First few slides are additional review problems from Chs. 1 and 2

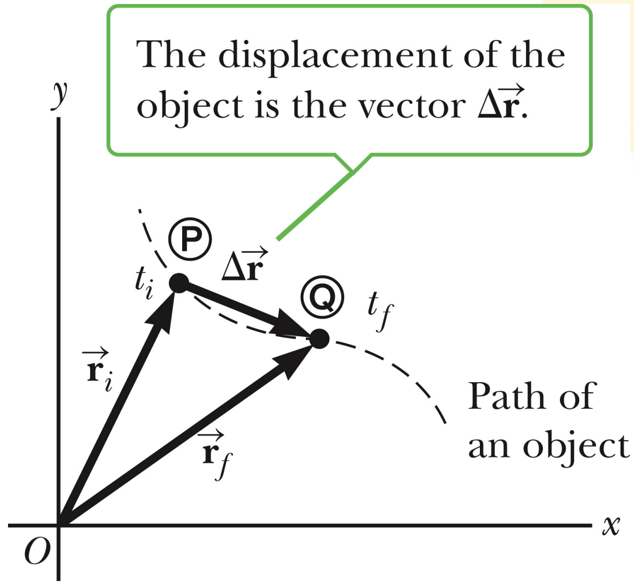
Average Speed

A person travels by car from one city to another with different constant speeds between pairs of cities. She drives for 35 min at 75 km/h, 12 min at 50 km/h, and 30 min at 50 km/h and spends 25 min eating lunch and buying gas.

(a) Determine the average speed for the trip.

(b) Determine the distance between the initial and final cities along the route.

Displacement, Velocity, Acceleration in 2d



In 2d problems, the position of an object is determined by its position vector.

If an object moves from an initial to a final position, the displacement will be a vector, too (unit: m):

$$\Delta\vec{\mathbf{r}} = \vec{\mathbf{r}}_f - \vec{\mathbf{r}}_i$$

Velocity (unit: m/s) and acceleration (unit: m/s^2) are also vectors:

$$\vec{\mathbf{v}}_{av} \equiv \frac{\Delta\vec{\mathbf{r}}}{\Delta t} \qquad \vec{\mathbf{a}}_{av} = \frac{\Delta\vec{\mathbf{v}}}{\Delta t}$$

An object can accelerate in different ways:

1. The magnitude of the velocity changes with time (the same as 1d problems)
2. The direction of the velocity may change with time, e.g. circular motion, at constant speed.
3. Magnitude and direction change in parallel.

Conversion of units

Every physical quantity has a unit. Make sure not to forget these in the exam!

Typical problem: Convert an acceleration of 25 m/s^2 to km/min^2.

Scientific notation

What would be the most accurate method for writing the following numbers in scientific notation:

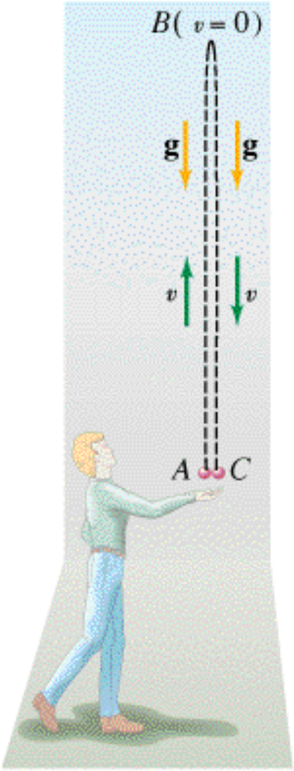
13,000

560,000

0.0003

0.01

Free Fall problem



A person drops a ball from a height of 3 m above the surface of the earth.

How long will it take the ball to hit the ground?

Example problem: 1d motion with constant acceleration

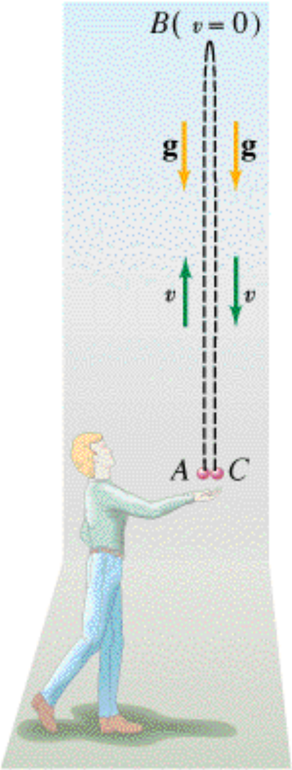
A car starts from rest and accelerates at 10 m/s^2 in a straight line on a level street for a distance of 100 m.

What is the velocity of the car at the end of this distance?

Free Fall example problem

A baseball is thrown up in the air at an initial velocity of 22.0 m/s.

(a) How high up does it go?
(b) How long is it in the air if you catch it at the same height you initially let go of the ball?



Some helpful equations:

$$v(t) = v_0 - gt$$

$$y(t) = y_0 + v_0 t - \frac{1}{2} g t^2$$

Example problem: Projectile motion

A student stands at the edge of a cliff and throws a stone horizontally over the edge with a speed of 18 m/s. The cliff is 50 m above a flat, horizontal beach.

(a) What are the coordinates of the initial position of the stone?

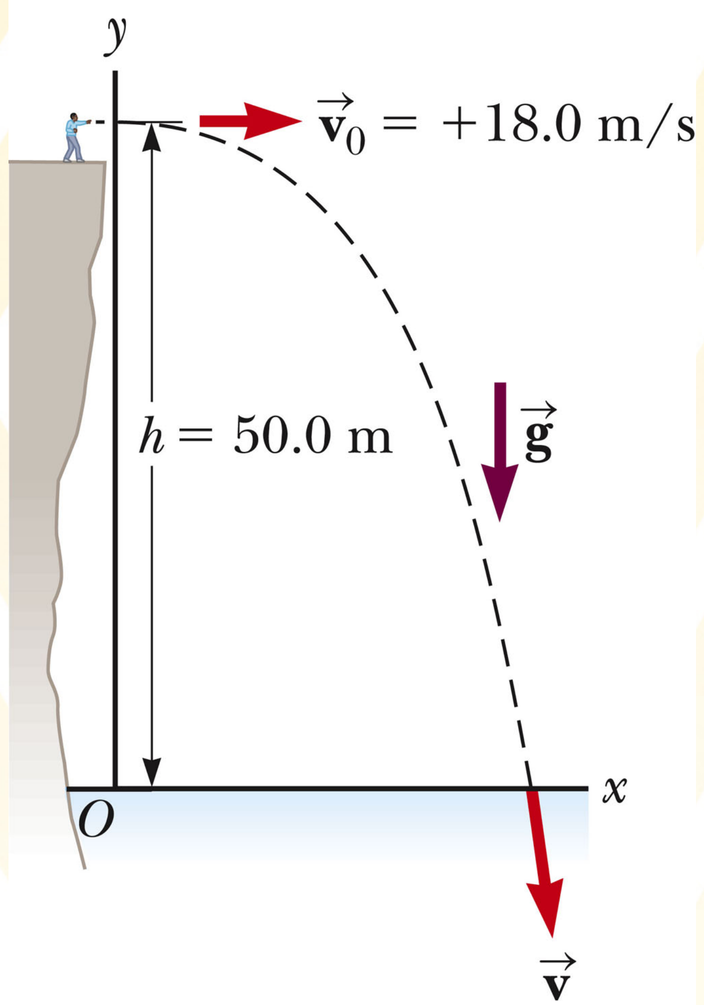
(b) What are the components of the initial velocity?

(c) Write the equations for the x- and y-components of the velocity of the stone with time.

(d) Write the equations for the position of the stone with time.

(e) When does the stone strike the beach?

(f) With what speed and angle does the stone land?



Today's lecture

•

The laws of motion:

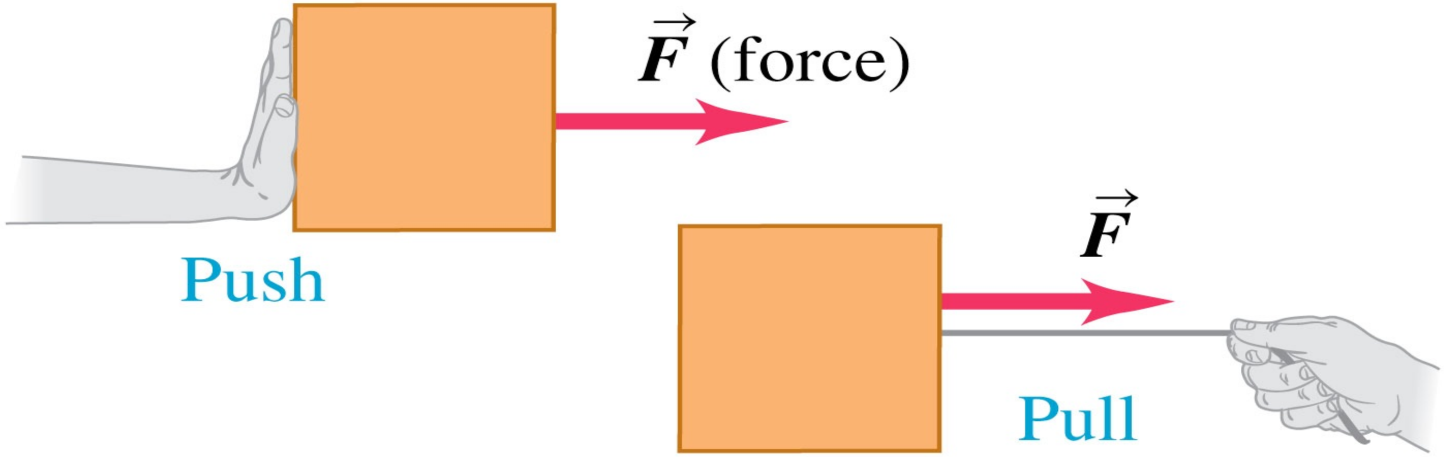
- What is a force?
- Newton's 1st law
- Newton's 2nd law

Motivation

- We have described motion in 1D and 2D, but what causes motion?
- In the late 1600s, Sir Isaac Newton formulated three laws governing moving objects, which we call **Newton's laws of motion**, after complex deduction from experimental results.
- The laws are simply stated, but incredibly profound.

What is a force?

- A force is a push or a pull.
- A force is an interaction between two objects or between an object and its environment.
- A force is a vector quantity, with magnitude and direction.



What is a force? - Newton's 2nd law

The acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass.

$$\boxed{\vec{F} = m\vec{a} = m\frac{\Delta\vec{v}}{\Delta t}}$$

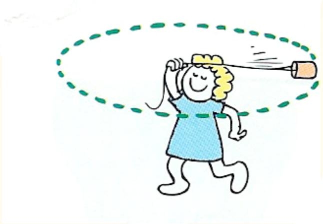
Unit: 1 N = 1 kg m/s^2

- This is one of the most important equations in physics.
- It means that every force on an object results in an acceleration of the object, i.e. a change of its velocity.

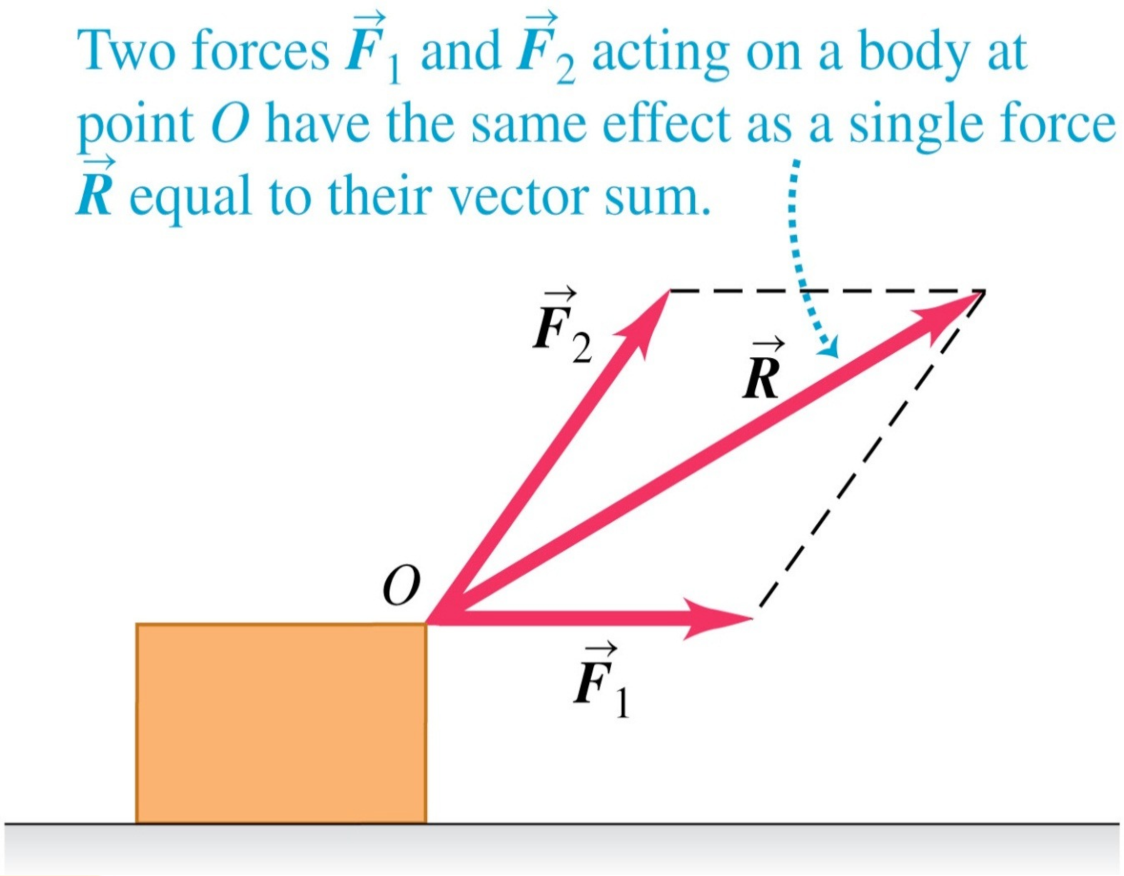
Note 1: There can be multiple forces acting on one object, that compensate each other. Then, there is no acceleration.

$$\sum \vec{F} = m\vec{a}$$

Note 2: An acceleration does not have to cause a change of the velocity's magnitude, but could change its direction only (circular motion is an accelerated motion).



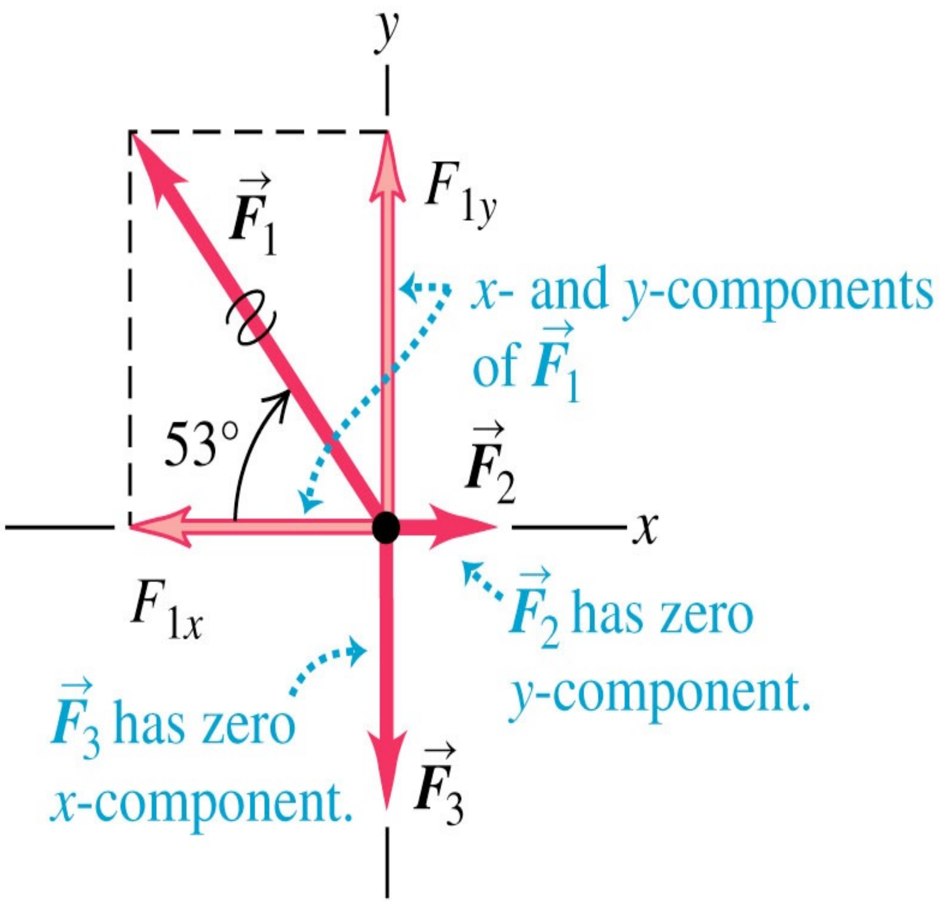
Superposition of forces



- Forces are vectors and must be added using vector addition.
- This can be done graphically (parallelogram) or algebraically.
- The vector sum of all forces acting on an object is called the resultant force or the net force.

$$\vec{R} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \cdots = \sum \vec{F}$$

Example: Adding 3 Forces



$F_1 = 250$ N, $\theta_1 = 127°$

$F_2 = 50$ N, $\theta_2 = 0°$

$F_3 = 120$ N, $\theta_3 = 270°$

$R_x = F_{1x} + F_{2x} + F_{3x}$

$R_y = F_{1y} + F_{2y} + F_{3y}$

Newton's first law

…is actually a special case of Newton's second law. If no force acts on an object or all applied forces compensate:

$$\sum \vec{F} = m\vec{a} = 0 \rightarrow \vec{a} = \frac{\Delta\vec{v}}{\Delta t} = 0$$

If there is no effective force, the object's velocity does not change.

An object moves with a velocity that is constant in magnitude and direction unless a non-zero net force acts on it.

Let's look at some consequences of Newton's first law…..

Newton’s first law

With no outside forces,
this object will
never move

With no outside forces,
this object will
never stop

Consequences of Newton's first law

When you ride a car, you and the car are moving at the same speed.

If you do not use the seat belts and the car breaks, a force will act on the car to decelerate it, but it will not act on you.

Thus, you continue to move at the original speed according to Newton's 1st law.

In space there is no friction and (except weak gravity) no forces.

Thus, once accelerated in one direction an object will continue moving in this direction forever.

Inertia, mass, and weight

Inertia is the tendency of an object to continue in its original state of motion.

Mass is a measure of the object's resistance to changes in its motion due to a force.

$$\vec{F} = m\vec{a} = m\frac{\Delta\vec{v}}{\Delta t}$$

The higher the mass, the smaller the acceleration for a given force.

Weight is the magnitude of the gravitational force acting on an object of mass, m.

$$w = mg$$

The weight depends on the gravitational constant, g, that is different for different planets.

Example: Application of Newton's Laws

An 80 kg movie stuntman jumps from a window of a building situated 30 m above a catching net. Assuming air resistance exerts a 100-N force on the stuntman as he falls, determine his velocity just before he hits the net.

Summary

- A force is the product of an object's mass and acceleration. Forces are the reason why objects change their velocity. Newton's second law:

$$\boxed{\vec{F} = m\vec{a} = m\frac{\Delta\vec{v}}{\Delta t}}$$

Unit: 1 N = 1 kg m/s^2

- Forces are vector quantities, since they have magnitude and direction.

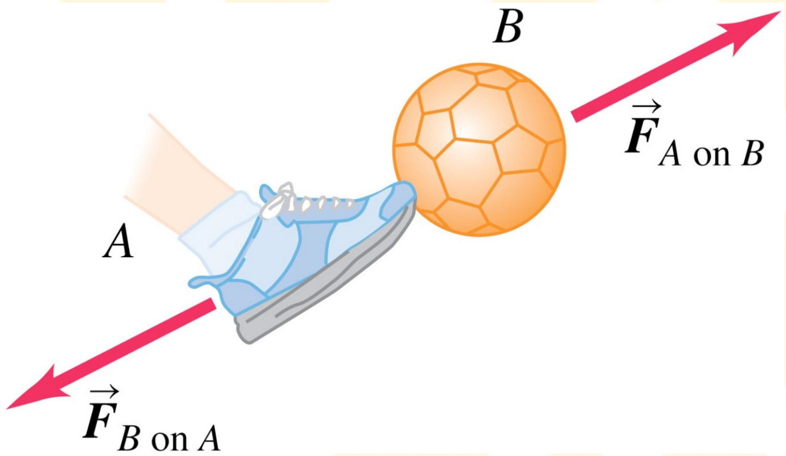
- An effective force changes an object's velocity (magnitude and/or direction). A circular motion is an accelerated motion.

- Newton's first law is a special case of Newton's second law (F = 0):

An object moves with a velocity that is constant in magnitude and direction unless a non-zero net force acts on it.

- *Inertia* is the tendency of an object to continue in its original state of motion.
  Mass is a measure of the object's resistance to changes in its motion due to a force.
  Weight is the magnitude of the gravitational force acting on an object of mass, m: $w = mg$

Newton’s 3rd law



$$\boxed{\text{Action} = - \text{Reaction}}$$

If object A exerts a force on object B (Action Force), object B will always exert a force on object A that is equal in magnitude, but opposite in direction (Reaction Force)

Important: - Forces in nature always exist in pairs (Action, Reaction).
- The action and reaction forces always act on different objects.

Is Newton's third law correct?

Let's say $F = 20$ N, $m_A = 5$ kg, and $m_B = 15$ kg. What is the acceleration of both blocks?

Newton's 2nd law: $F = 20\ \text{N} = (m_A + m_B)\, a = 20\ \text{kg} \cdot a \quad \rightarrow \quad a = 1\ \text{m/s}^2$ (for both blocks!)

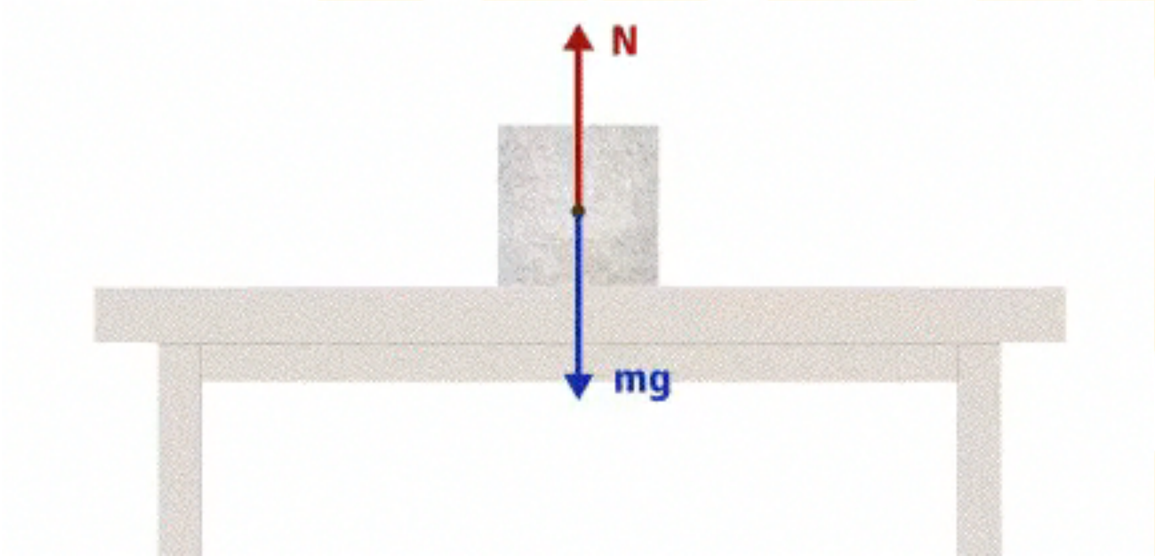
Now, let's look at block B only. What must be the force of block A on B so that $a = 1\ \text{m/s}^2$?

$F_{AB} = m_B \cdot 1\ \text{m/s}^2 = 15\ \text{kg} \cdot 1\ \text{m/s}^2 = 15\ \text{N}$

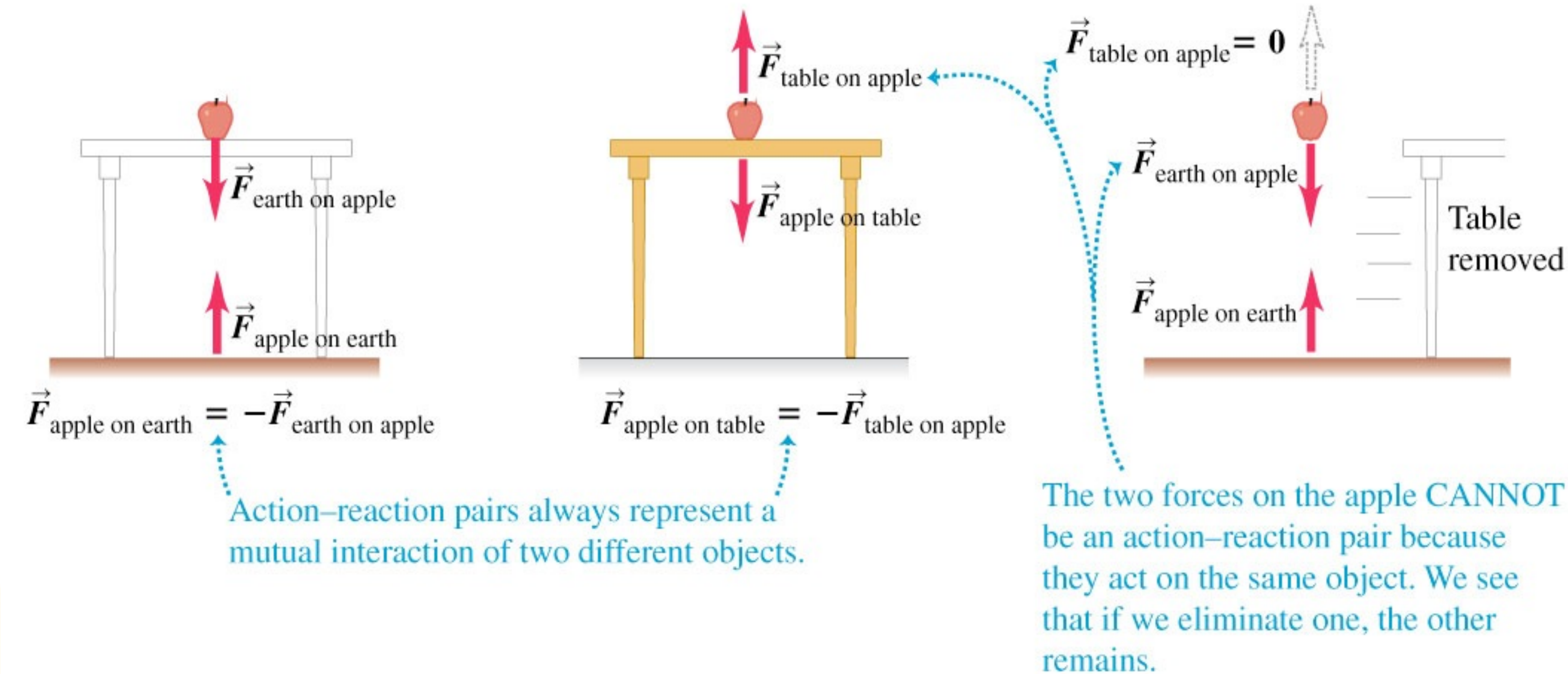
Now, let's look at block A only. What must be the force of block B on A so that $a = 1\ \text{m/s}^2$?

$F_A = F + F_{BA} \qquad F_A = m_A \cdot 1\ \text{m/s}^2 = 5\ \text{kg} \cdot 1\ \text{m/s}^2 = 5\ \text{N} \quad \rightarrow \quad \boxed{F_{BA} = -15\ \text{N} = -F_{AB}}$

Normal forces

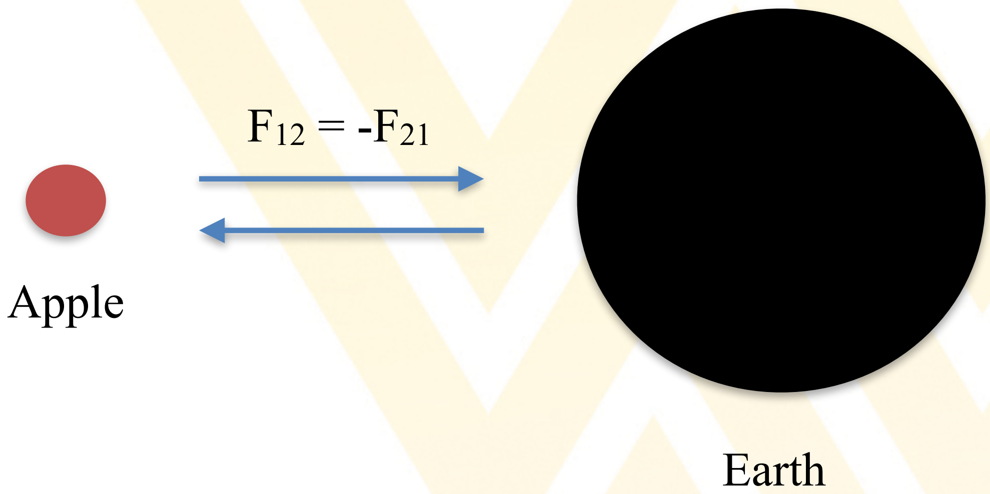


Applying Newton's third law



The force exerted by the table on the apple is called a normal force, since it acts perpendicular to the surface of the table.

Does the earth move towards the apple?



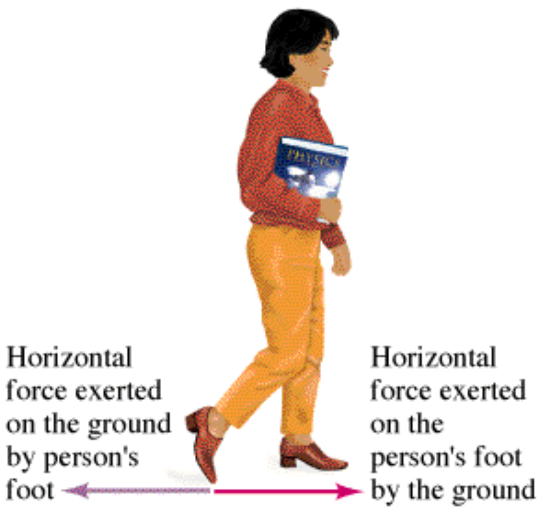
The force exerted by the apple on earth has the same magnitude as the force exerted by earth on the apple. However, the mass of the apple, m_a, is much smaller than the mass of earth, m_e.

$F_{12} = m_a \cdot a_a \quad \rightarrow \quad a_a = F_{12}/m_a$ is high, since m_a is small.

$F_{21} = -F_{12} = m_e \cdot a_e \quad \rightarrow \quad a_e = -F_{12}/m_e$ is small, since m_e is high.

$s = 1/2\ a\ t^2 \quad \rightarrow$ During a given time, t, the apple moves a longer distance than the earth. The latter is so small that it cannot be measured.

Walking - a consequence of Newton's 3rd law



When we walk, we exert a force, F_{GP}, on the ground. This forces pushes earth, but not ourselves!

Due to Newton's 3rd law, earth exerts a force, $F_{PG} = -F_{GP}$, on us. This force pushes us forward!