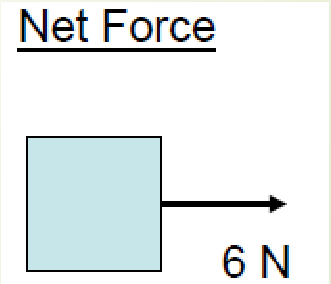


- Arrow are used to represent force vector is proportional to the magnitude of the force.
- SI Unit of force is *Newton (N).*

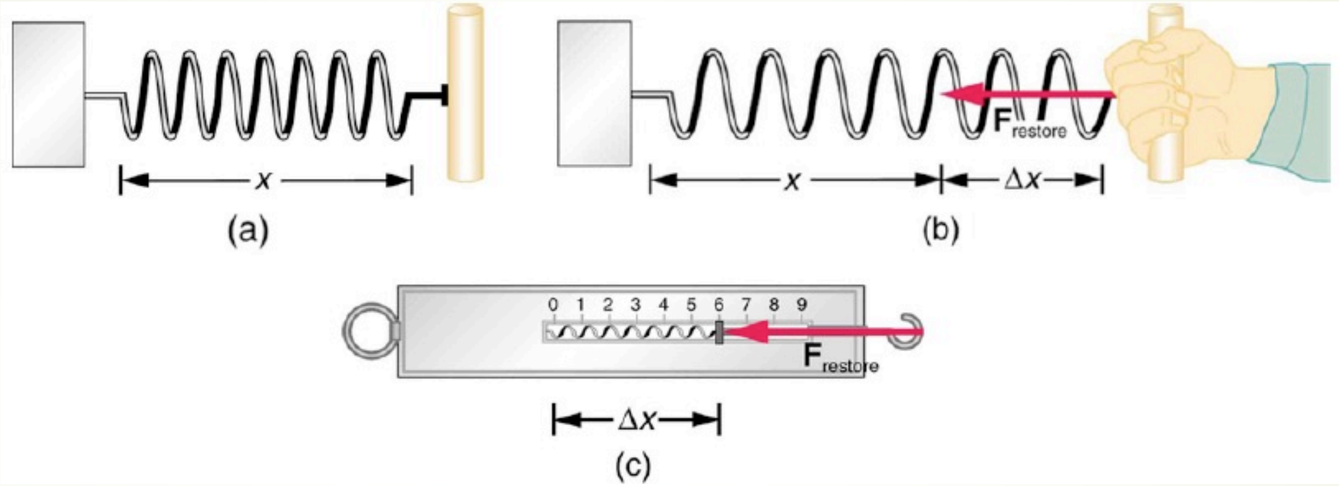
$$1\ \text{N} = 1\ \text{kg} \cdot \text{m/s}^2$$



- Often, more than one force acts on an object. The ***net force*** is the vector sum of all of the forces acting on an object. $F_{net} = \sum F_i$



How to measure Force



- Spring scale: Larger force = Larger stretch (a.k.a. displacement (Δx)). On a budget? Can use a rubber band!

- If you know k_{spring} and & **g**, Equilibrium: Spring force balances gravity force

$$\boldsymbol{F}_{spring} = k_{spring}\,\Delta\boldsymbol{x} = m\boldsymbol{g} = \boldsymbol{F}_{gravity}$$

$m = (k_{spring}\,\Delta\boldsymbol{x})/\boldsymbol{g}$…… $\Delta\boldsymbol{x}$ gives us the mass *m!*

Newton's First Law of motion
The Law of Inertia

- Newton's 1st Law: A body at rest remains at rest, or, if in motion, remains in motion at a constant velocity, ***unless*** acted upon by a net external force, $\boldsymbol{F_{net}}$.

So,

- Newton's 1st Law: So if the $\boldsymbol{F_{net}}$ acting on a object is NOT ZERO, the velocity (magnitude, or direction, or both) must change… Newton's 1st law is just a special case of $\boldsymbol{F_{net}} = m\boldsymbol{a}$ (Newton's 2nd Law), where $\boldsymbol{F_{net}} = 0$.

- Newton's 1st law is often called the law of inertia.

- *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.

Mass and Inertia

- Mass is the amount of material (number and kind of atoms) in an object.

- Mass is a also measure of inertia because, mass resists acceleration. For a given force, acceleration produced is <u>inversely</u> proportional to mass,

$$\mathbf{a} \propto \frac{1}{m}$$

- SI Units for mass is Kilogram (kg).

- **Mass is *NOT* weight!**
  A 1 kg mass has a weight of 9.8 N (***W*= *mg***, where g = 9.8 m/s^2)

Newton's Second Law of motion
The Law of Inertia

- Newton's 2nd Law: When a ***net external*** force acts on an object of mass *m*, the acceleration **a** that results is directly proportional to the net force and has a magnitude that is inversely proportional to the mass.

$$\boldsymbol{a} = \frac{\boldsymbol{F_{net}}}{m} \quad \text{or} \quad \boldsymbol{F_{net}} = m\boldsymbol{a}$$

- The direction of the acceleration, $\boldsymbol{a}$ is the same as the direction of the net force, $\boldsymbol{F_{net}}$.

- The 2nd law is a more general statement than Newtons' 1st law of motion, which it encompasses. Since, $\boldsymbol{F_{net}} = m\boldsymbol{a}$, and if $\boldsymbol{F_{net}} = 0$, then $\boldsymbol{a} = \boldsymbol{0}$; i.e. constant or uniform motion.

Newton's Second Law of motion
The Law of Inertia

Concept questions:

- Suppose you push with the same force on two wagons. What is the acceleration of wagon B ***compared to*** that of wagon A? Justify your answer.

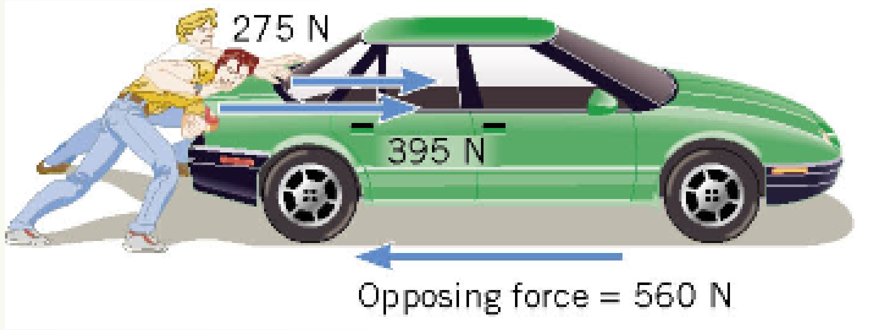
  Wagon A has a mass of 10 kg
  and wagon B has a mass of 40 kg.

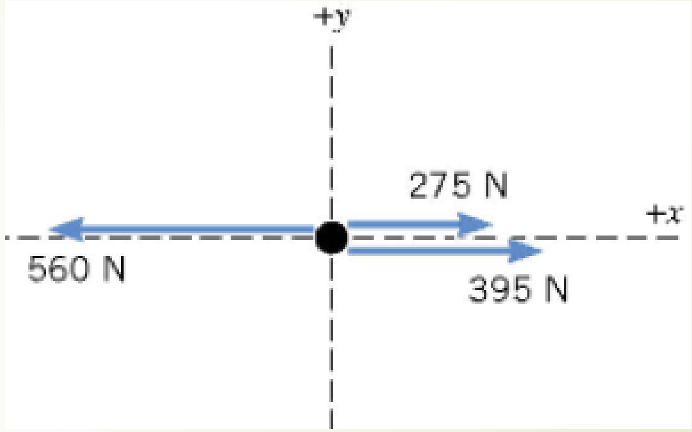
- Does the mass of an object affect the force of gravity on it?

- Does the mass of an object affect the rate of acceleration caused by gravity?

Free-body diagram

- A ***free-body-diagram*** is a diagram that represents the object and the forces that act on it.





The net force in this case is: $\boldsymbol{F_{net}} = 275\ N + 395\ N - 560\ N = +110\ N$

And $\boldsymbol{F_{net}}$ is directed along the $+\boldsymbol{x}$ axis.

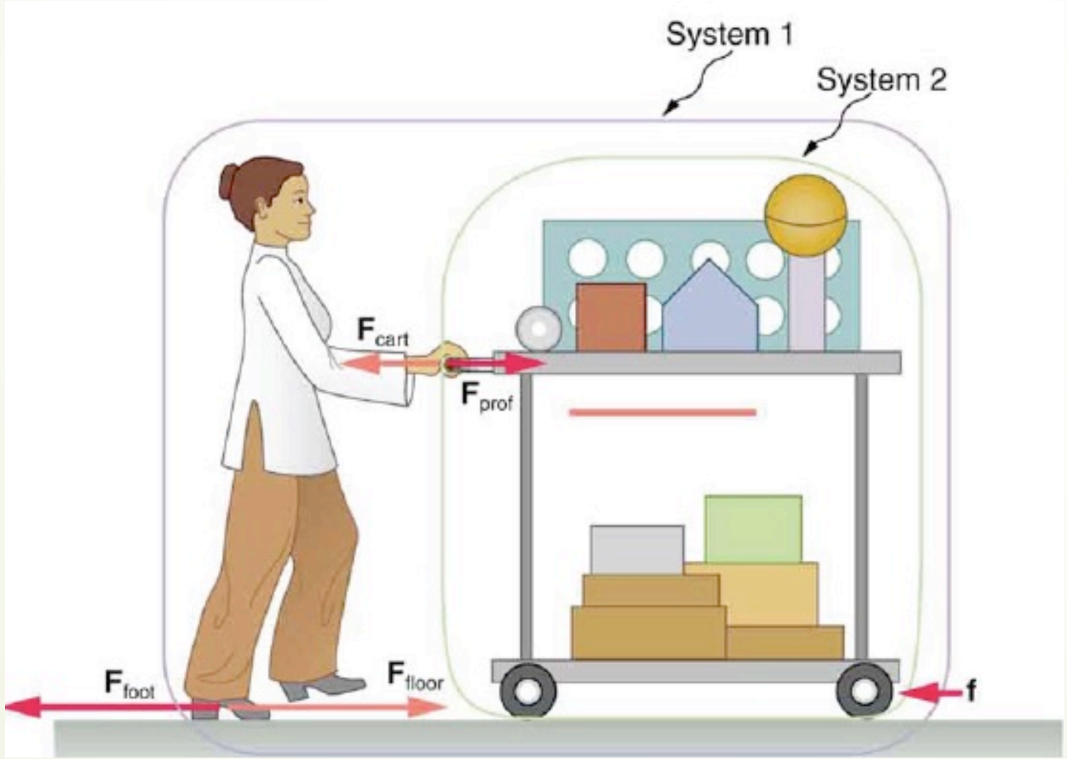
If the mass of the car is 2200 kg then, by Newton's second law, the acceleration is: $\boldsymbol{a} = \frac{\boldsymbol{F_{net}}}{m} = \frac{+\,110\ N}{2200\ kg} = +0.05\ \text{m}/s^2$

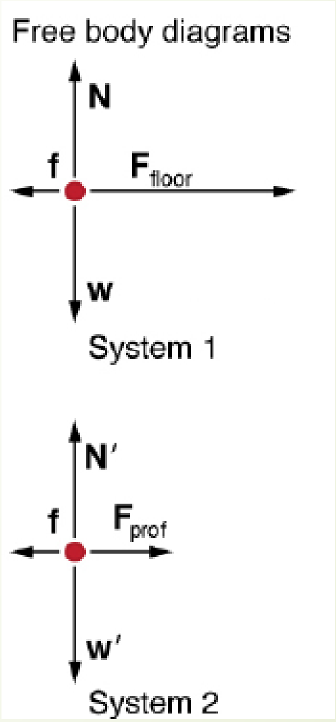
**Connecting dynamics to kinematics: If starting from rest, how far the car will go after 10s of pushing! *(Answer: 2.5 m)*

System of interest

Choosing the correct system:

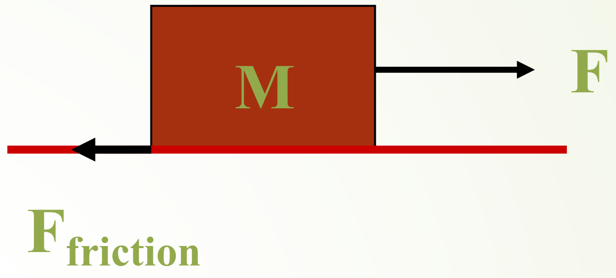
- The system of interest is the stuff we care about
- Need to define "the system" before solving problem
- It's possible to have systems within a system



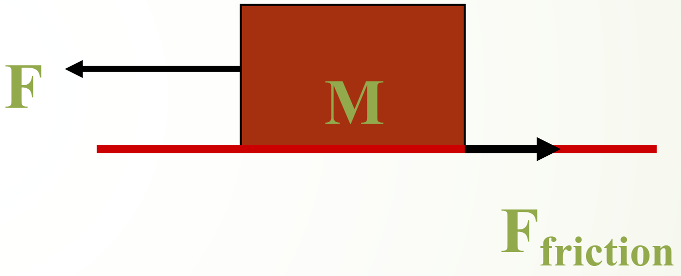


Frictional forces

Friction affects Motion



Friction always act
to oppose motion



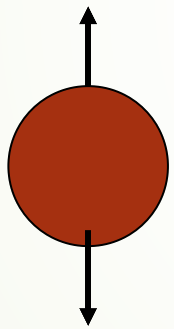
To Move M → Pull force F must be greater than $F_{friction}$

To maintain motion → F need to be only equal to $F_{friction}$

i.e Net force is zero → Constant velocity

Frictional forces and Drag

Terminal velocity **:When air drag is not negligible the acceleration of fall is less than g**



Downward Net Force = weight – air drag

When falling high distances the air drag builds up to equal weight

Net force = 0

Object reaches its <u>terminal velocity</u>

Frictional forces and Drag

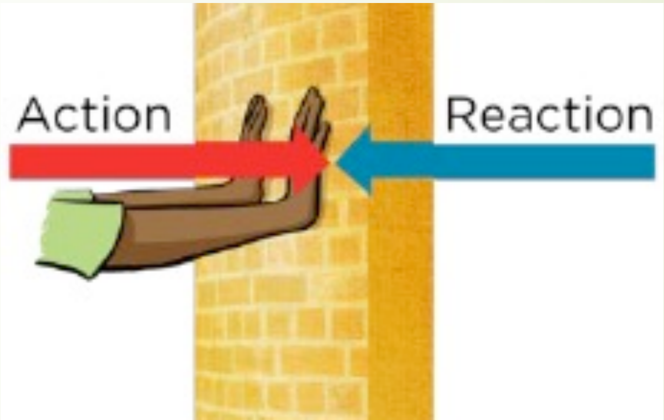
Force	Frictional Force	Net Force	Acceleration
50 N	0 N		
	0 N		5 m/s^2
60 N	30 N		
60 N	60 N		

Use F= m*a* with m = 15 kg

Newton's Third Law of motion

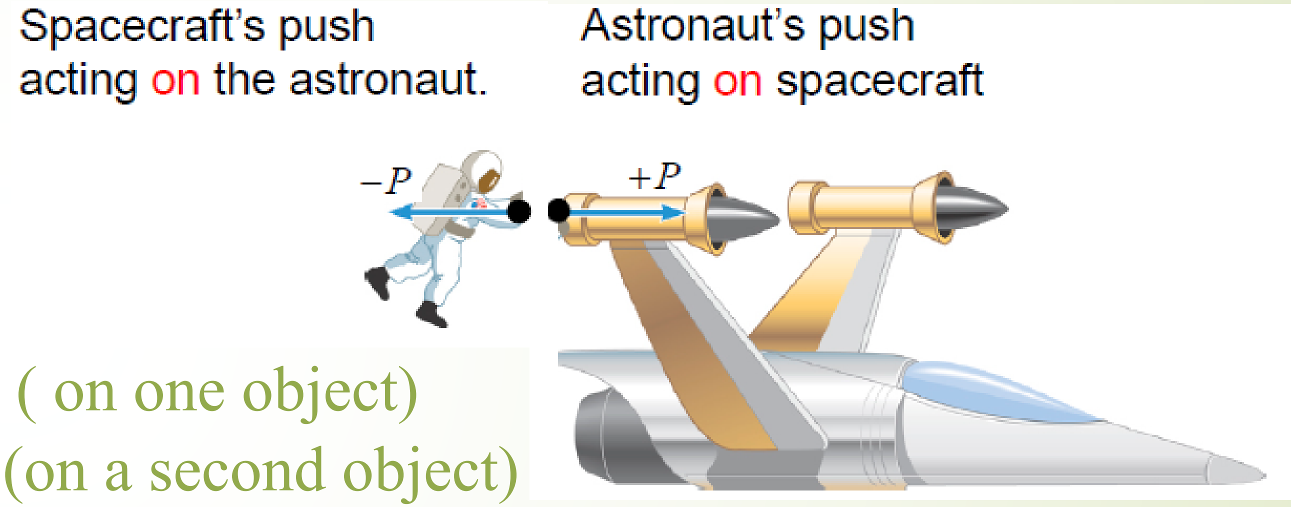
- Newton's 3rd Law: Whenever one body exerts a force on a second body, the second body exerts an oppositely directed force of equal magnitude on the first body.
- Forces always come in action-reaction pairs!
- Since the action force & reaction force are acting on different objects, you will never have both the action force & its reaction force on the same free-body diagram.

***Newton's 3st law can appear to be violated if you can't see the resulting movement of a massive object.



Newton's Third Law of motion

Example: An Astronaut "pushes" on the spacecraft and Spacecraft "responds" by pushing on the Astronaut. Suppose that the magnitude of the force, 30 N. If the mass of the spacecraft is 10,000 kg and the mass of the astronaut is 90 kg, what are the accelerations?



Solution:

On the Spacecraft $\Sigma\, \boldsymbol{F}_{x,S} = +P$. (on one object)

On the Astronaut $\Sigma\, \boldsymbol{F}_{A,S} = -P$. (on a second object)

Spacecraft acceleration: $\boldsymbol{a} = \frac{+P}{m} = \frac{+30\ N}{10000kg} = +0.003\ \text{m}/s^2$ or $3\ \text{mm}/s^2$

Astronaut acceleration: $\boldsymbol{a} = \frac{-P}{m} = \frac{+30\ N}{90\ kg} = +0.3\ \text{m}/s^2$ $(100\ times\ larger\ than\ the\ spacecraft)$

Newton's Law of Gravitation

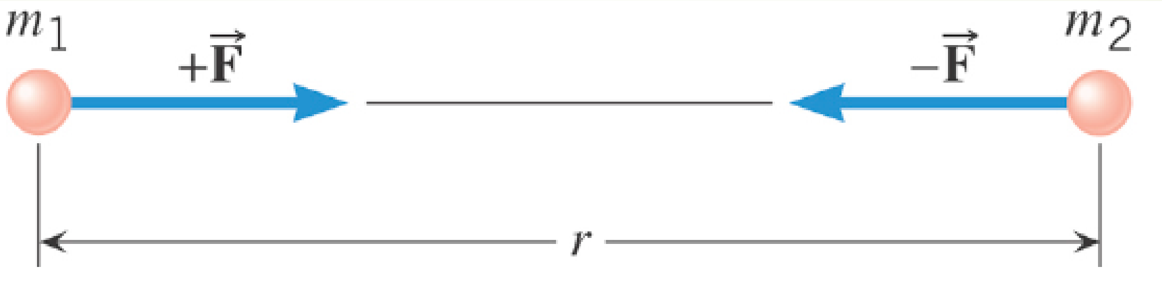
For two particles that have masses m_1 and m_2 and are separated by a distance *r*, the force has a magnitude given by

$$F = \frac{Gm_1 m_2}{r^2} \quad ; G = 6.673\, x\, 10^{-11}\ N.\frac{m^2}{kg^2}$$

$$\Downarrow$$

$$mg = \frac{GmM_E}{R_E^2} \quad or, \quad g = \frac{GM_E}{R_E^2} = 9.81\ \text{m}/s^2$$

The same magnitude of force acts on each mass, no matter what the values of the masses.



Newton's Law of Gravitation

Relation Between Mass and Weight

- Gravity acts between objects that have mass.
- The gravitational force is always attractive along a line between objects.
- Gravity is always pulling you down towards Earth. Use $\mathbf{g} = \mathbf{9.8\ m/s^2}$ then put sign on force.
- Weight is defined as:

$$W = F_{gravity} = mg$$
$$W\ (in\ N) = m(in\ kg)\ x\ 9.8\ \mathrm{m/s^2}$$

- Therefore, weight depends on where you are Mass of an (unchanged) object is constant.