Today: 4.1 & 4.2

L11

Today: 4.1 & 4.2

L11

Forces

Today: 4.1 & 4.2

L11

Newton's
1st
law

L11

Today: 4.1 & 4.2

Monday: 4.3 & 4.4

ASU

Today: 4.1 & 4.2

L11

Monday: 4.3 & 4.4

Newton's 2nd law

L11

Today: 4.1 & 4.2

Monday: 4.3 & 4.4

Mass &
Weight

Force & interaction

Force & interaction

- A force is a push or a pull.

Force & interaction

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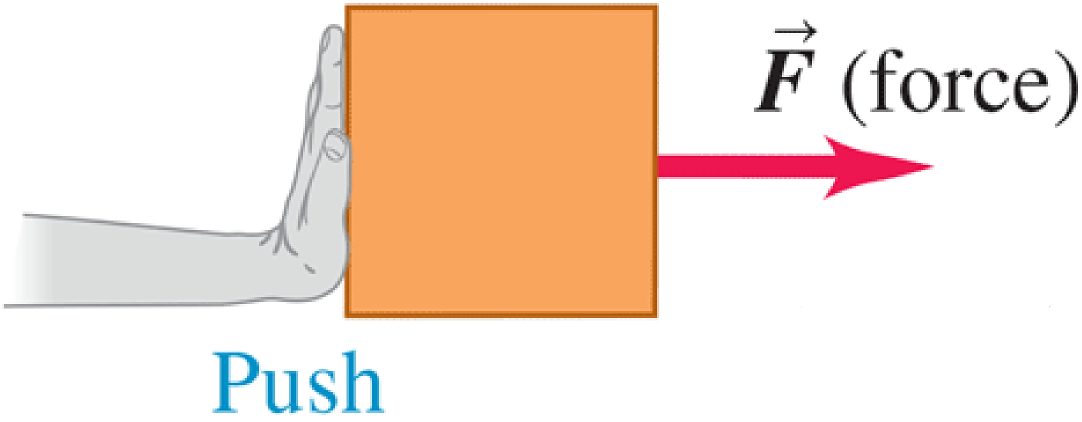

Force & interaction

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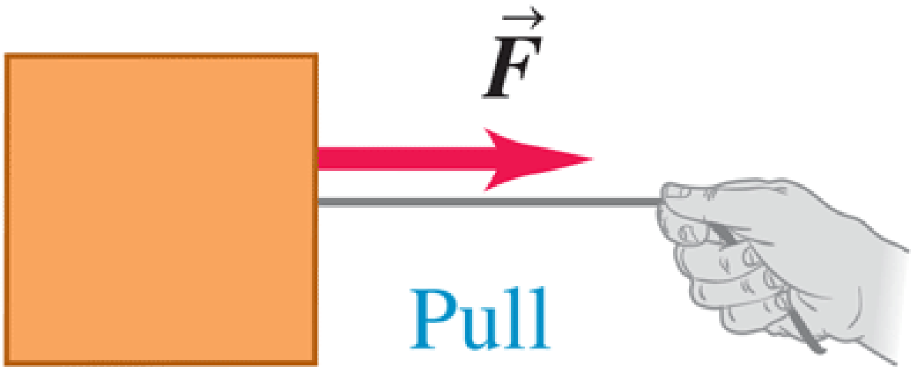
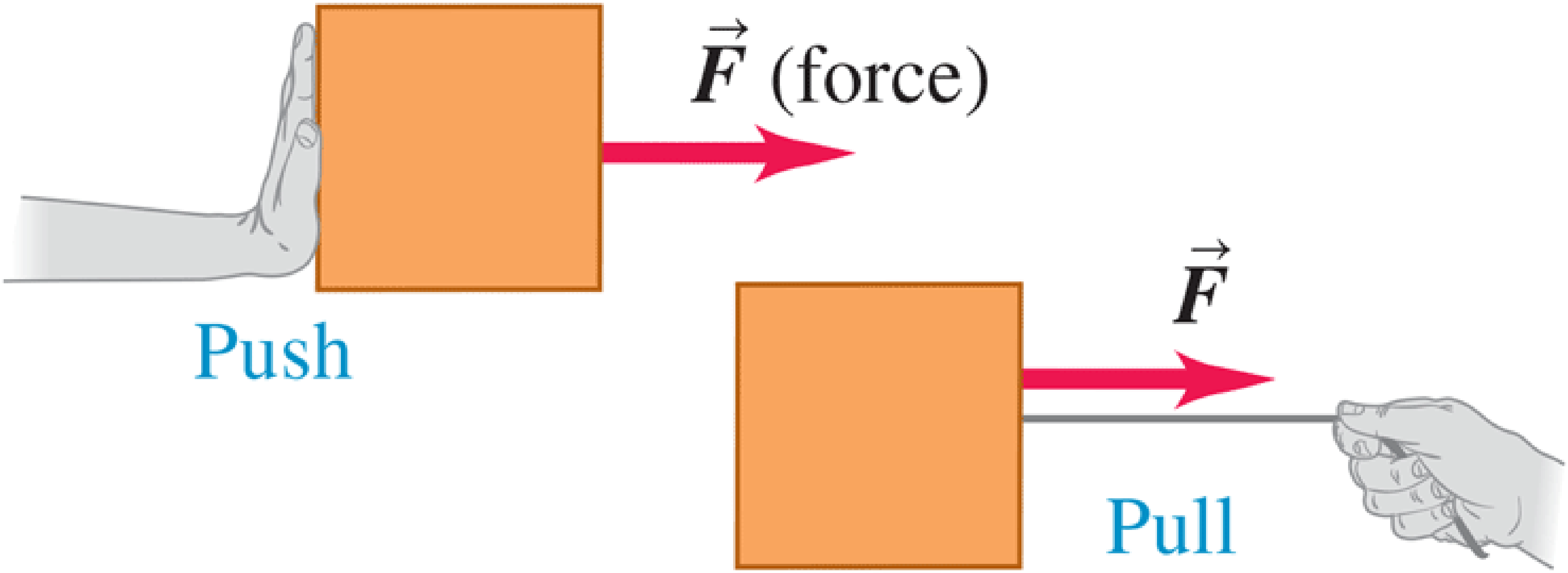


Force & interaction

- A force is a push or a pull.
- A force is an interaction between two objects or between an object and its environment.



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- A force is a push or a pull.
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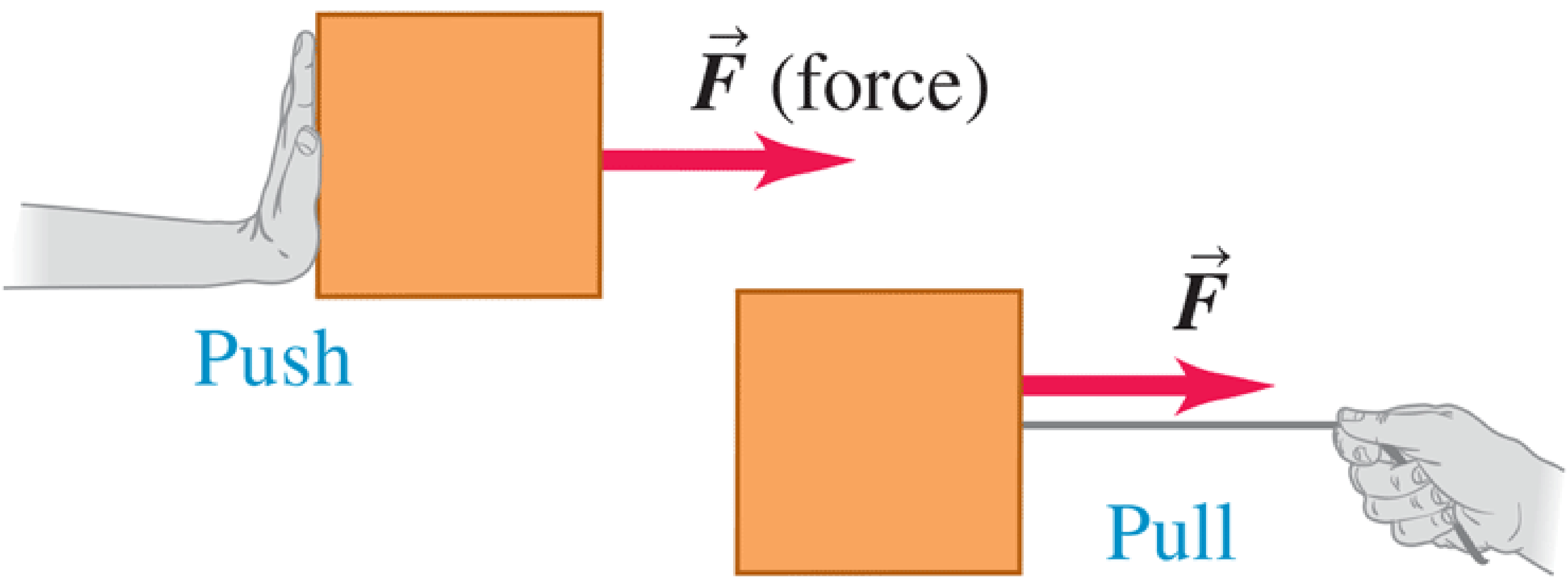

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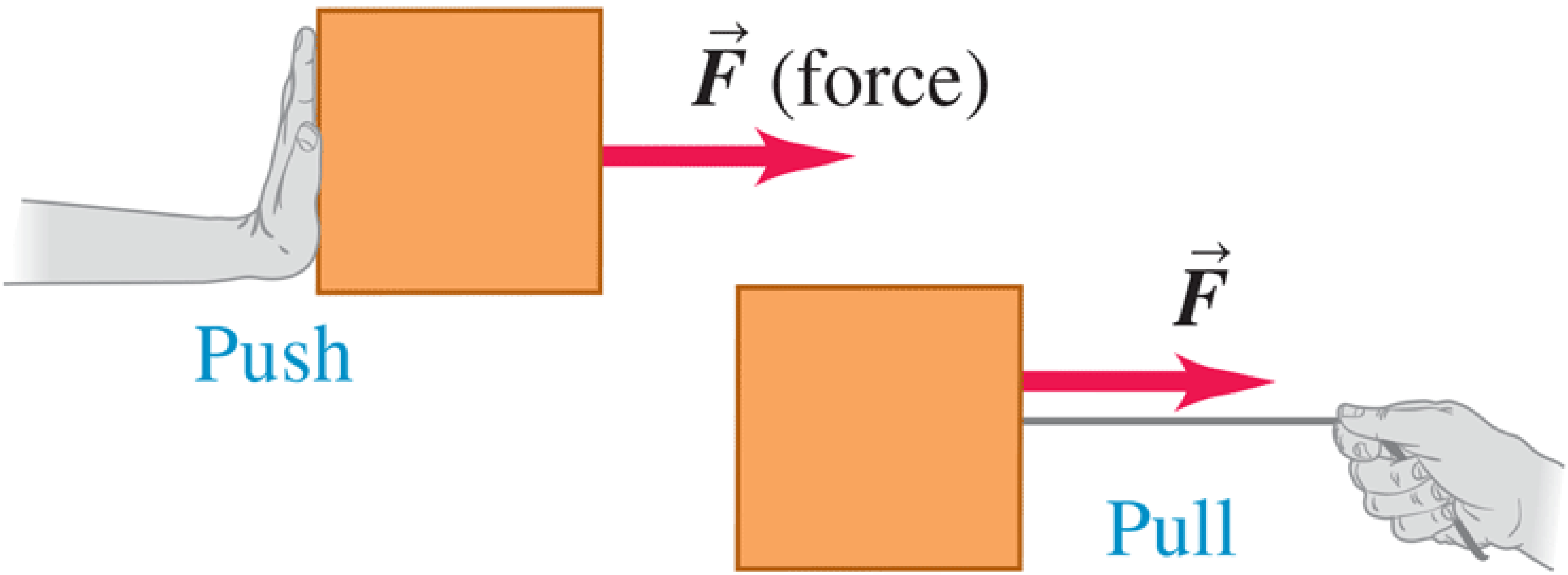
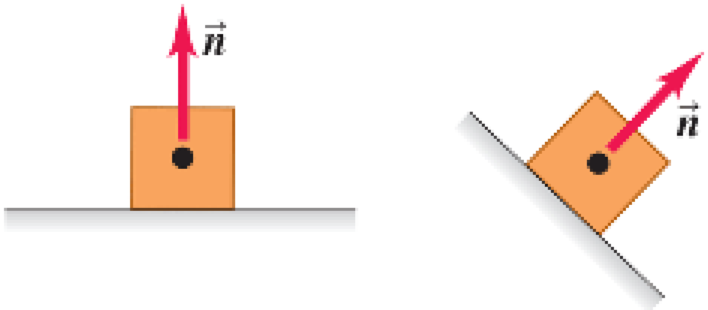


Force & interaction

(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.



Contact force

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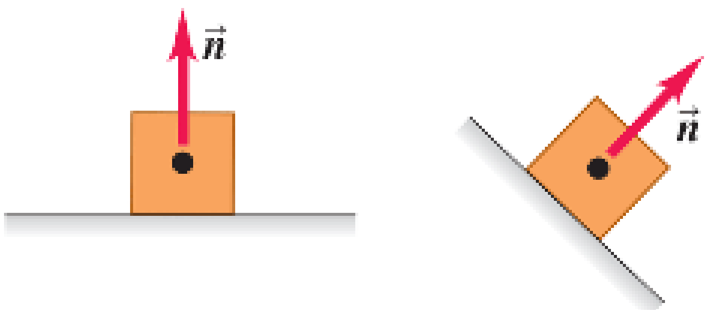
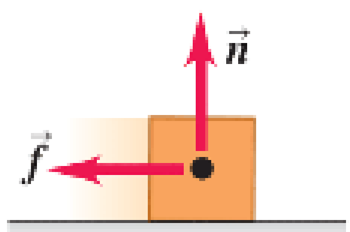


(b) **Friction force $\vec{f}$:** In addition to the normal force, a surface may exert a friction force on an object, directed parallel to the surface.



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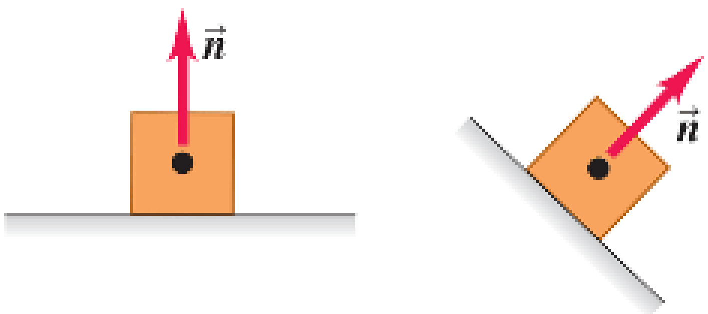

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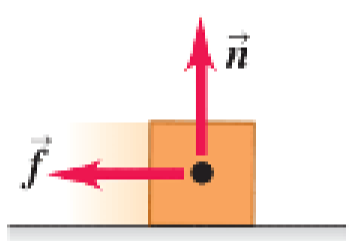
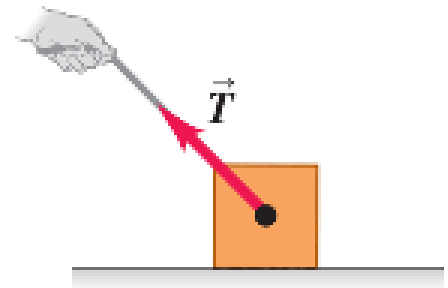
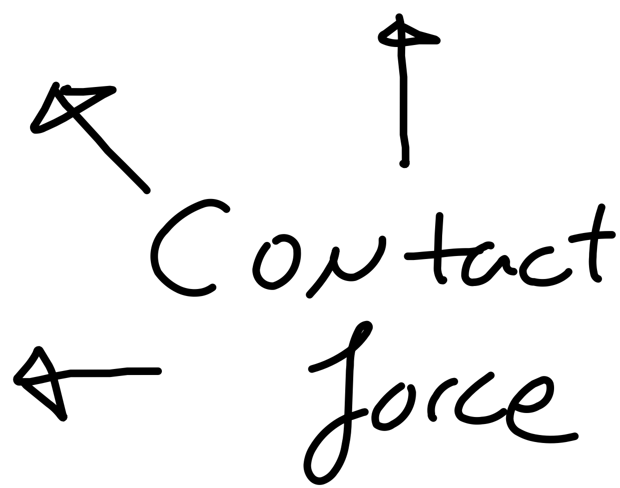


(c) **Tension force $\vec{T}$:** A pulling force exerted on an object by a rope, cord, etc.

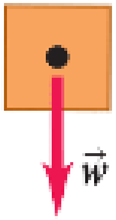




Force & interaction

Long range force

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



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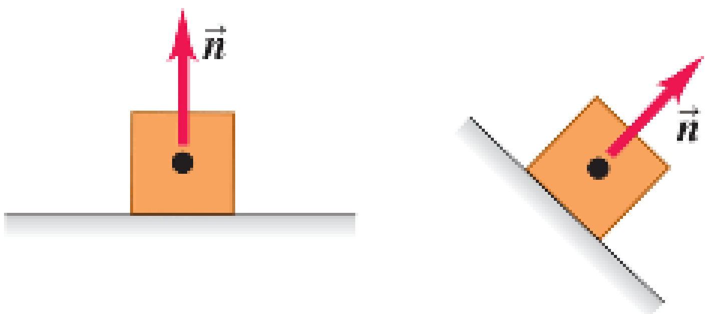

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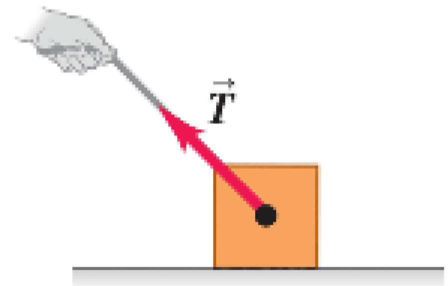

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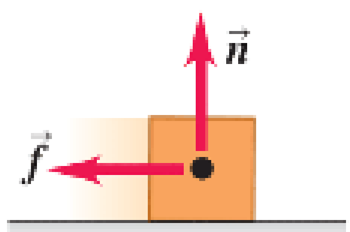

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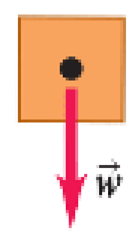

Force & interaction

Let

$\vec{F} \equiv$ force vector

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Units of force:

Force & interaction

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Units of force: $N \equiv$ Newton (SI)

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Also Force =

Force & interaction

Let

$\vec{F} \equiv$ force vector

Units of force: $N \equiv$ Newton (SI)

Pound $\equiv$ lb (US)

Also force = (mass)*

Force & interaction

Let

$\vec{F} \equiv$ force vector

Units of force: $N \equiv$ Newton (SI)

Pound $\equiv$ lb (US)

Also force = (mass)*(distance)

Force & interaction

Let

$\vec{F} \equiv$ force vector

Units of force: $N \equiv$ Newton (SI)

Pound $\equiv$ lb (US)

Also $\text{Force} = \dfrac{(\text{mass})*(\text{distance})}{(\text{time})^2}$

ASU

Force & interaction

Table 4.1 Typical Force Magnitudes

Sun's gravitational force on the earth	3.5×10^{22} N
Weight of a large blue whale	1.9×10^{6} N
Maximum pulling force of a locomotive	8.9×10^{5} N
Weight of a 250 lb linebacker	1.1×10^{3} N
Weight of a medium apple	1 N
Weight of the smallest insect eggs	2×10^{-6} N
Electric attraction between the proton and the electron in a hydrogen atom	8.2×10^{-8} N
Weight of a very small bacterium	1×10^{-18} N
Weight of a hydrogen atom	1.6×10^{-26} N
Weight of an electron	8.9×10^{-30} N
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1 lb = 4.45 N

Force & interaction

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Also

1 lb = 4.45 N or 1 N = 0.225 lb

ASU

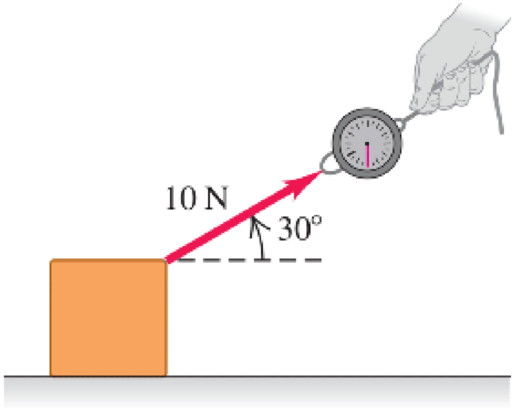
Force & interaction

Force is a vector

Force & interaction

Force is a Vector

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



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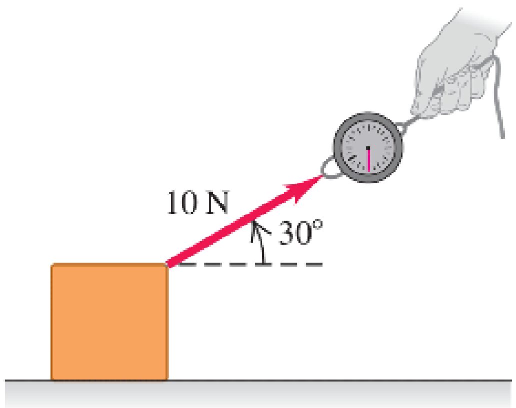

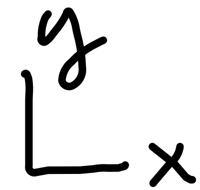

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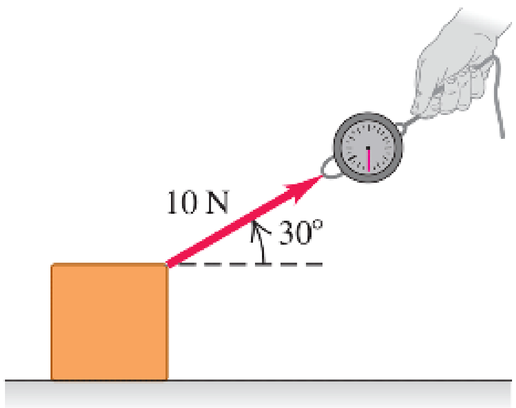

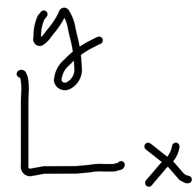

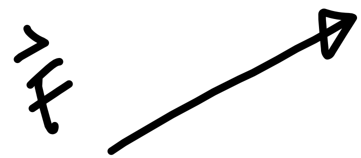

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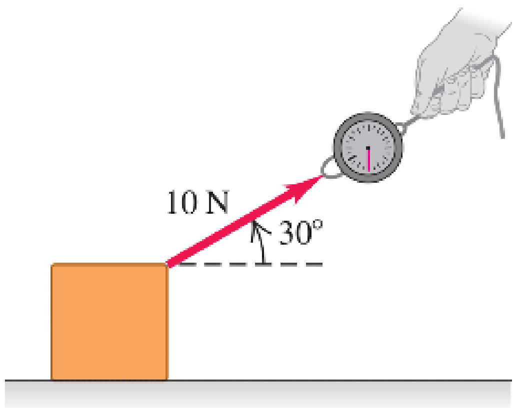
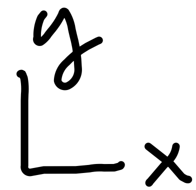
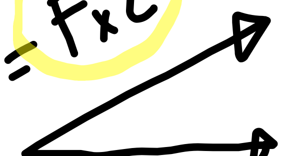




$\vec{F} = F_x \hat{i} +$



$F(\cos 30°)\hat{i}$

Force & interaction

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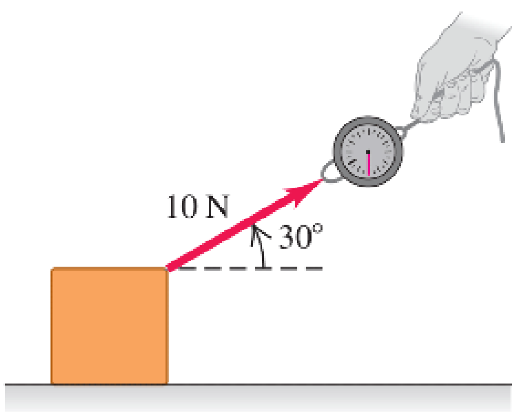

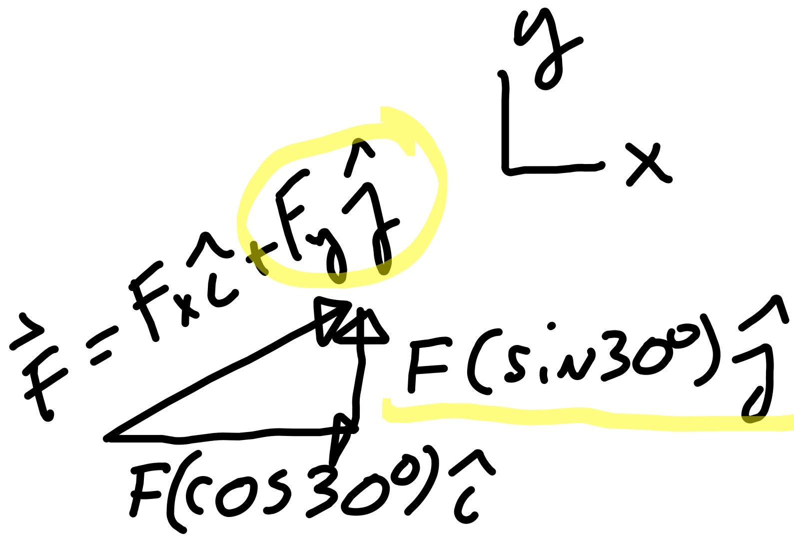

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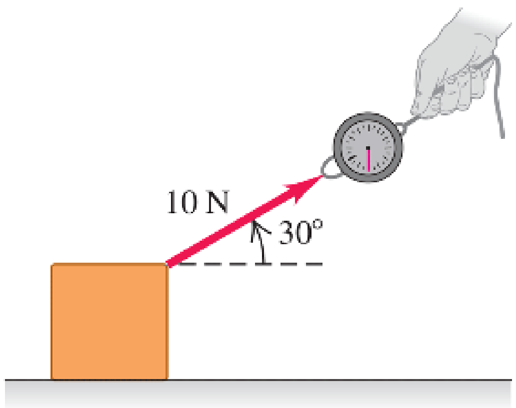
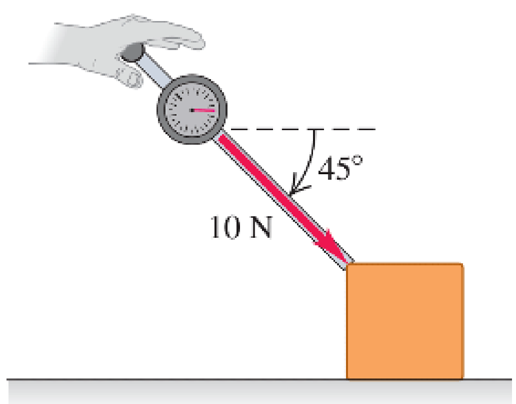
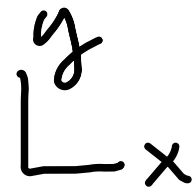
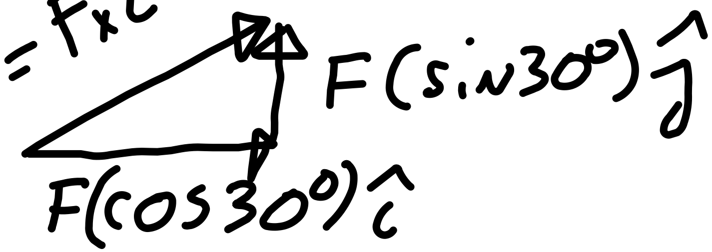


(b) A 10 N push directed 45° below the horizontal





$\vec{F} = F_x\hat{i} + F_y\hat{j}$



Force & interaction

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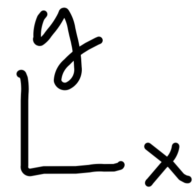

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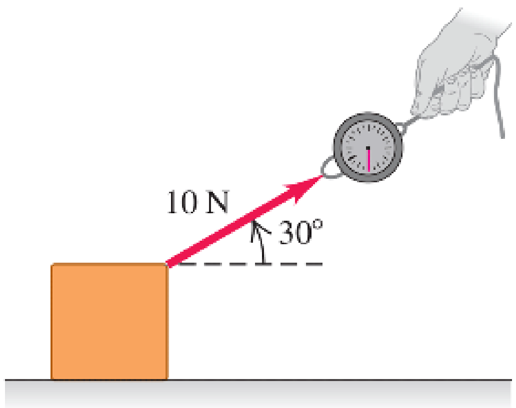

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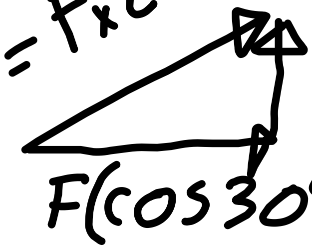

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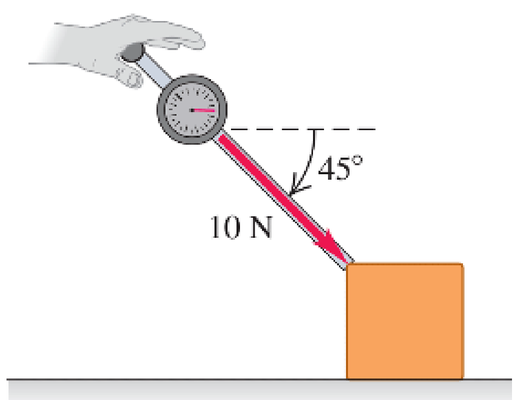
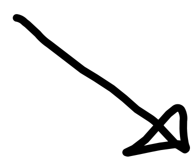


$\vec{F}$



Force & interaction

Force is a Vector

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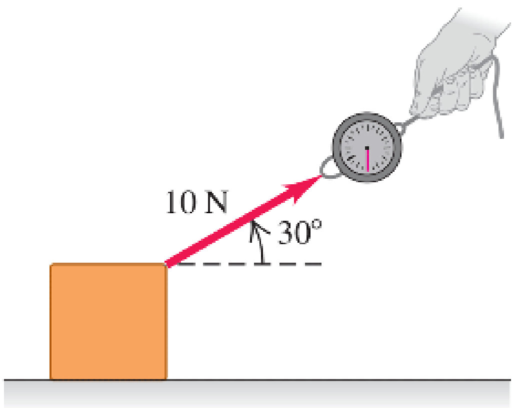

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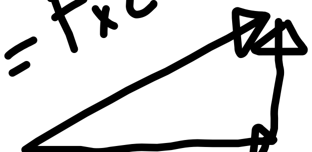

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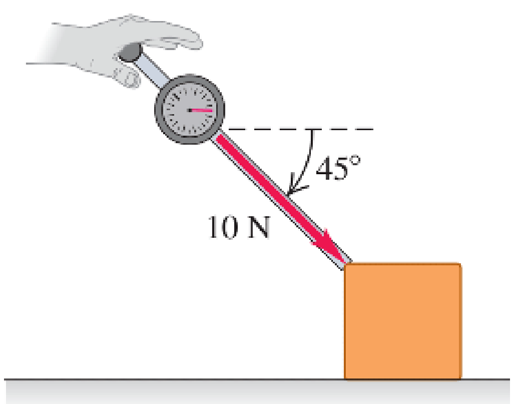

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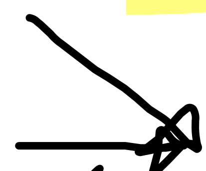

ASU

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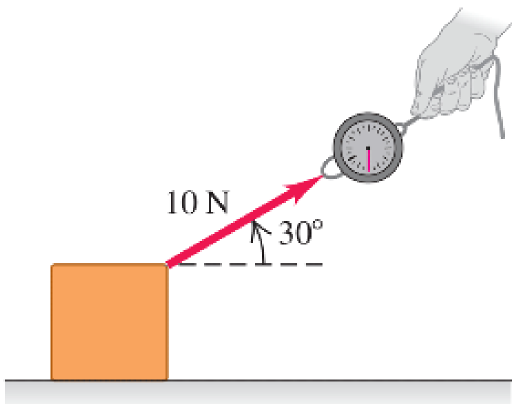

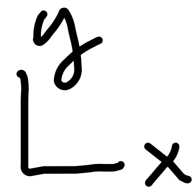

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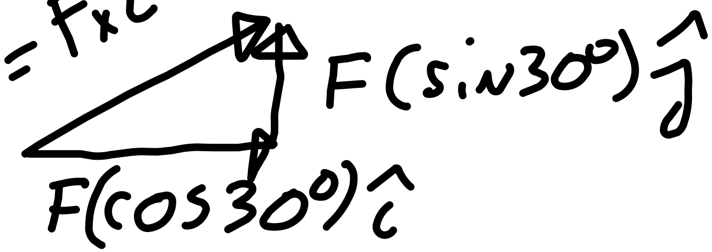

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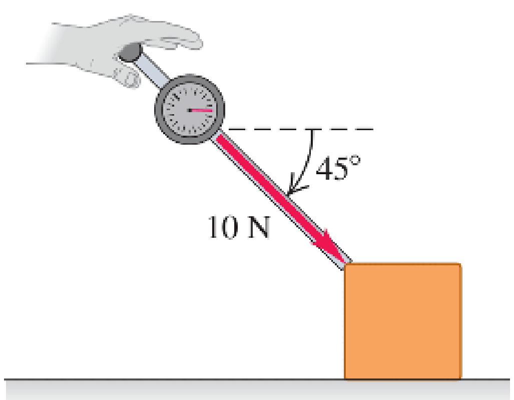

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Superposition

Superposition

Any number of forces applied at a point on an object have the same effect as a single force equal to the vector sum of the forces

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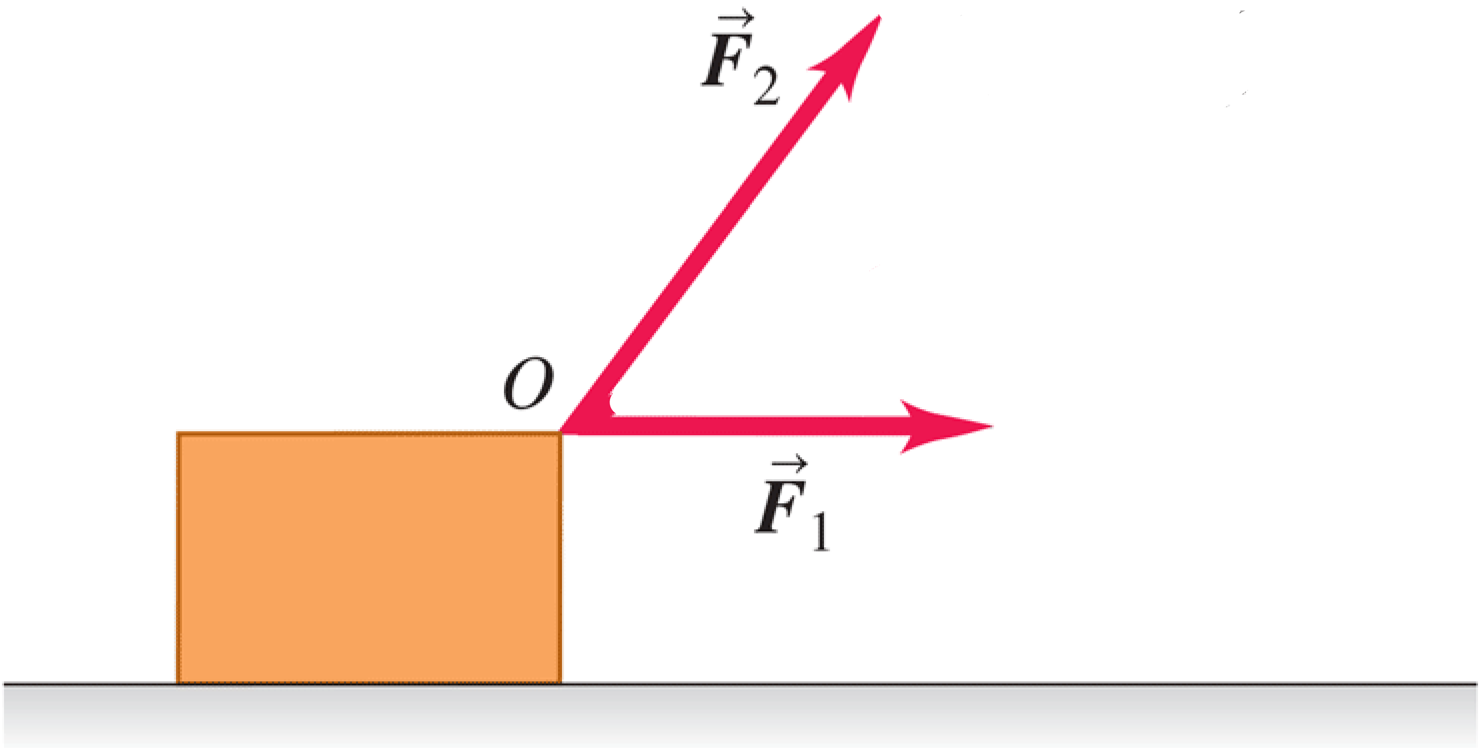
Superposition of forces

Superposition

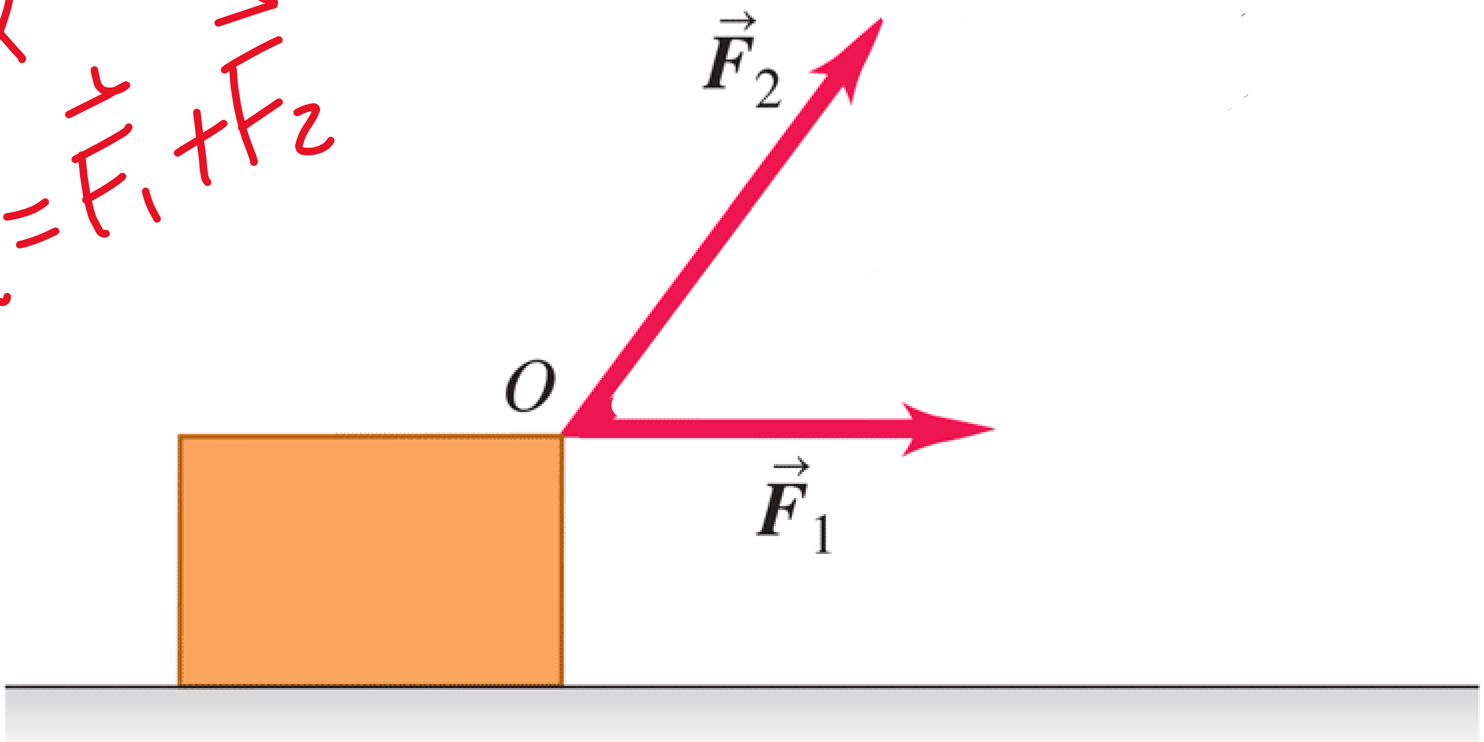
Two forces $\vec{F}_1$ and $\vec{F}_2$ acting on an object at point O



Superposition

Two forces $\vec{F}_1$ and $\vec{F}_2$ acting on an object at point O

Let $\vec{R} = \vec{F}_1 + \vec{F}_2$



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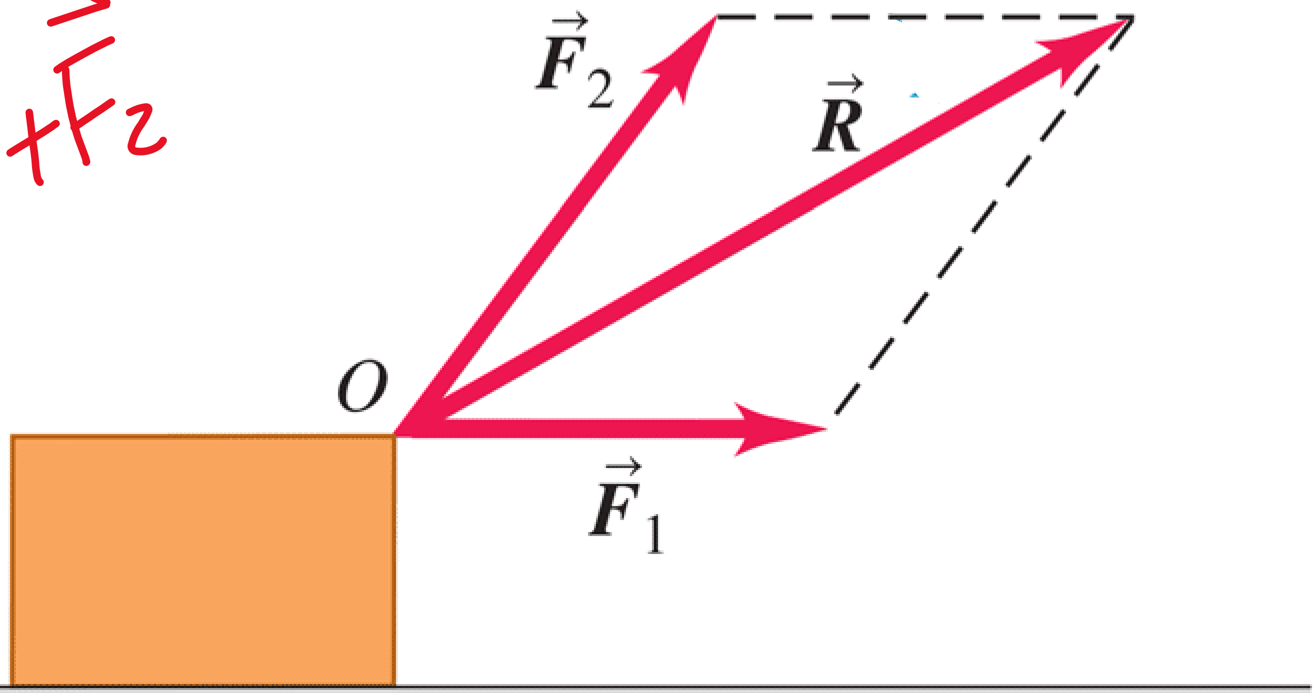
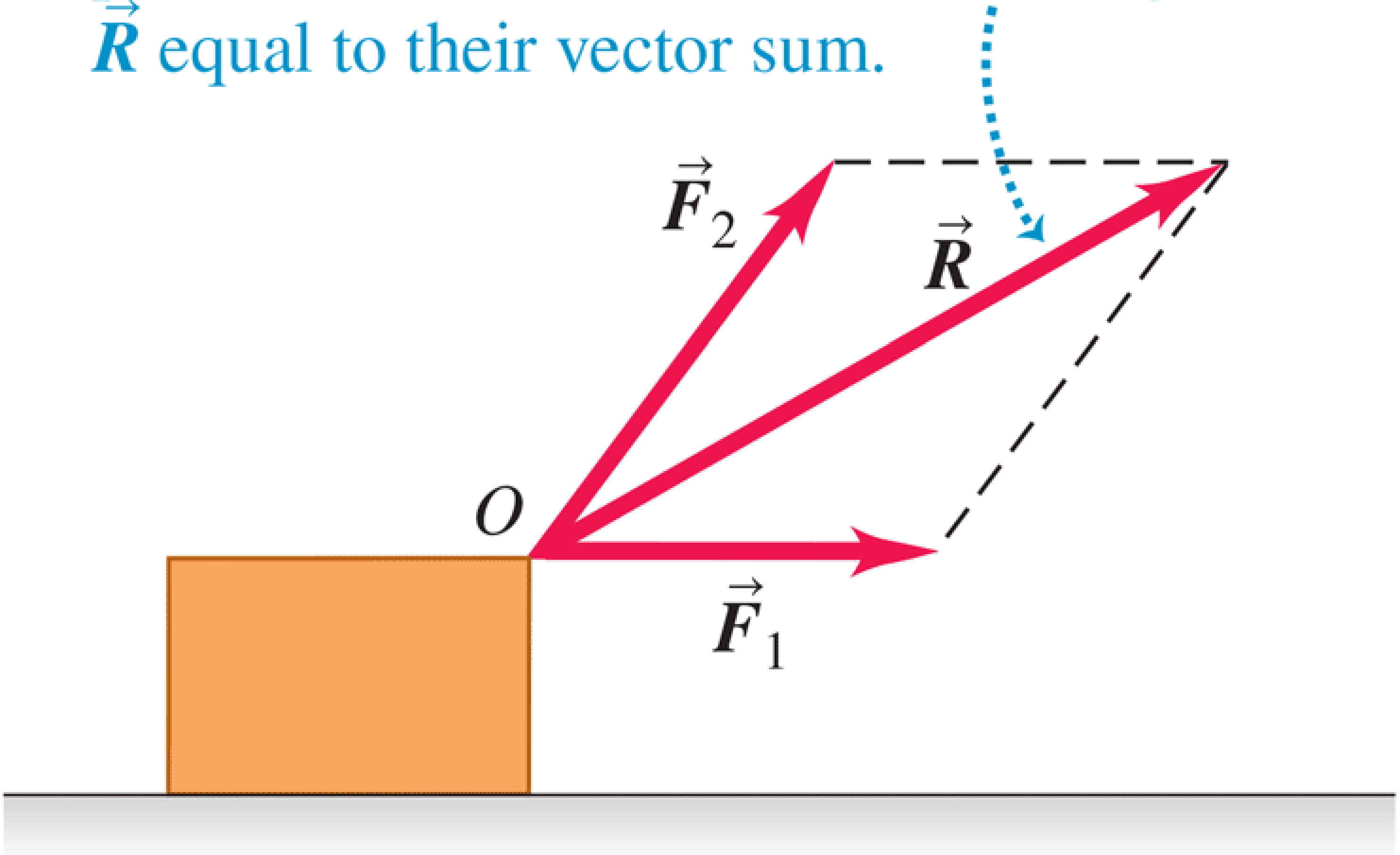


Superposition

Two forces $\vec{F}_1$ and $\vec{F}_2$ acting on an object at point O have the same effect as a single force $\vec{R}$ equal to their vector sum.



Superposition

Notation: $\Sigma \equiv$ sum

Superposition

Notation: $\Sigma \equiv \text{sum}$

Now $\vec{R} = \Sigma \vec{F}$

Superposition

Notation: $\Sigma \equiv$ sum

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

Superposition

Notation: $\Sigma \equiv \text{sum}$

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

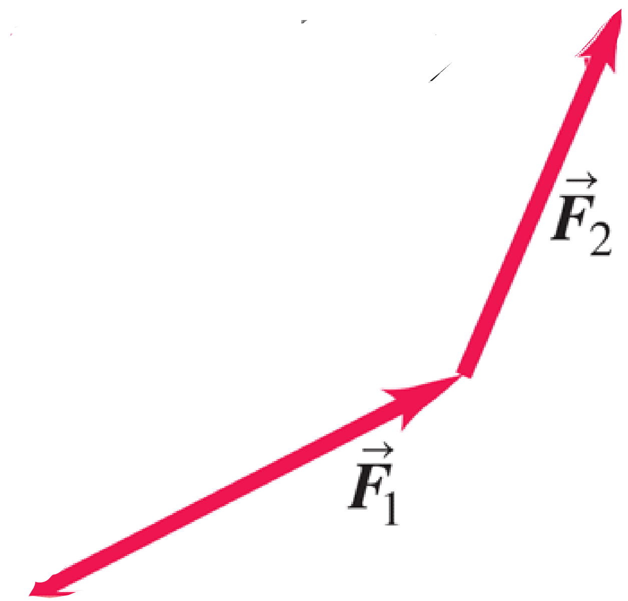
$\Rightarrow R_x = \Sigma F_x$

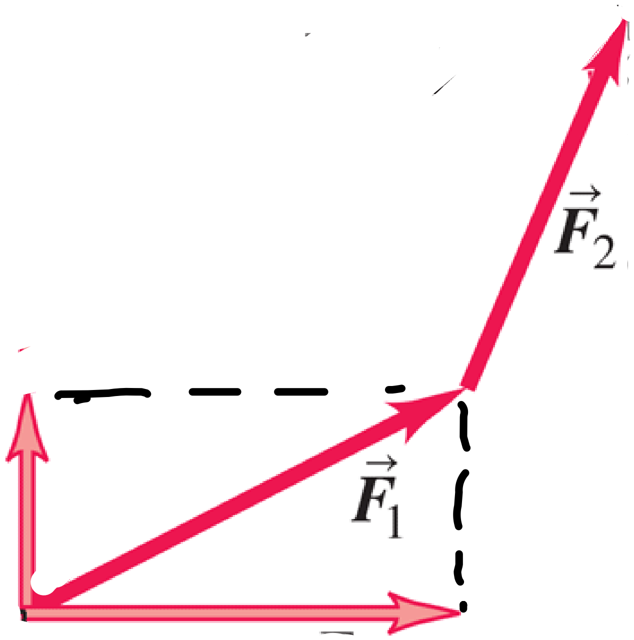
Superposition

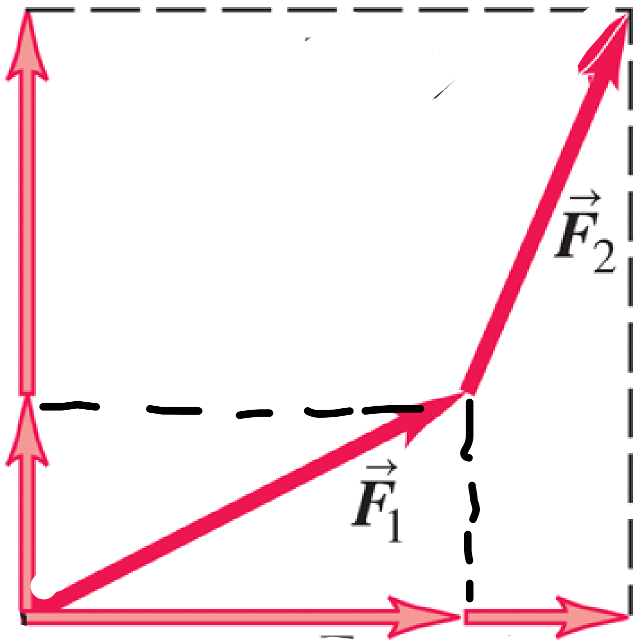
Notation: $\Sigma \equiv$ sum

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

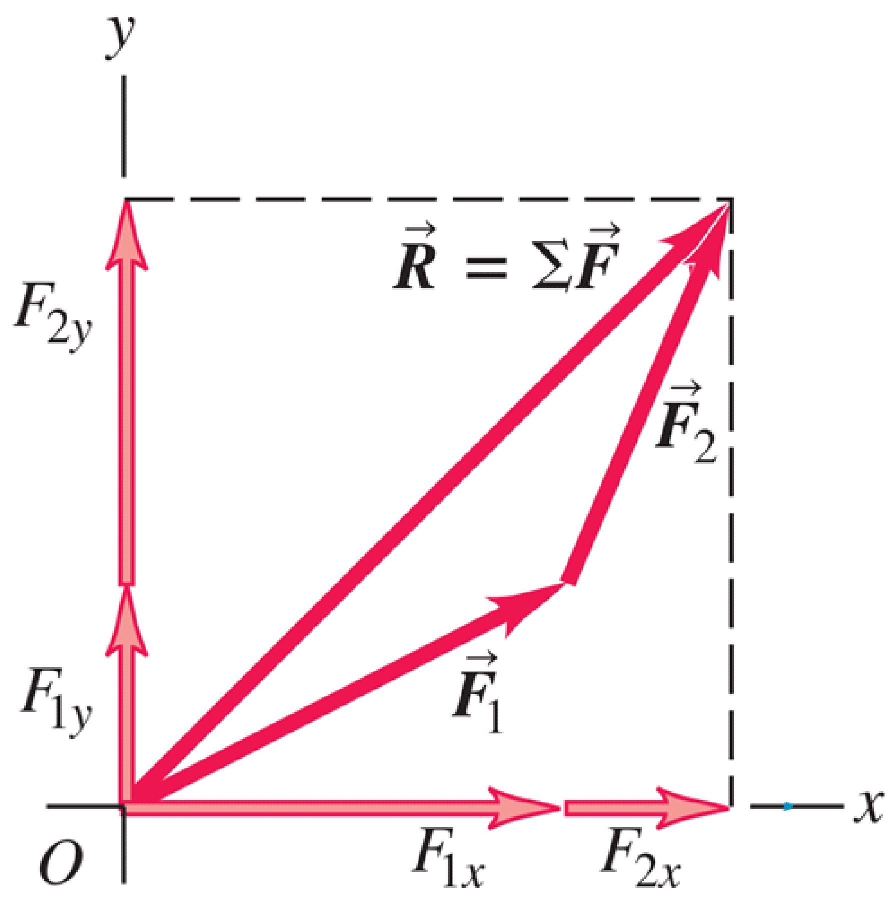
$\Rightarrow R_x = \Sigma F_x$ \& $R_y = \Sigma F_y$


$\vec{F}_2$
$\vec{F}_1$

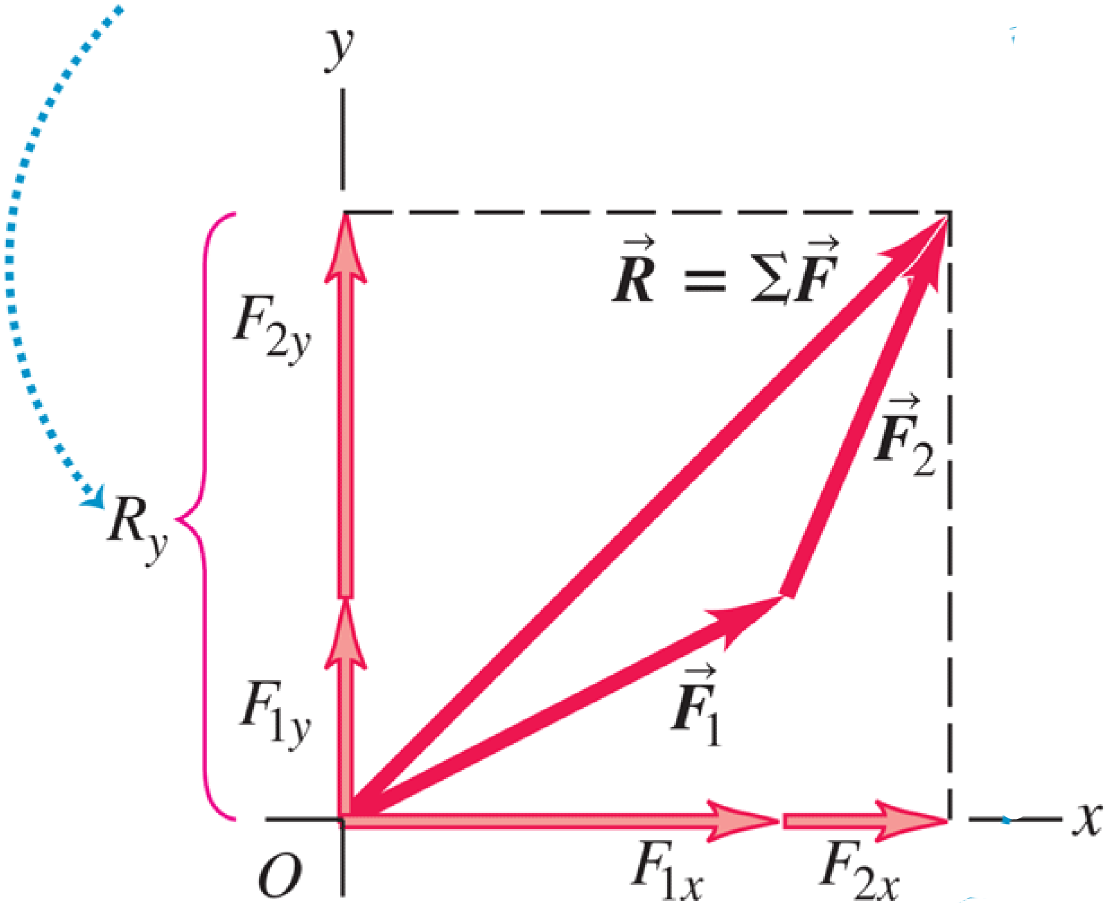

$\vec{F}_2$
$\vec{F}_1$



$\vec{F}_2$
$\vec{F}_1$

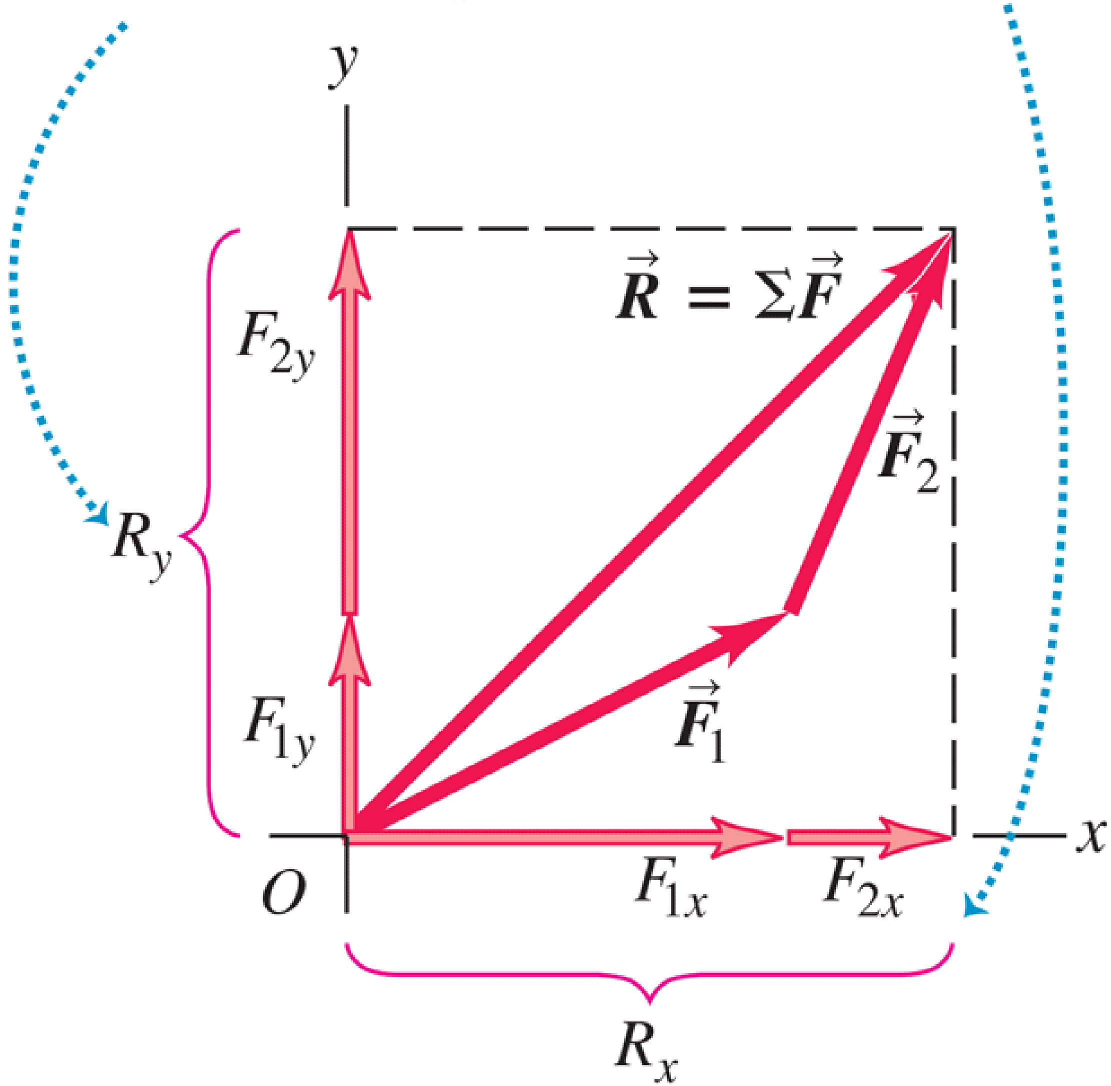

y
$\vec{R} = \Sigma\vec{F}$
F_{2y}
$\vec{F}_2$
F_{1y}
$\vec{F}_1$
x
O
F_{1x}
F_{2x}

The y-component of $\vec{R}$ equals the sum of the y-components of $\vec{F}_1$ and $\vec{F}_2$.



The y-component of $\vec{R}$ equals the sum of the y-components of $\vec{F}_1$ and $\vec{F}_2$.

The same is true for the x-components.



Superposition

Once we have R_x & R_y we can find R

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$$R = \left[R_x^2 + R_y^2\right]^{1/2}$$

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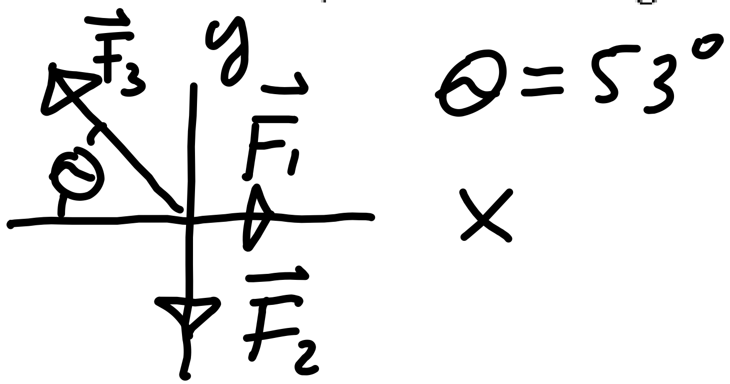
In 3d:

$$R = \left[R_x^2 + R_y^2 + R_z^2\right]^{1/2}$$

Three professional wrestlers are fighting over a champion's belt. Figure 4.7a shows the horizontal force each wrestler applies to the belt, as viewed from above. The forces have magnitudes $F_1 = 50\ \text{N}$, $F_2 = 120\ \text{N}$, and $F_3 = 250\ \text{N}$. Find the x- and y-components of the net force on the belt, and find its magnitude and direction.



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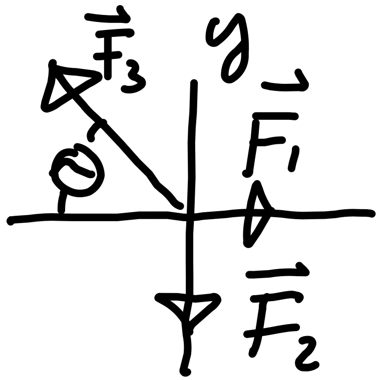

$\theta = 53°$

x

$\Rightarrow \vec{F}_1 = 50\mathrm{N}\ \hat{i}$

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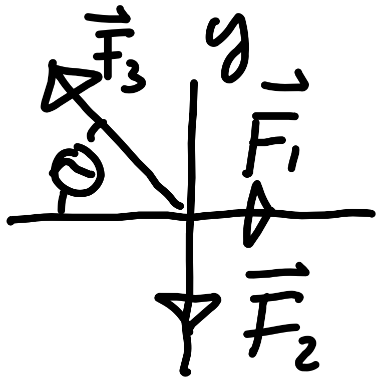

$\theta = 53°$

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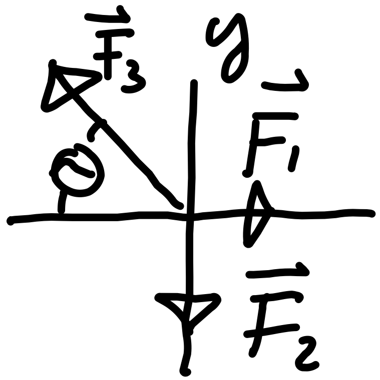

$\theta = 53^\circ$

x

$\Rightarrow \vec{F}_1 = 50\mathrm{N}\,\hat{i}$

& $\vec{F}_2 = 120\mathrm{N}(-\hat{j})$

& $\vec{F}_3 = F_{3x}\hat{i} + F_{3y}\hat{j}$

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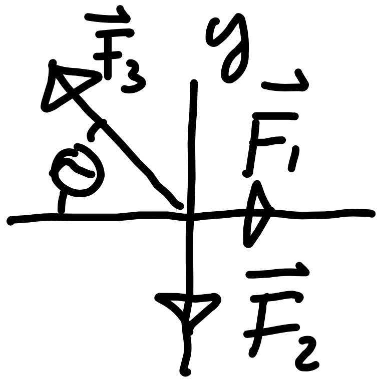

$\theta = 53^\circ$

$\Rightarrow \vec{F}_1 = 50N\,\hat{i}$

$\&\ \vec{F}_2 = 120N(-\hat{j})$

$\&\ \vec{F}_3 = F_{3x}\hat{i} + F_{3y}\hat{j},$

where $F_{3x} = -250\,N\cos(53^\circ) = -150N$

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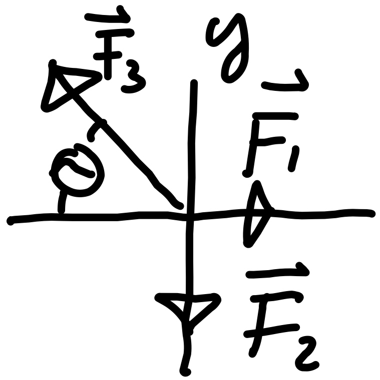

$\theta = 53^\circ$

$\Rightarrow \vec{F}_1 = 50N\,\hat{i}$

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$\& \ \vec{F}_3 = F_{3x}\hat{i} + F_{3y}\hat{j}$,

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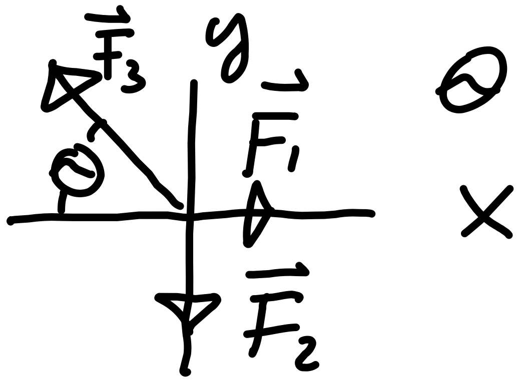

$\theta = 53°$

$\Rightarrow \vec{F}_1 = 50\text{N}\,\hat{i}$

& $\vec{F}_2 = 120\text{N}(-\hat{j})$

& $\vec{F}_3 = F_{3x}\hat{i} + F_{3y}\hat{j}$,

where $F_{3x} = -250\text{ N}\cos(53°) = -150\text{ N}$ &

$F_{3y} = -250\text{N}\sin(53°) = 200\text{ N}$

so $R_x = 50\text{N} -$

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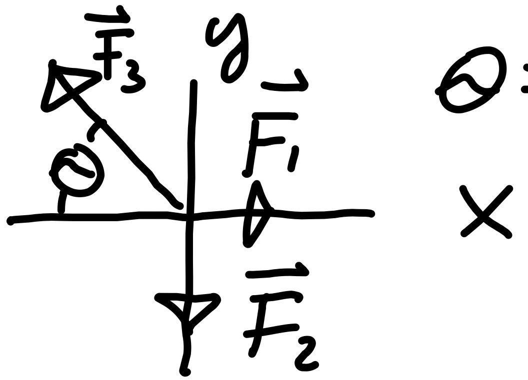

$\theta = 53°$

$\Rightarrow \vec{F}_1 = 50N\,\hat{i}$

$\& \ \vec{F}_2 = 120N(-\hat{j})$

$\& \ \vec{F}_3 = F_{3x}\hat{i} + F_{3y}\hat{j},$

where $F_{3x} = -250\,N\cos(53°) = -150N$ &

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so $R_x = 50N - 150N$

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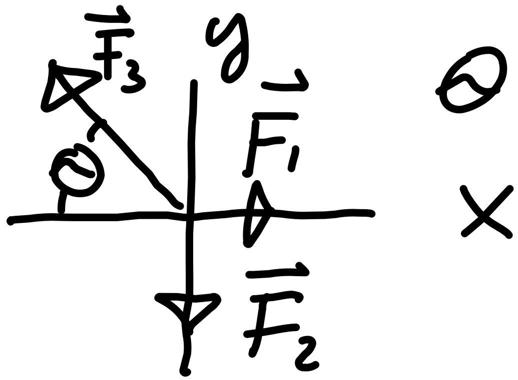

$\theta = 53°$

$\Rightarrow \vec{F}_1 = 50N\,\hat{i}$

& $\vec{F}_2 = 120N(-\hat{j})$

& $\vec{F}_3 = F_{3x}\hat{i} + F_{3y}\hat{j}$,

where $F_{3x} = -250N\cos(53°) = -150N$ &

$F_{3y} = -250N\sin(53°) = 200N$

so $R_x = 50N - 150N = -100N$

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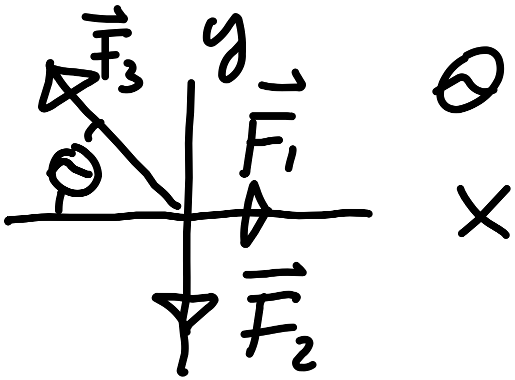

$\theta = 53°$

$\Rightarrow \vec{F}_1 = 50N\,\hat{i}$

& $\vec{F}_2 = 120N(-\hat{j})$

& $\vec{F}_3 = F_{3x}\hat{i} + F_{3y}\hat{j}$,

where $F_{3x} = -250\ N\cos(53°) = -150N$ &

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so $R_x = 50N - 150N = -100N$ &

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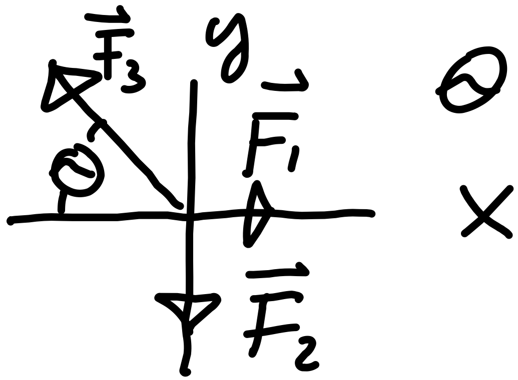

$\theta = 53°$

$\Rightarrow \vec{F}_1 = 50\mathrm{N}\,\hat{i}$

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$F_{3y} = -250\mathrm{N}\sin(53°) = 200\mathrm{N}$

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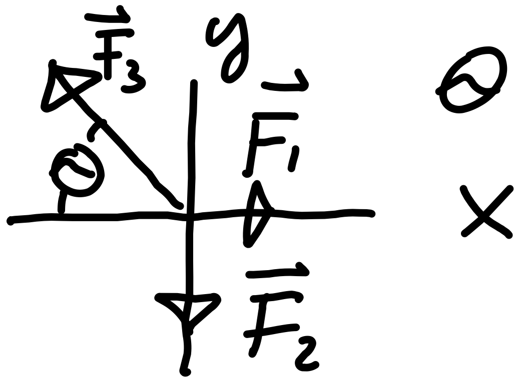

$\theta = 53°$

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& $\vec{F}_3 = F_{3x}\hat{i} + F_{3y}\hat{j}$,

where $F_{3x} = -250\,N\cos(53°) = -150\,N$ &

$F_{3y} = -250\,N\sin(53°) = 200\,N$

so $R_x = 50N - 150N = -100N$ &

$R_y = -120N + 200N = 80N$

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So $\vec{R} = -100\text{N}\,\hat{i} + 80\text{N}\,\hat{j}$

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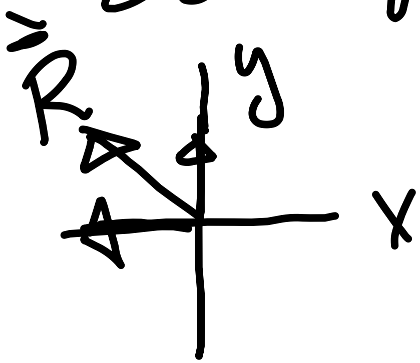

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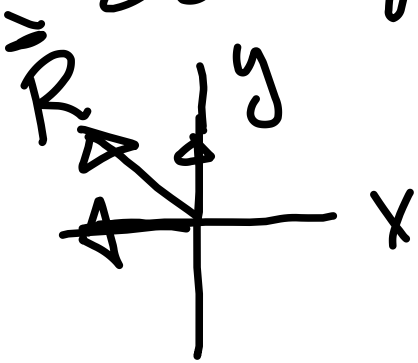

& $R = \sqrt{R_x^2 + R_y^2}$

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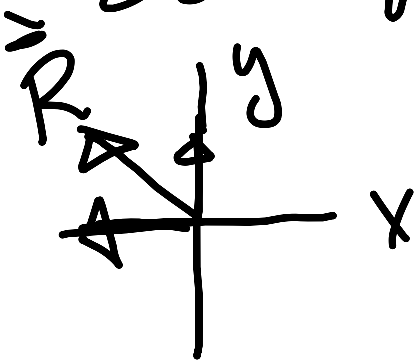

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$$R = \sqrt{R_x^2 + R_y^2}$$

$$= \sqrt{100^2 + 80^2}\ N$$

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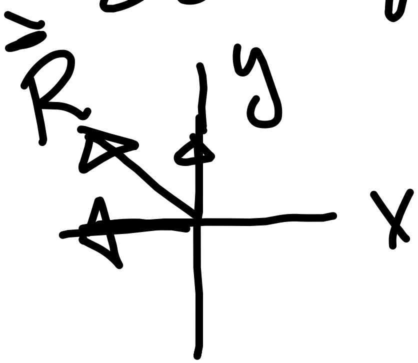

&

$$R = \sqrt{R_x^2 + R_y^2} = \sqrt{100^2 + 80^2}\ \mathrm{N} = 128\mathrm{N}$$

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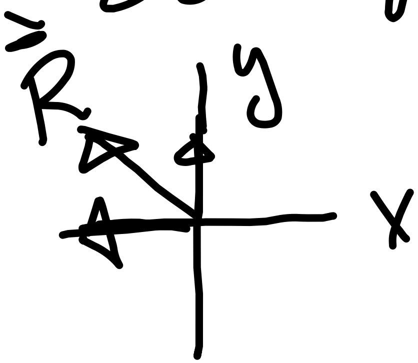

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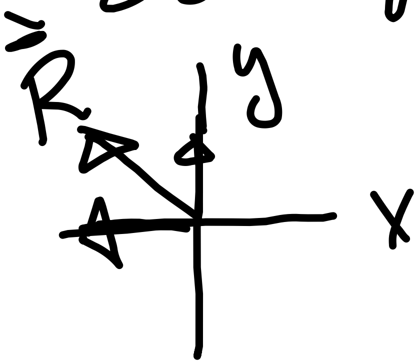

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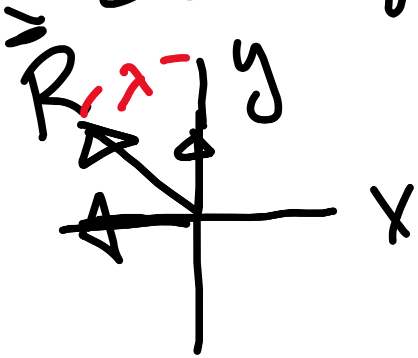

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$\tan\lambda = \frac{R_x}{R_y}$

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&

$$R = \sqrt{R_x^2 + R_y^2}$$

$$= \sqrt{100^2 + 80^2}\ N = 128N$$

$$\tan\lambda = \frac{R_x}{R_y} = \frac{100}{80}$$

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So $\vec{R} = -100\mathrm{N}\,\hat{i} + 80\mathrm{N}\,\hat{j}$

&

$$R = \sqrt{R_x^2 + R_y^2}$$

$$= \sqrt{100^2 + 80^2}\ \mathrm{N} = 128\mathrm{N}$$

$$\tan\lambda = \frac{R_x}{R_y} = \frac{100}{80} \Rightarrow \lambda = \tan^{-1}\left(\frac{100}{80}\right)$$

ASU

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So $\vec{R} = -100N\,\hat{i} + 80N\,\hat{j}$

& $R = \sqrt{R_x^2 + R_y^2}$

$= \sqrt{100^2 + 80^2}\,N = 128N$

$\tan\lambda = \frac{R_x}{R_y} = \frac{100}{80} \Rightarrow \lambda = \tan^{-1}\left(\frac{100}{80}\right)$

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$$\vec{R} = -100\,\mathrm{N}\,\hat{i} + 80\,\mathrm{N}\,\hat{j}$$

&

$$R = \sqrt{R_x^2 + R_y^2} = \sqrt{100^2 + 80^2}\ \mathrm{N} = 128\,\mathrm{N}$$

$$\tan\lambda = \frac{R_x}{R_y} = \frac{100}{80} \Rightarrow \lambda = \tan^{-1}\left(\frac{100}{80}\right)$$

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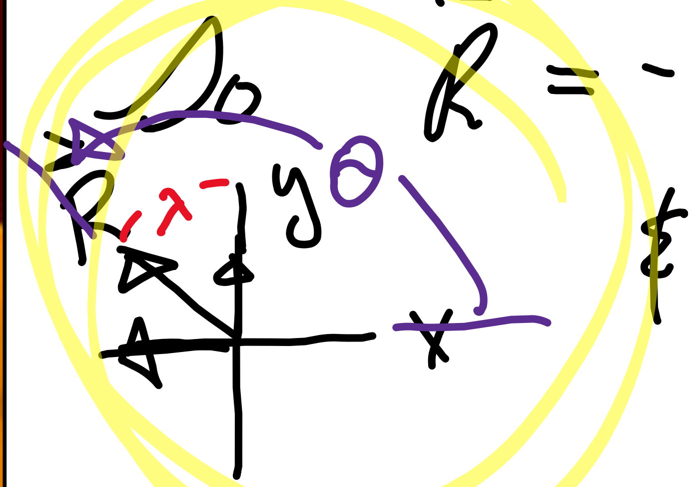


$$\vec{R} = -100\text{N}\,\hat{i} + 80\text{N}\,\hat{j}$$

$$R = \sqrt{R_x^2 + R_y^2}$$

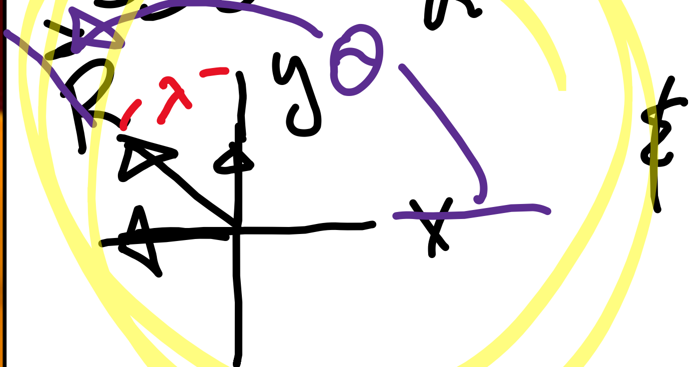
$$= \sqrt{100^2 + 80^2}\ \text{N} = 128\text{N}$$

$$\tan\lambda = \frac{R_x}{R_y} = \frac{100}{80} \Rightarrow \lambda = \tan^{-1}\left(\frac{100}{80}\right)$$

$$\Rightarrow \lambda = 51^\circ \quad \text{But } \theta = 90^\circ + \lambda$$

Three professional wrestlers are fighting over a champion's belt. Figure 4.7a shows the horizontal force each wrestler applies to the belt, as viewed from above. The forces have magnitudes $F_1 = 50\ \text{N}$, $F_2 = 120\ \text{N}$, and $F_3 = 250\ \text{N}$. Find the x- and y-components of the net force on the belt, and find its magnitude and direction.

So



$$\vec{R} = -100N\,\hat{i} + 80N\,\hat{j}$$

$$R = \sqrt{R_x^2 + R_y^2} = \sqrt{100^2 + 80^2}\,N = 128N$$

$$\tan\lambda = \frac{R_x}{R_y} = \frac{100}{80} \Rightarrow \lambda = \tan^{-1}\left(\frac{100}{80}\right)$$

$$\Rightarrow \lambda = 51^\circ \quad \text{But } \theta = 90^\circ + \lambda$$

So $\theta = 141^\circ$

Newton's First law

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

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$$\vec{F} = m\vec{a}$$ so, if

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$\vec{v} = \text{constant}$

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No force $\Rightarrow$ constant velocity

Newton's First law

$\vec{F} = m\vec{a}$ so, if

$\vec{F} = 0$ then $\vec{a} = 0$ &

$\vec{v} = \text{constant}$

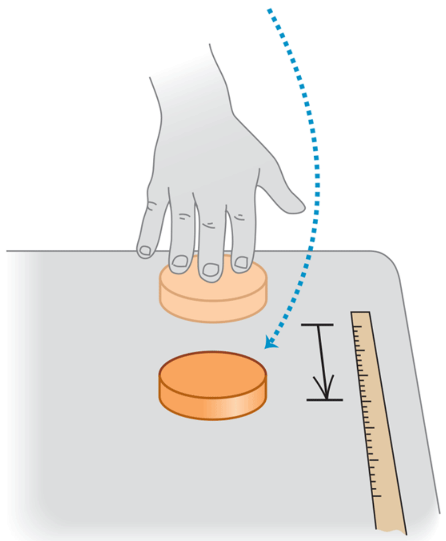
No force ⇒ constant velocity

Net force ⇒ acceleration

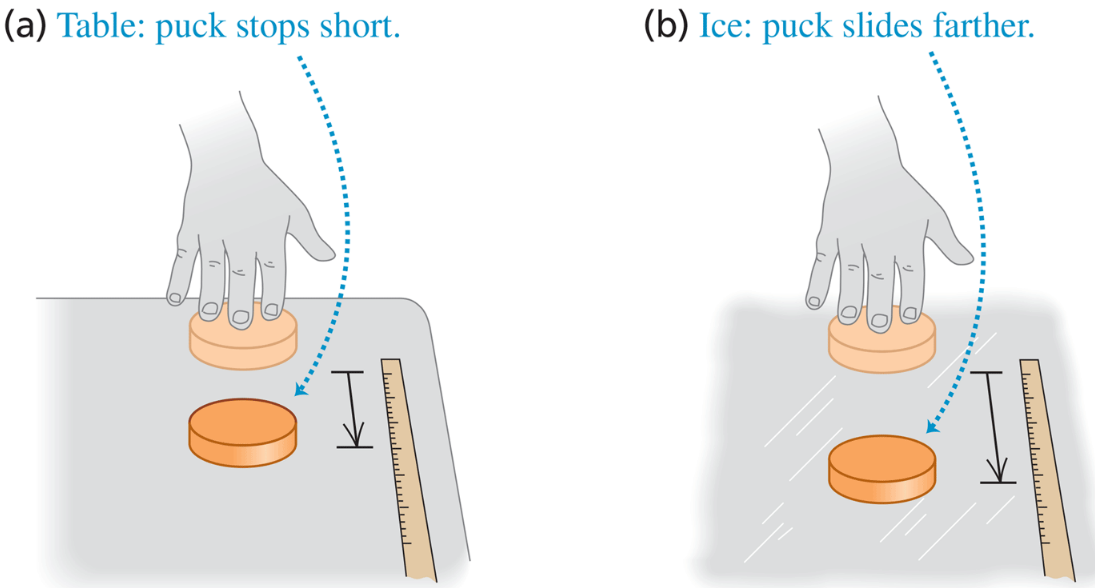
Motion of disk on different surfaces

Motion of disk on different surfaces

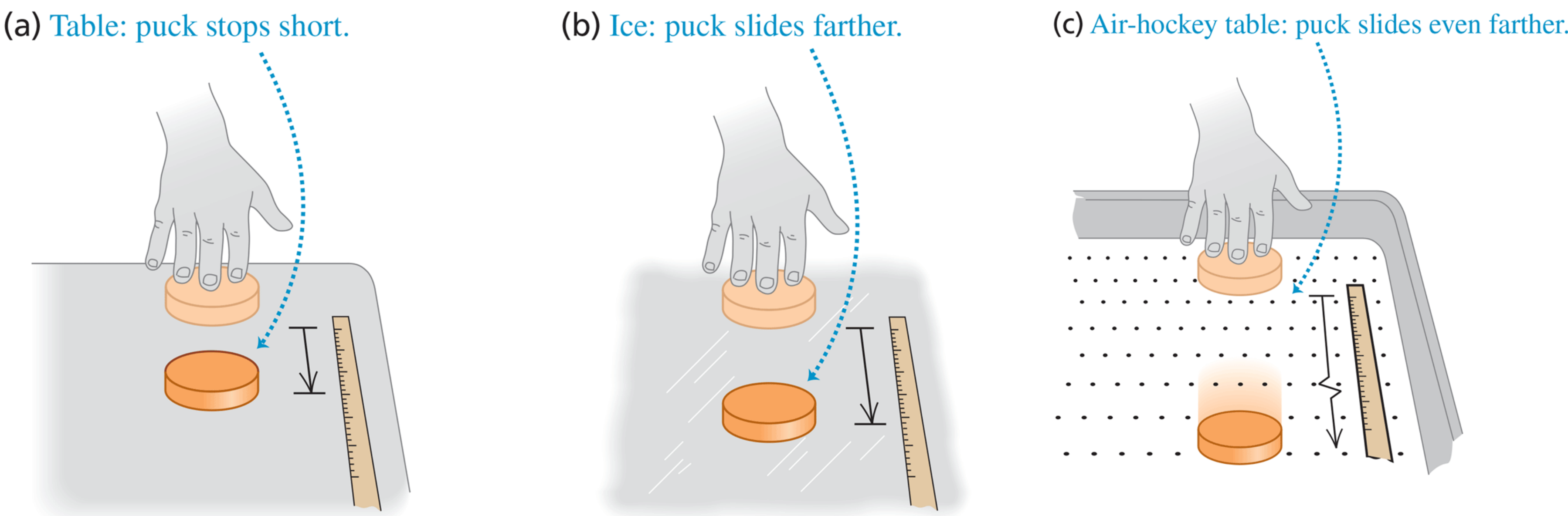
(a) Table: puck stops short.



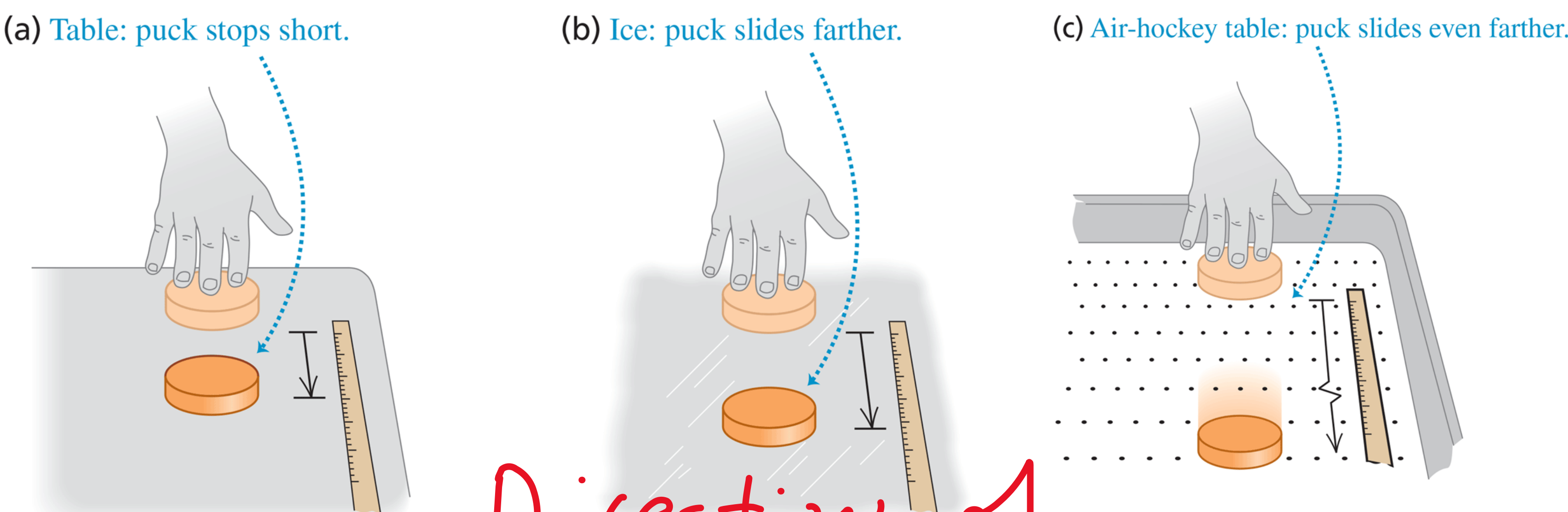
Motion of disk on different surfaces



Motion of disk on different surfaces



Motion of disk on different surfaces



Direction of

Less frictional force opposing the motion of disk

Newton's First law

$$\vec{F} = m\vec{a}$$ ← mathematical form

Newton's First law

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

word form

Newton's first law of motion

An object acted on by no net external force has a constant velocity (which may be zero) and zero acceleration

Newton's First law

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

Newton's first law of motion
An object acted on by no net external force has a constant velocity (which may be zero) and zero acceleration

Inertia ≡ Tendency of an object to keep moving once it is in motion

Inertial Frame

An inertial frame of reference is a reference frame where $\vec{F} = m\vec{a}$ is valid.

ASU

Inertial frame

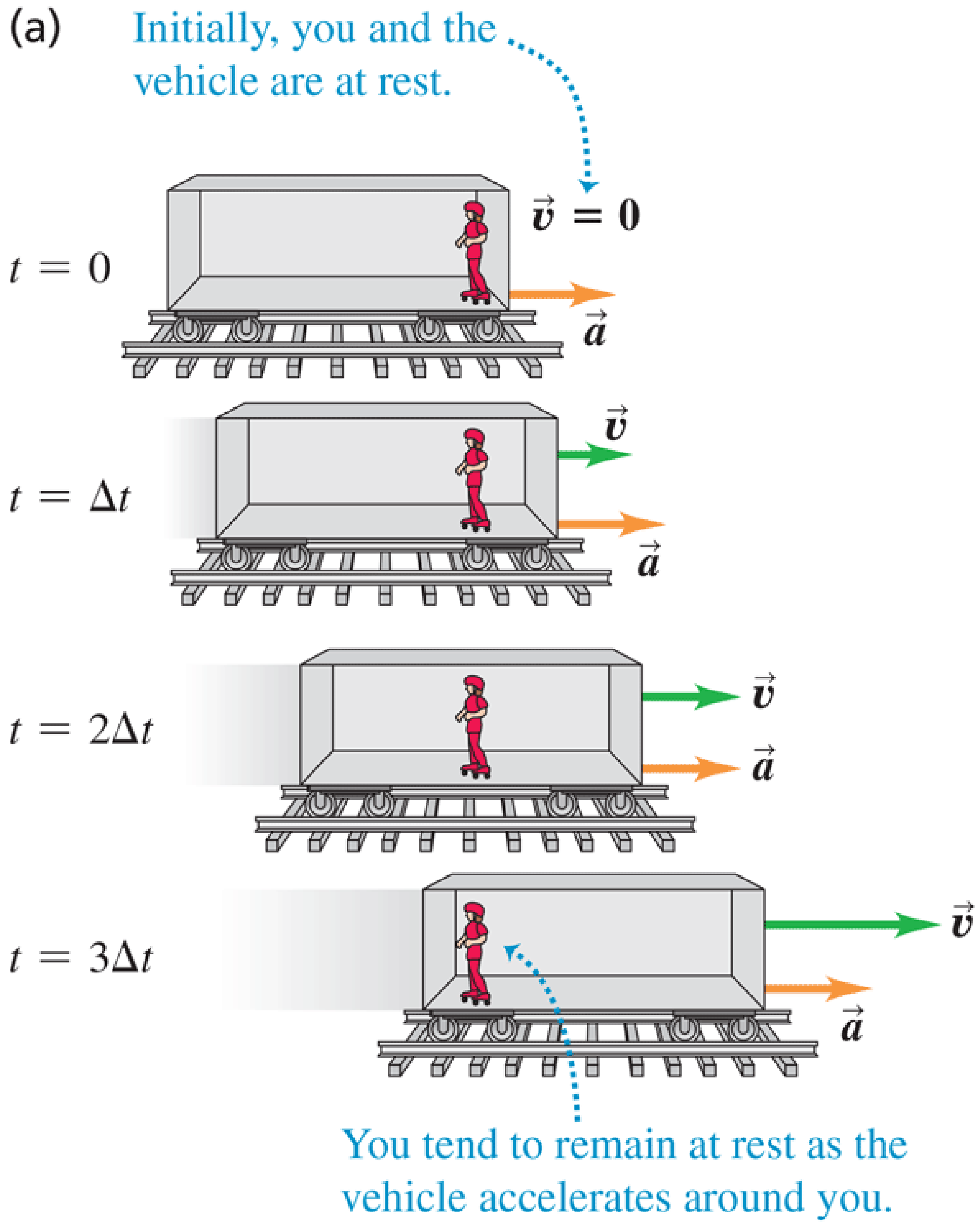
An inertial frame of reference is a reference frame where $\vec{F} = m\vec{a}$ is valid.

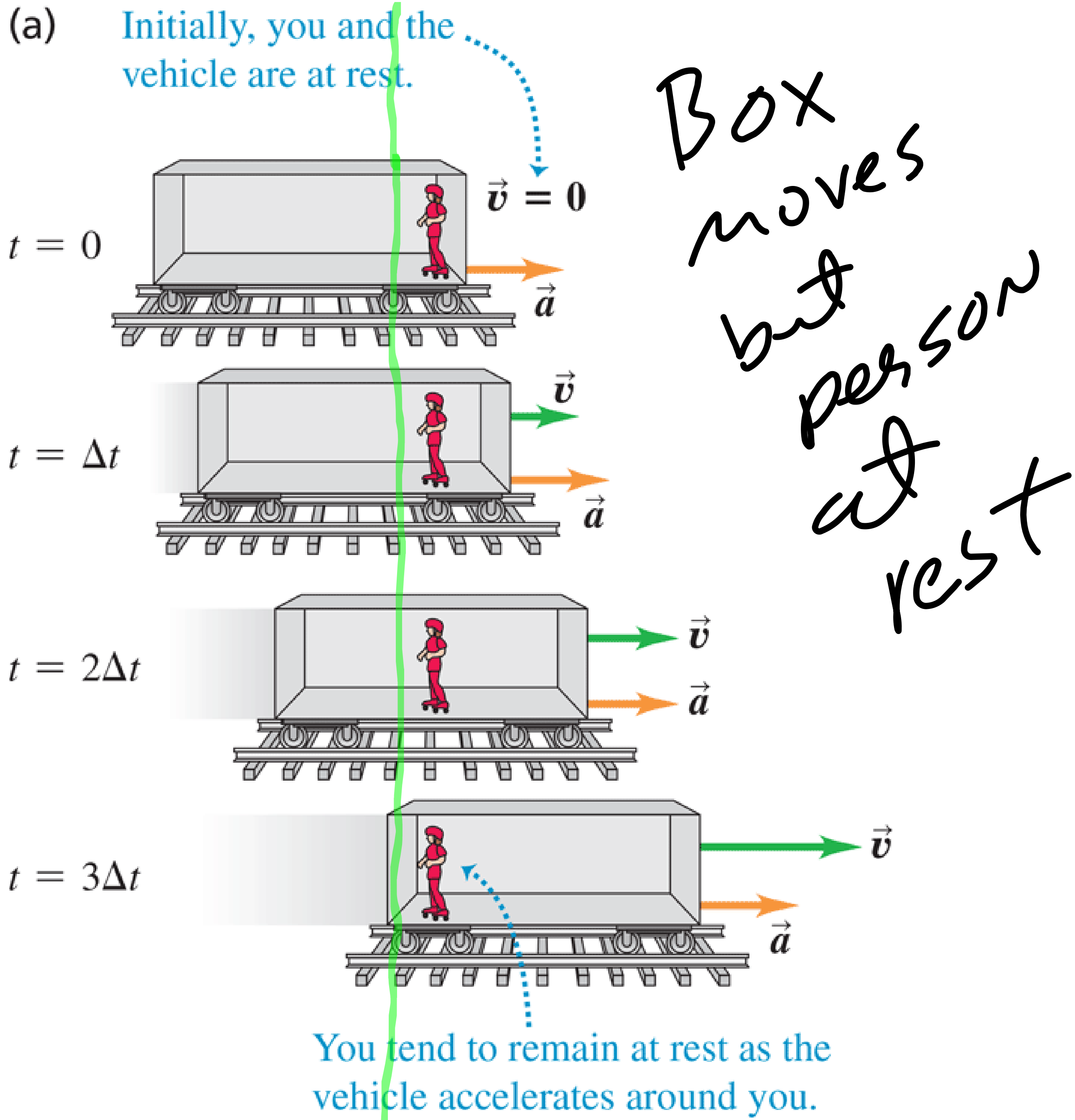
A non inertial frame is just a frame that is itself accelerating

Inertial frame

An inertial frame of reference is a reference frame where $\vec{F} = m\vec{a}$ is valid.

A non inertial frame is just a frame that is itself accelerating $\rightarrow$ messes up $\vec{F} = m\vec{a}$ since there is acceleration of the frame not being accounted for


(a)
Initially, you and the vehicle are at rest.
$t = 0$
$\vec{v} = 0$
$\vec{a}$
$t = \Delta t$
$\vec{v}$
$\vec{a}$
$t = 2\Delta t$
$\vec{v}$
$\vec{a}$
$t = 3\Delta t$
$\vec{v}$
$\vec{a}$
You tend to remain at rest as the vehicle accelerates around you.


(a)
Initially, you and the vehicle are at rest.
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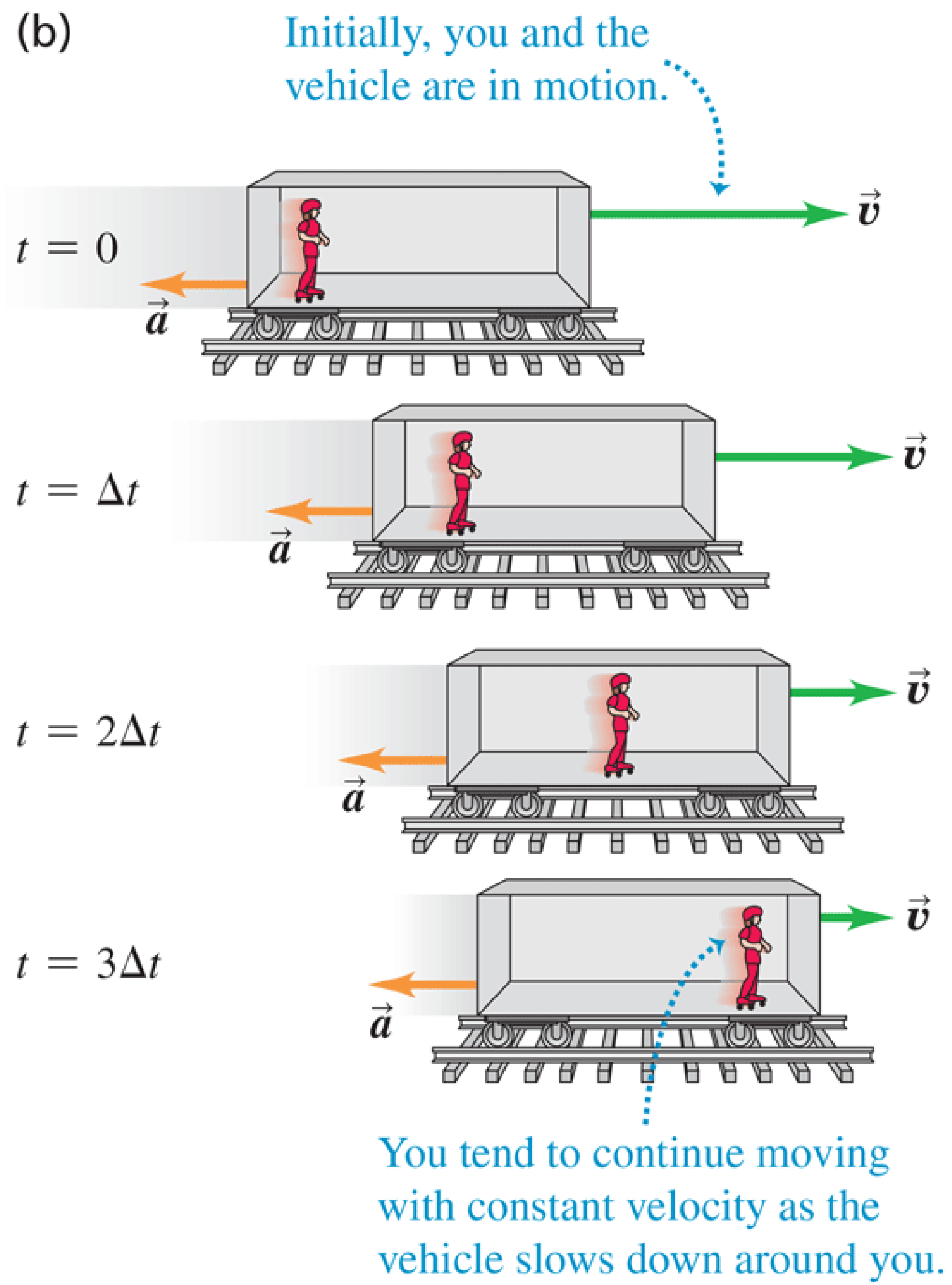
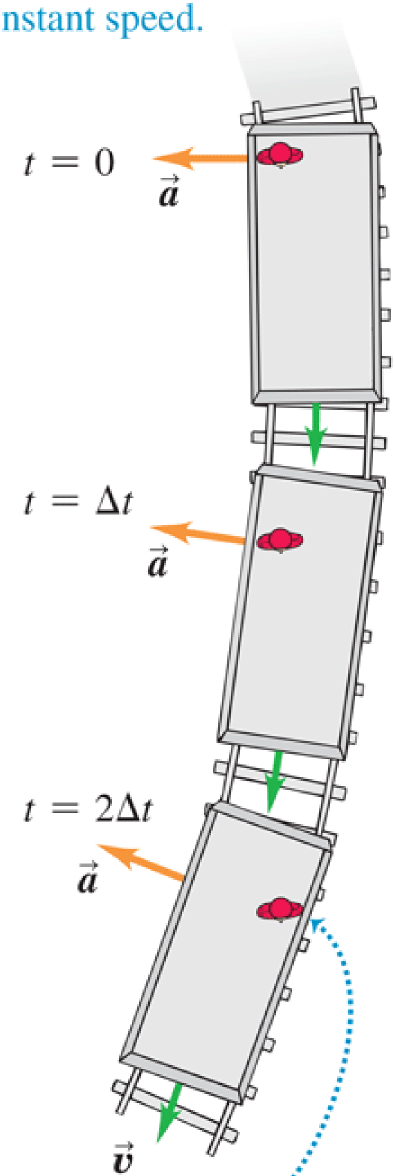
$\vec{v}$
$\vec{a}$
$t = 2\Delta t$
$\vec{v}$
$\vec{a}$
$t = 3\Delta t$
$\vec{v}$
$\vec{a}$
You tend to remain at rest as the vehicle accelerates around you.
Box moves but person at rest


(b)
Initially, you and the vehicle are in motion.
t = 0
t = Δt
t = 2Δt
t = 3Δt
You tend to continue moving with constant velocity as the vehicle slows down around you.

(c) The vehicle rounds a turn at constant speed.



You tend to continue moving in a straight line as the vehicle turns.