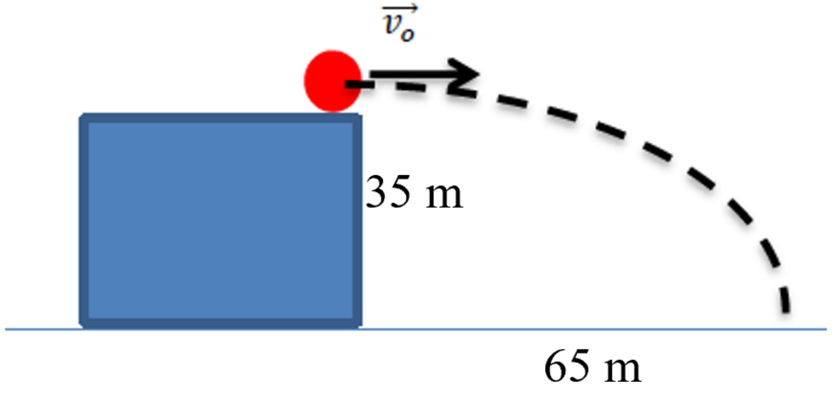
Example:

A ball is thrown off a **35 m** high cliff with an initial horizontal velocity of $\boldsymbol{v_0}$ **m/s**. The ball strikes the ground at a point **65 m** horizontally away from and below the point of release. What is the initial speed of the ball?



$x_0 = 0, x = v_0 t, v_{0x} = v_0, v_x = v_0, a_x = 0,$

$y_0 = 0, y = -h, v_{0y} = 0, v_y = -gt, a_y = -g,$

Vertical free fall: $y - y_0 = -\frac{1}{2}gt^2 = -h$

Use y to solve t, so $\frac{9.8}{2}t^2 = 35\text{ m} \rightarrow t = 2.67\text{ s}$

Use t to solve x, so $x = v_0 t = 65\text{ m} = v_0(2.67\text{ s}) \rightarrow v_0 = 24\text{ m/s}$

Example:

A firefighter, a distance **5 m** from a burning building directs a stream of water from a fire hose at angle **40 degrees** above the horizontal. If the initial speed of the stream is **10 m/s**, at what **height** does the water strike the building?

$$v_{0x} = v_0 cos\alpha_0$$
$$x = x_0 + v_{0x}t$$

$$v_{0x} = 10 \times cos40° = 7.66 \text{ m/s}$$
$$5 = 0 + 7.66t$$
$$t = 0.65 \text{ s}$$

$$v_{0y} = v_0 sin\alpha_0$$
$$v_y = v_{0y} - gt$$
$$y = y_0 + v_{0y}t - \frac{1}{2}gt^2$$

$$v_{0y} = 10 \times sin40° = 6.43 \text{ m/s}$$
$$y = 0 + 6.43t - \frac{1}{2}9.8t^2$$
$$= 6.43 \times 0.65 - 4.9 \times 0.65^2 = 2.1 \text{ m}$$

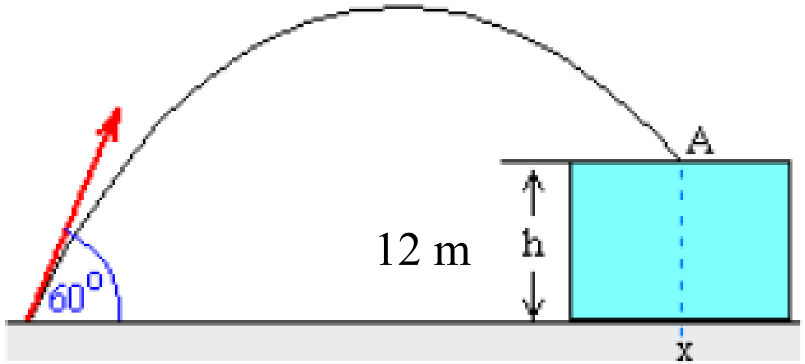
Example:

A stone is projected at a cliff of height **12 m** with an initial speed of v_0 directed **60 degrees** above the horizontal, as shown. **Four seconds** later the stone strikes the cliff. What is the initial velocity of the stone?

$$v_{0y} = v_0 sin\alpha_0 \qquad v_{0x} = v_0 cos\alpha_0$$

$$v_y = v_{0y} - gt \qquad x = x_0 + v_{0x}t$$

$$y = y_0 + v_{0y}t - \frac{1}{2}gt^2$$



Known? Unknown?

$t = 4$ s

$y = 12$ m

$v_0 = ?$

$x = ?$

$v_{0x} = ?$

$v_{0y} = ?$

$$12 = 0 + 4v_{0y} - \frac{9.8}{2}16$$

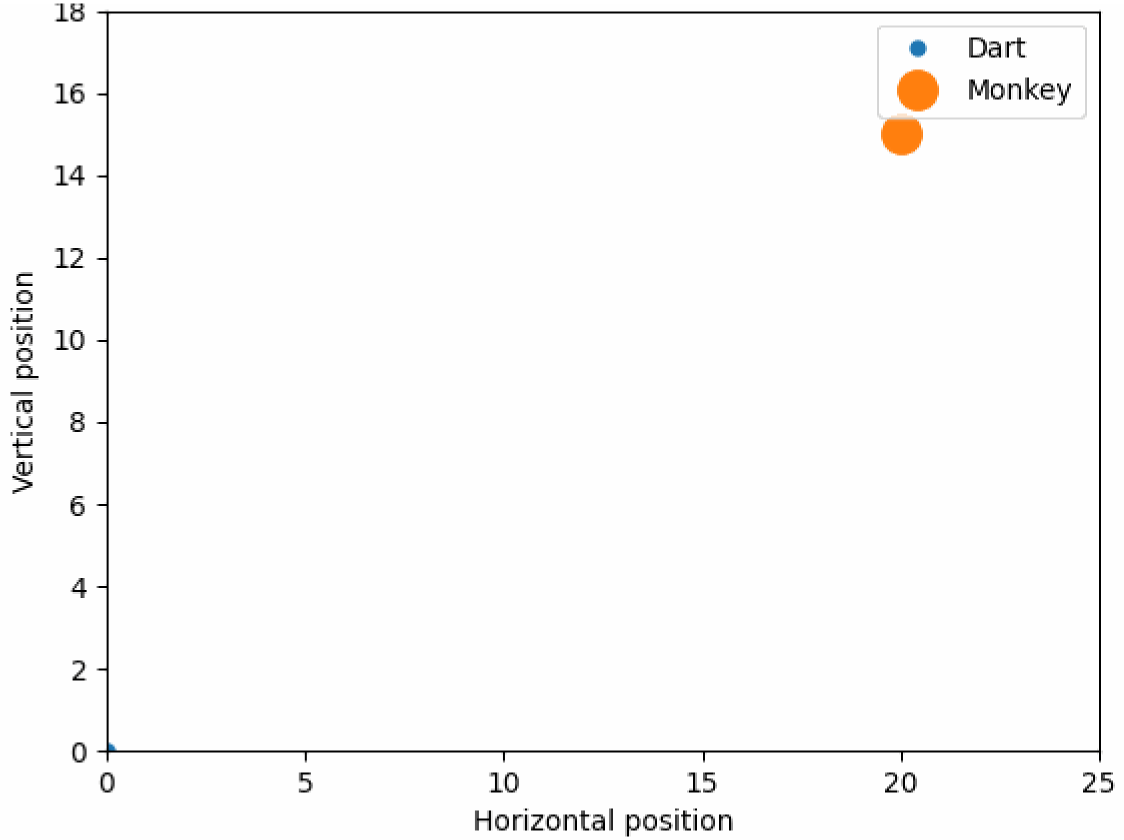
$$v_{0y} = 22.6$$

$$22.6 = v_0 sin60°$$

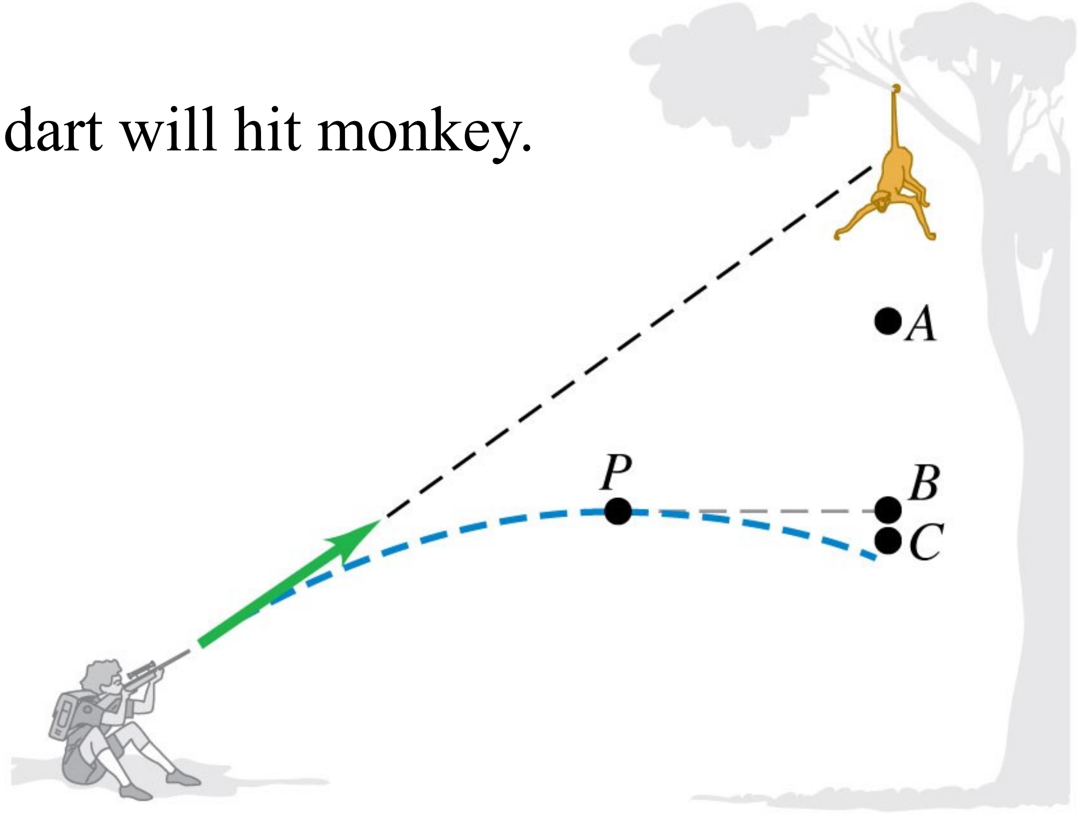
$$v_0 = 26 \text{ m/s}$$

Example:

A zookeeper fires a dart directly at a monkey. The monkey lets go at the same instant that the dart leaves the gun barrel. Ignore air resistance. Can the monkey avoid the dart?



No!
The dart will hit monkey.



Example:

A zookeeper fires a dart directly at a monkey. The monkey lets go at the same instant that the dart leaves the gun barrel. The dart reaches a maximum height *P* before striking the monkey. Ignore air resistance.

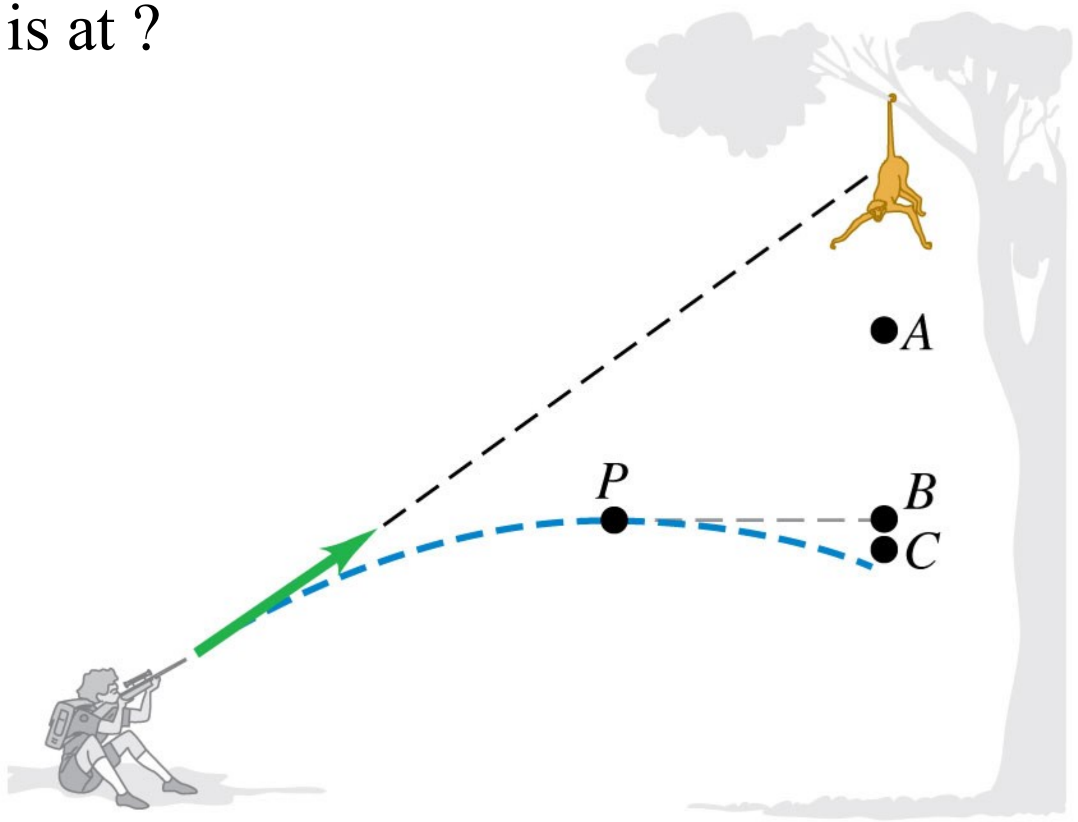
When the dart is at *P*, the monkey is at ?

A. is at *A* (higher than *P*).

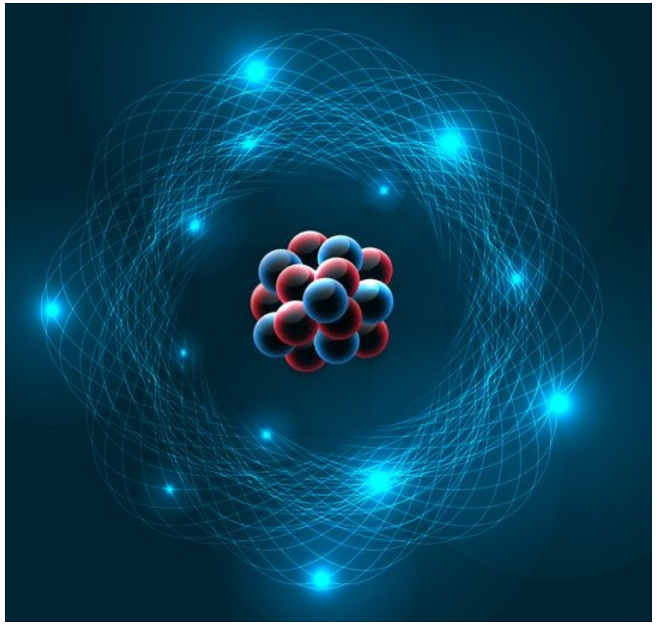
B. is at *B* (at the same height as *P*).

C. is at *C* (lower than *P*).

D. not enough information given to decide



Physics 111: Mechanics
Chapter 04



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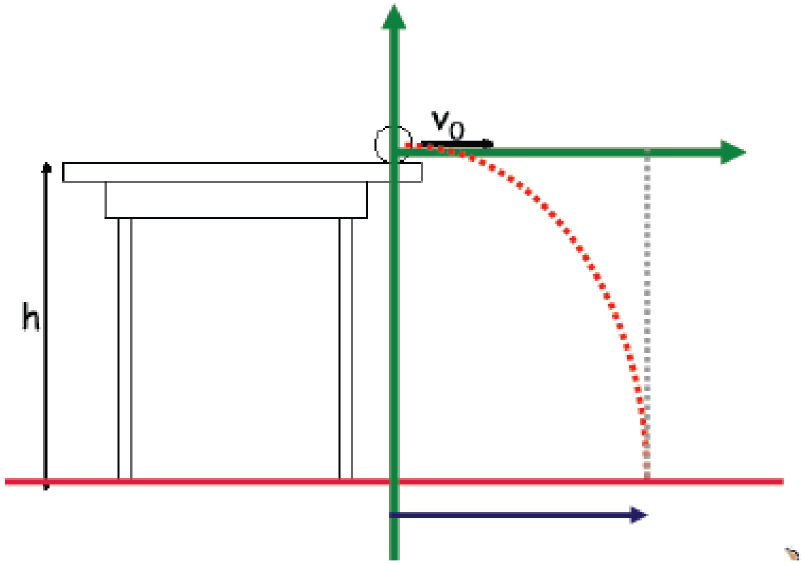
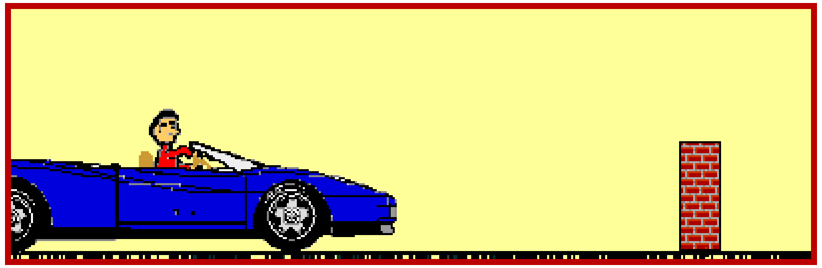
Kinematics and Dynamics

- Kinematics describes object's motion by answering: When? Where? How fast? How far? How long? Without asking: why is object moving in a certain way?



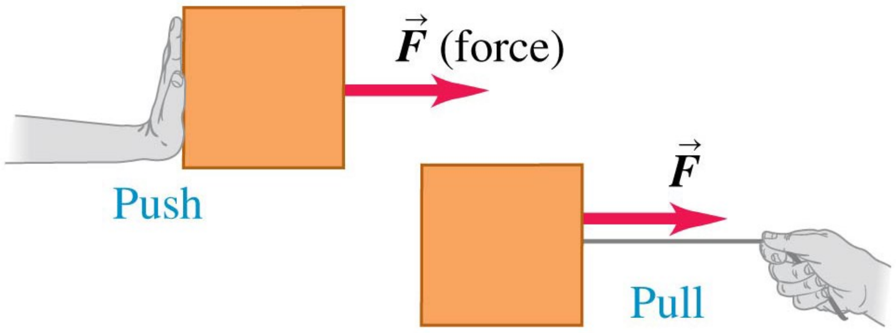
- Dynamics describes object's motion by answering: Why is the object moving in a certain way? What causes the object to change its velocity?

- Dynamics studies motion on a deeper level than kinematics: It studies the **causes of changes** in object's motion.



Dynamics: Driving force

- Describes the relationship between the motion of objects in our everyday world and the forces acting on them.
- Language of dynamics



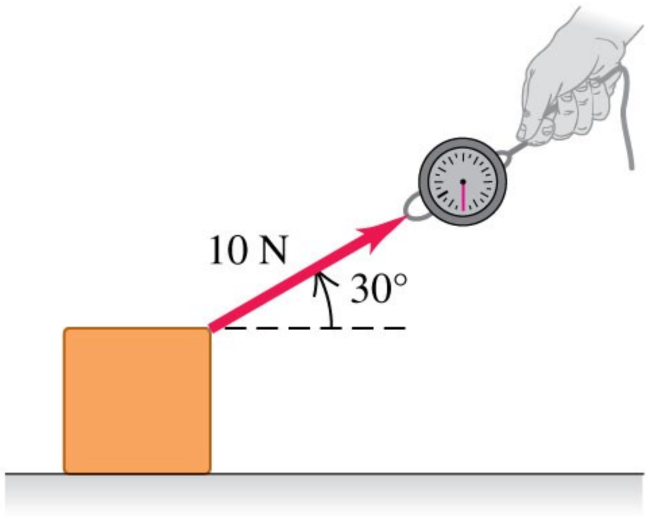
  - ✓ **Force**: The measure of interaction between two objects (pull or push). It is a **vector** quantity – it has a **magnitude** and **direction**.
  - ✓ **Mass**: The measure of how difficult it is to change object’s velocity (sluggishness or **inertia of the object**)

Force

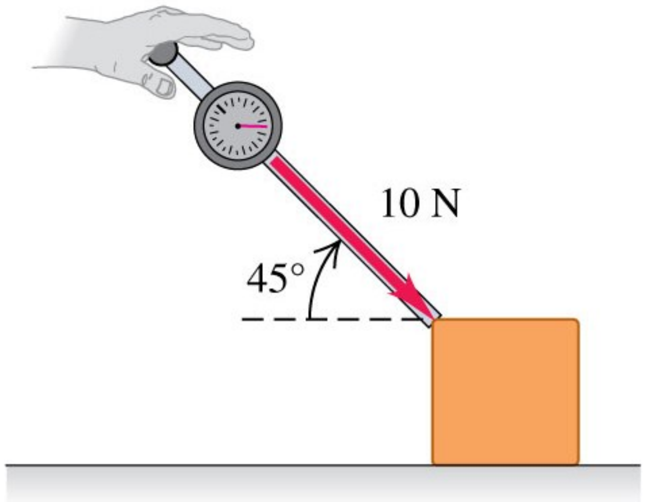
- May be a **contact force** or a **field force**
  - ✓ Contact forces result from physical contact between two objects
  - ✓ Field forces act between disconnected objects. Also called "**action at a distance**".

- **Draw a force**: Use a vector arrow to indicate the magnitude and direction of the force.

(a) A 10-N pull directed 30° above the horizontal

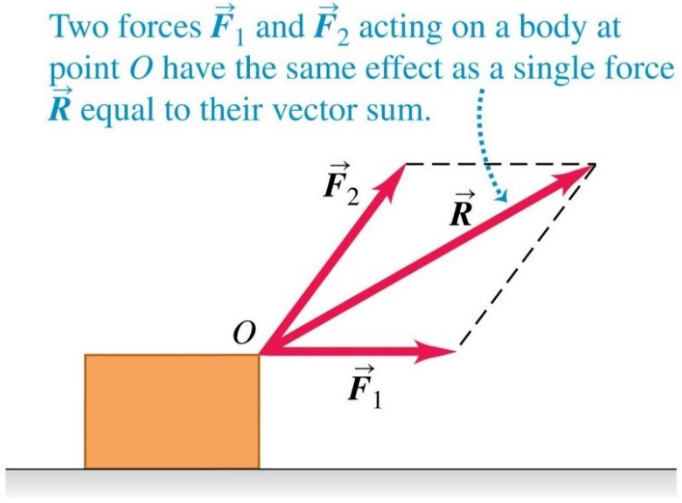


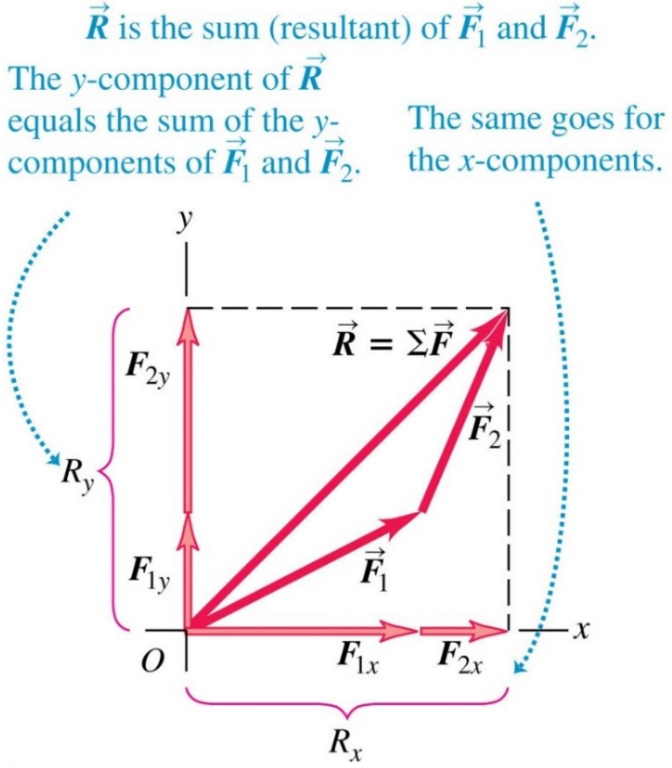
(b) A 10-N push directed 45° below the horizontal



Vector Nature of Force

- **Add:** Several forces acting at a point on an object have the same effect as their vector sum acting at the same point.
- You must use the rules of vector addition to obtain the "sum" of forces on an object.





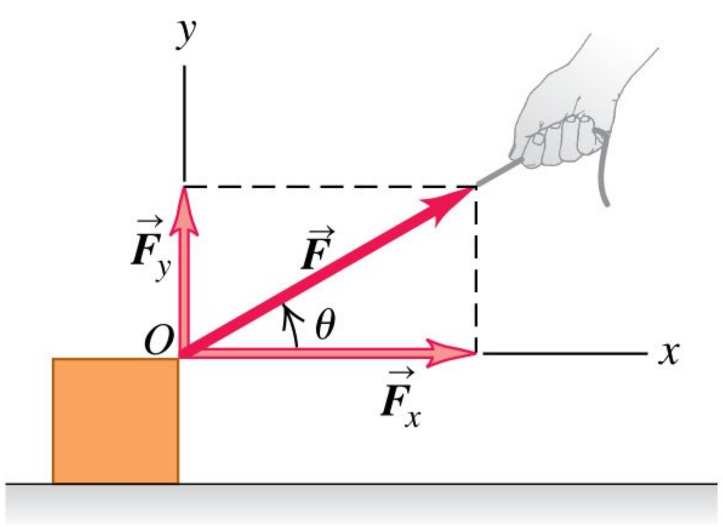
- **Net force**: a resultant force acting on object

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

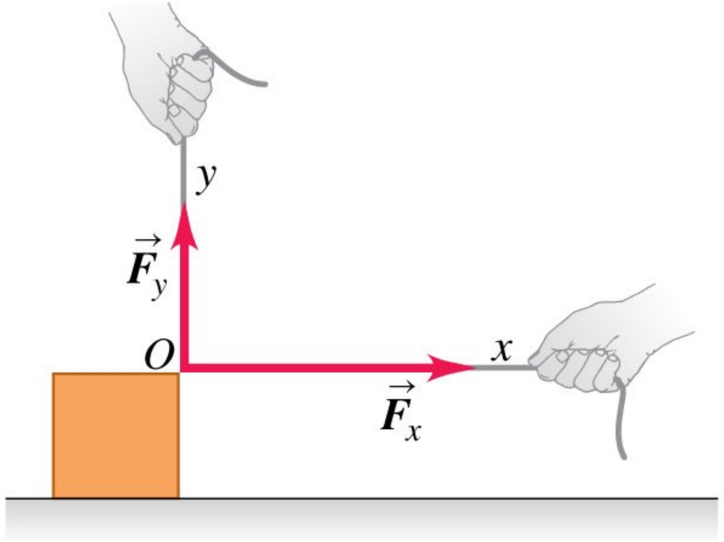
Decomposing a force into component vectors

- Choose perpendicular x and y axes.
- F_x and F_y are the components of a force along these axes.
- Use trigonometry to find these force components.

(a) Component vectors: $\vec{F}_x$ and $\vec{F}_y$
Components: $F_x = F\cos\theta$ and $F_y = F\sin\theta$



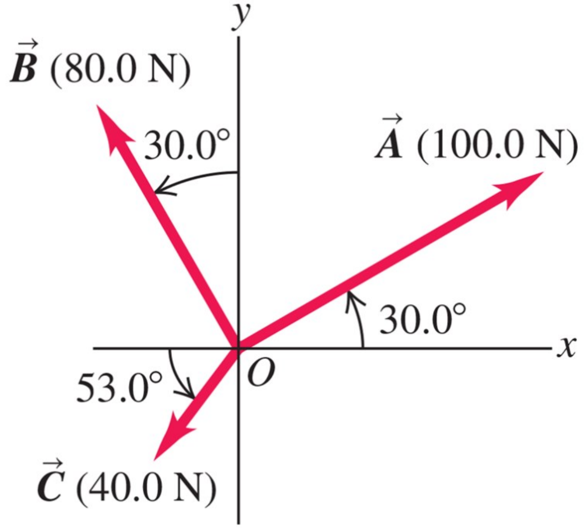
(b) Component vectors $\vec{F}_x$ and $\vec{F}_y$ together have the same effect as original force $\vec{F}$.



Example: components of a force

Three horizontal ropes pull on a stone on the ground, producing the vector forces $\vec{A}$, $\vec{B}$ and $\vec{C}$. Find the magnitude and direction of net force on the stone.

$$\vec{F}_{net} = \sum \vec{F} = \vec{A} + \vec{B} + \vec{C}$$



$A_x = +A\cos 30.0° = +86.6\,\text{N}$, $\quad A_y = +A\sin 30.0° = +50.00\,\text{N}$.

$B_x = -B\sin 30.0° = -40.00\,\text{N}$, $\quad B_y = +B\cos 30.0° = +69.28\,\text{N}$.

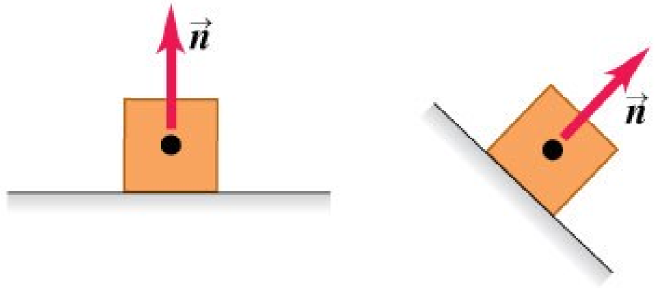
$C_x = -C\cos 53.0° = -24.07\text{N}$, $\quad C_y = -C\sin 53.0° = -31.90\,\text{N}$.

$F_{net,x} = A_x + B_x + C_x = 22.53\text{ N}$ $\quad F_{net,y} = A_y + B_y + C_y = 87.34\text{ N}$

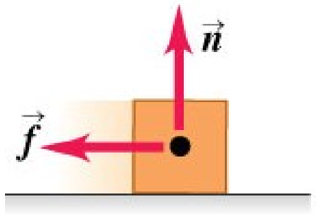
$F_{net} = \sqrt{F_{net,x}^2 + F_{net,y}^2} = 90.2\text{ N}$ $\quad \tan\alpha = |F_{net,y}/F_{net,x}| = 3.88.$ $\quad \alpha = 75.54°.$

Various Forces

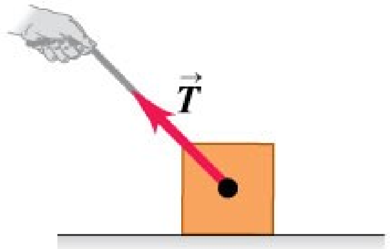
(a) **Normal force $\vec{n}$:** When an object rests or pushes on a surface, the surface exerts a push on it that is directed perpendicular to the surface.



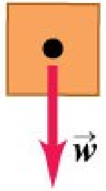
(b) **Friction force $\vec{f}$:** In addition to the normal force, a surface may exert a frictional force on an object, directed parallel to the surface.



(c) **Tension force $\vec{T}$:** A pulling force exerted on an object by a rope, cord, etc.

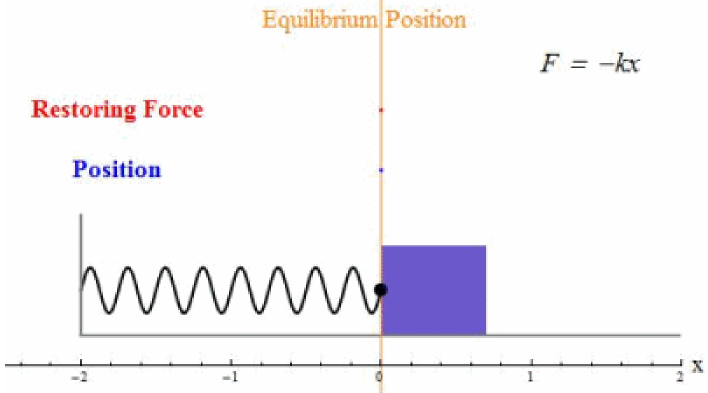


(d) **Weight $\vec{w}$:** The pull of gravity on an object is a long-range force (a force that acts over a distance).



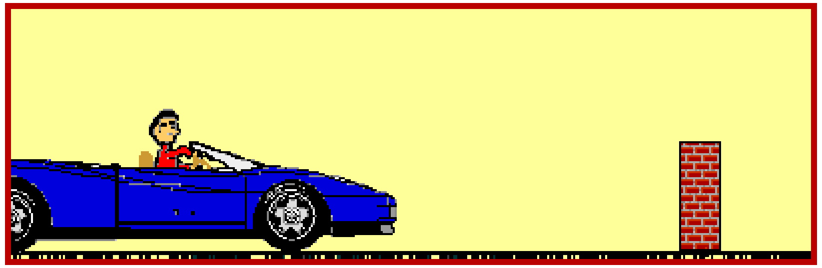
Gravitational Force

- Spring Force



Newton's First Law

- **Laziness of nature:** An object at rest tends to stay at rest and an object in motion tends to stay in motion with the same speed and in the same direction unless acted upon by an unbalanced force
- An object at rest remains at rest as long as no net force acts on it
- An object moving with constant velocity continues to move with the same speed and in the same direction (the same velocity) as long as no net force acts on it
- "Keep on doing what it is doing"



Newton's First Law

- When Newton's First Law is valid?
- When forces are balanced, the acceleration of the object is zero
  - ✓ Object at rest: $v = 0$ and $a = 0$
  - ✓ Object in motion: $v \neq 0$ and $a = 0$, **constant velocity**.
- If the **net force** is **zero**, forces are balanced.

$$\vec{F}_{net} = \sum \vec{F} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \cdots = 0$$

Mass and inertia

- Every object continues in its state of rest, or uniform motion in a straight line, unless it is compelled to change that state by unbalanced forces impressed upon it.
- **Inertia** is a property of objects to **resist changes** in motion!
- The word inertia comes from Latin and literally means "laziness".
- **Mass** is a measure of the amount of inertia.
- **Mass** is a measure of the resistance of an object to changes in its velocity.
- Mass is an inherent property of an object.

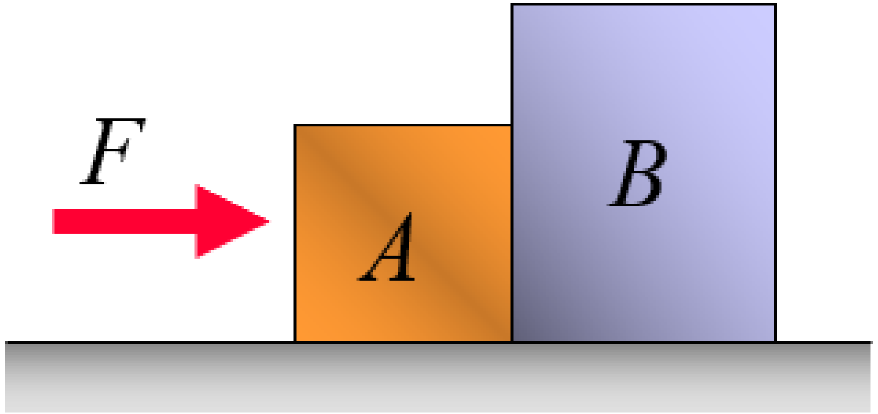
Scalar quantity and SI unit: kg

Example: A lightweight crate A (mass 2.0 kg) and a heavy crate B (mass 4.5 kg) are side-by-side on a horizontal surface with fiction. You apply a horizontal force [F] N to crate A, causing A and B to move in a **constant velocity**. What is the net force applied on B? (Unit in N)

Q1: What type of motion of A and B?

Constant speed

Net force one each object is zero



$\vec{a}_B = ?$

Newton's Second Law

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

$$\vec{F}_{net} = \sum \vec{F} = m\vec{a} \qquad \vec{a} = \frac{\vec{F}_{net}}{m} = \frac{\sum \vec{F}}{m}$$

- SI unit of force is a Newton (N)

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

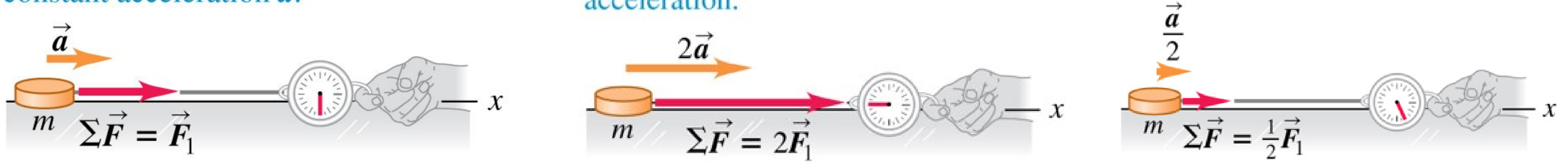
Newton’s Second Law: Examples

- The acceleration of an object is proportional to the net force on the object.

(a) A constant net force $\Sigma\vec{F}$ causes a constant acceleration $\vec{a}$.

(b) Doubling the net force doubles the acceleration.

(c) Halving the force halves the acceleration.

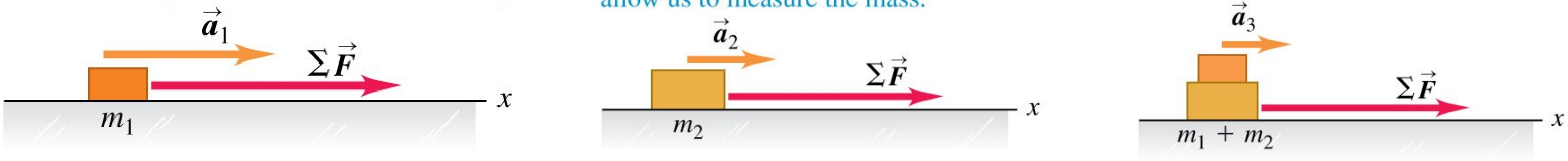


- The acceleration of an object is inversely proportional to the object’s mass if the net force remains fixed.

(a) A known force $\Sigma\vec{F}$ causes an object with mass m_1 to have an acceleration $\vec{a}_1$.

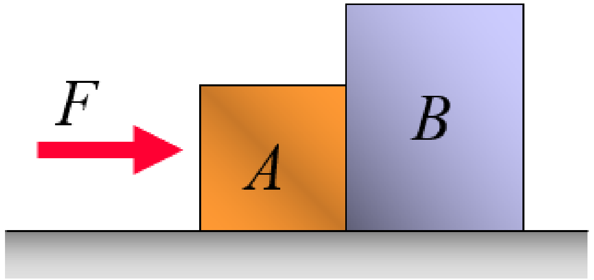
(b) Applying the same force $\Sigma\vec{F}$ to a second object and noting the acceleration allow us to measure the mass.

(c) When the two objects are fastened together, the same method shows that their composite mass is the sum of their individual masses.



Example:

A lightweight crate (A) and a heavy crate (B) are side-by-side on a frictionless horizontal surface. You apply a horizontal force F to crate A, causing A and B to accelerate together to the right. How do the magnitudes of the following forces compare: (i) the force F, (ii) the net force on A, and (iii) the net force on B?



Q1: What type of motion of A and B?

A and B both accelerate, Newton's second law

Q2: What is the acceleration of A and B?

Moving together, so the same.

A. F = net force on A = net force on B

B. F > net force on A = net force on B

C. F > net force on A > net force on B

D. F > net force on B > net force on A ✓

Q3: Suppose the acceleration is a, what is the net force on B and A, respectively?

$F_{net\ on\ B} = a*m_B$, $F_{net\ on\ A} = a*m_A$ $F = a*(m_A+m_A)$