Rutgers University
Department of Physics & Astronomy

01:750:271 Honors Physics I
Fall 2015

Lecture 6

Midterm 1: Monday October 10th 2015

- Motion in one, two and three dimensions
- Forces and Motion I (Newton's laws)
- No energy and work.
- Practice problems and sample exam posted at physics.rutgers.edu/ugrad/271/exams.html

Webassign Troubleshooting

- If correct answers are marked incorrect by the system, please send me a screenshot of the problem in question and your answer after the due date.

5. Forces and Motion I

- **Force:** $\sim$ physical effect which changes the velocity of an object

- **Newton's 1st law**

  If no net force acts on a body,

  $$\vec{F}_{\text{net}} = 0,$$

  the body's velocity cannot change;

  the body cannot accelerate.

- **Inertial System:** reference system where Newton's laws are valid

What is the main effect of a nonzero net force?

- An applied force can set a static object in motion or can stop a moving object.

$$\Downarrow$$

change in velocity, hence acceleration.

What is the relation between the net force acting on an object and the resulting acceleration?

$$\Downarrow$$

Newton's second law

$$\boxed{\vec{F}_{\text{net}} = m\vec{a},}$$

- **m=Mass:** **intrinsic characteristic** of a body relating a force on the body to the resulting acceleration.

- **Force unit:** Newton (N)

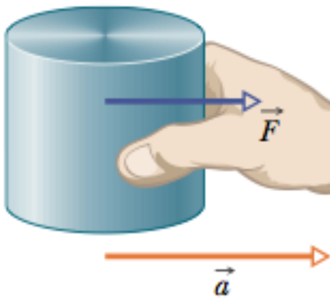

Fig. 5-1 A force $\vec{F}$ on the standard kilogram gives that body an acceleration $\vec{a}$.

1 Newton = the force exerted on a standard mass of 1 kg to produce an acceleration of 1 m/s^2.

Home Page

Title Page

Page 6 of 30

Go Back

Full Screen

Close

Quit

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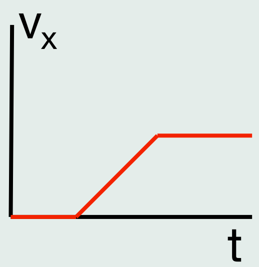
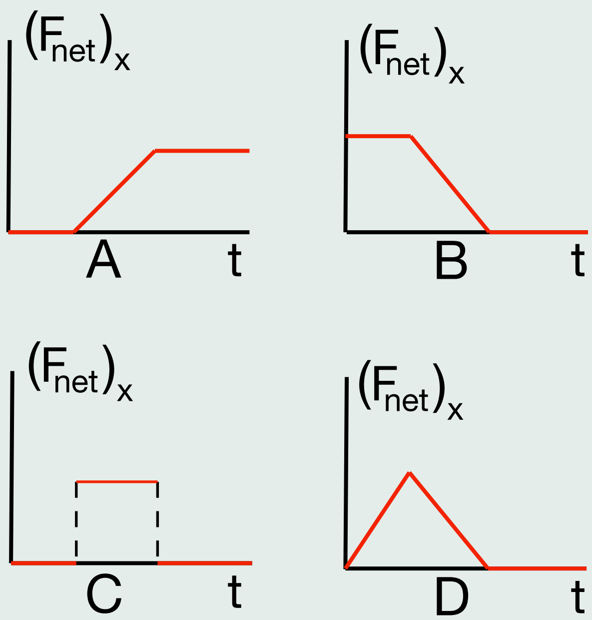
The graph below represents the x-component of the velocity of an object as a function of time.

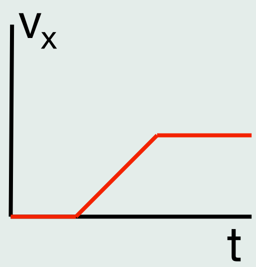


Which of the following graphs represents the time dependence of the x-component of the net force acting on the object?



Answer

The graph below represents the x-component of the velocity of an object as a function of time.



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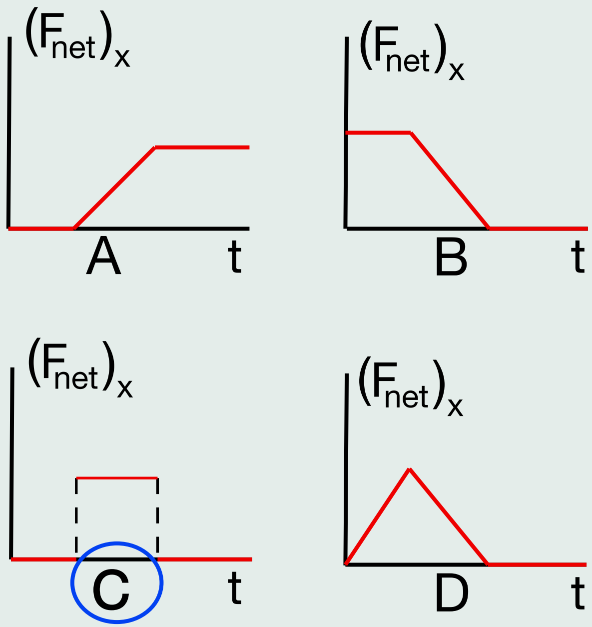
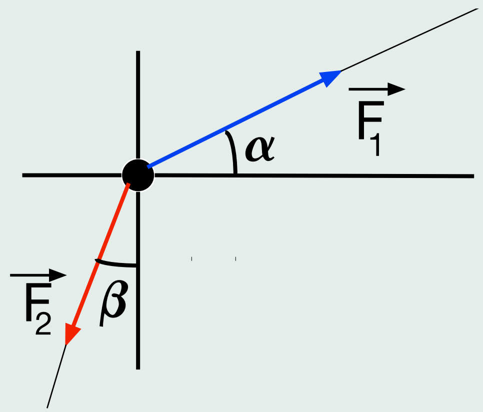
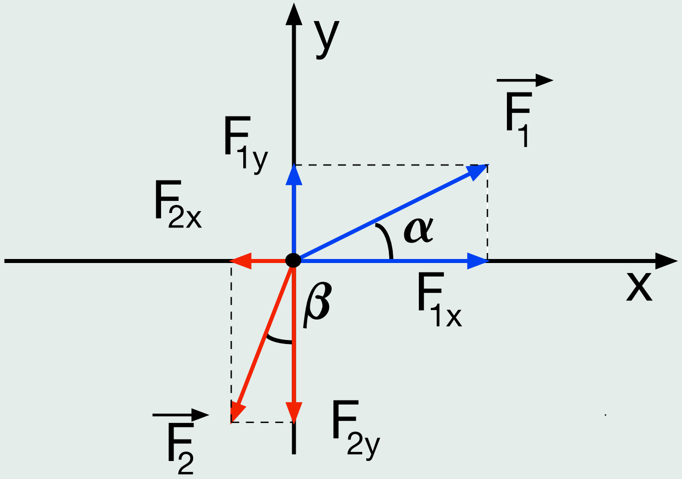


- **Example**: puck on frictionless ice

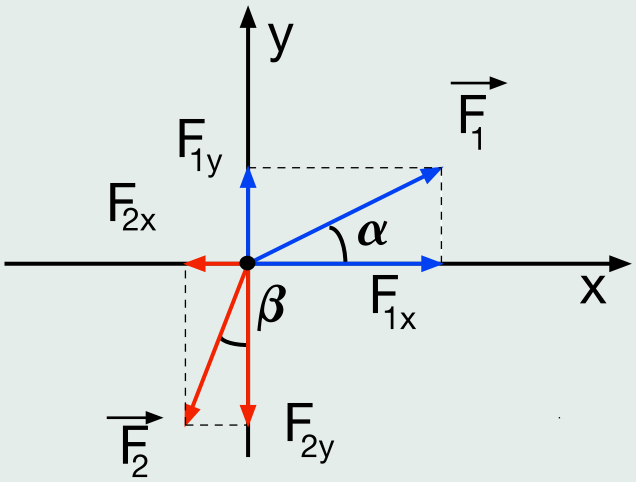


A puck of mass m is simultaneously pulled by two ideal cords as shown above. What is its acceleration?



Free body diagram.

Recall: ideal cord = massless, unstretchable cord



Free body diagram.

Newton's secon law:

$$\vec{F}_{\text{net}} = m\vec{a}$$

$$\vec{F}_{\text{net}} = \vec{F}_1 + \vec{F}_2$$

$$\begin{aligned}\left(\vec{F}_{\text{net}}\right)_x &= F_{1x} + F_{2x}\\ &= F_1\cos\alpha - F_2\sin\beta\end{aligned}$$

$$\begin{aligned}\left(\vec{F}_{\text{net}}\right)_y &= F_{1y} + F_{2y}\\ &= F_1\sin\alpha - F_2\cos\beta\end{aligned}$$

$$ma_x = F_1\cos\alpha - F_2\sin\beta$$

$$ma_y = F_1\sin\alpha - F_2\cos\beta$$

- **Gravitational force**

  - Pull force $\vec{F}_g$ acting on any object near the Earth's surface. How do we compute it ?

  - Free fall acceleration $\vec{a} = -g\widehat{j}$.

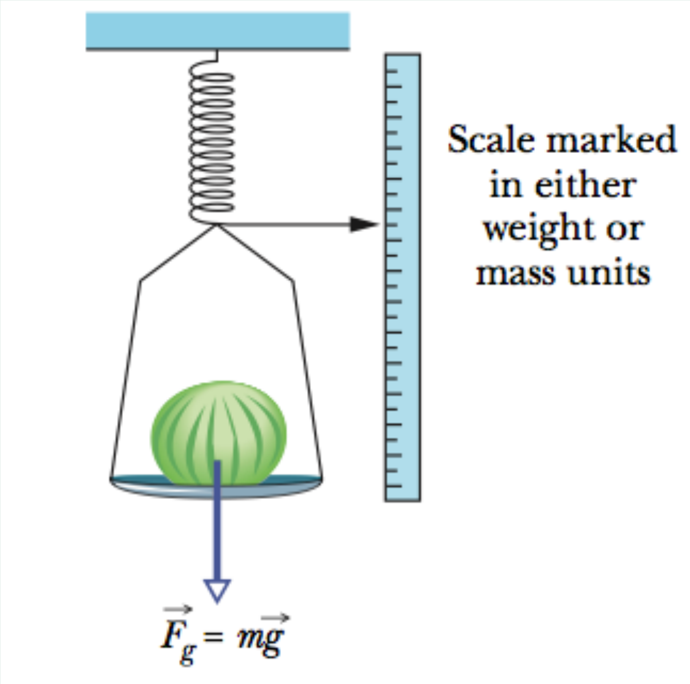
  - Newton's second law for freely falling object:

$$\boxed{\vec{F}_g = -mg\widehat{j}}$$

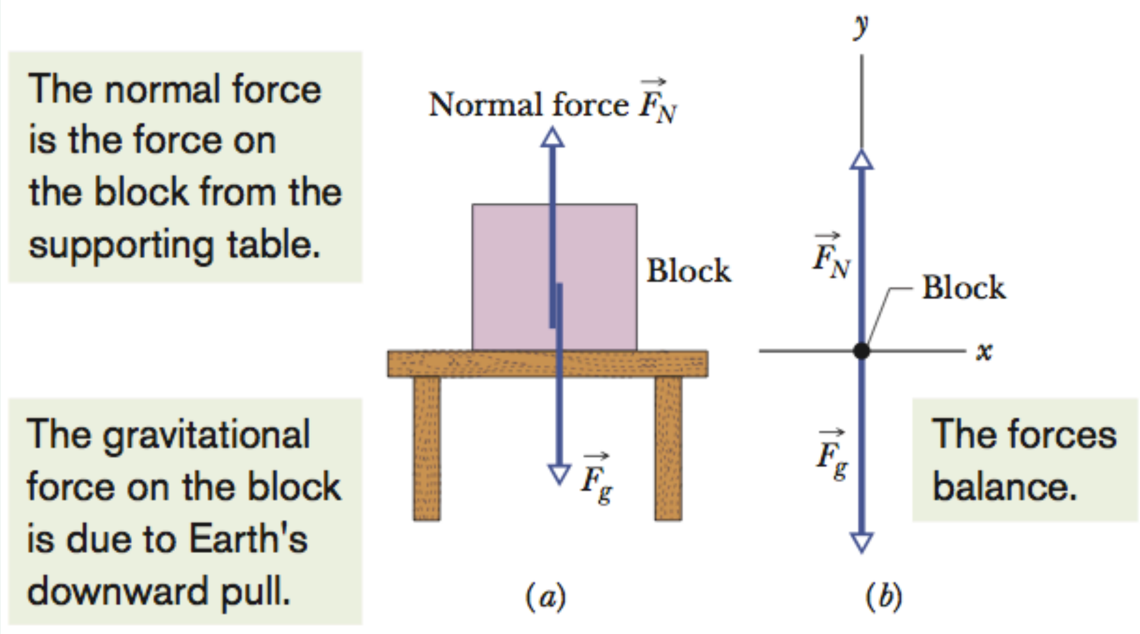
  - Note: approximation of a more general theory (studied later)

- **Weight:** magnitude of gravitational force acting on the object.

$$W = F_g = mg$$



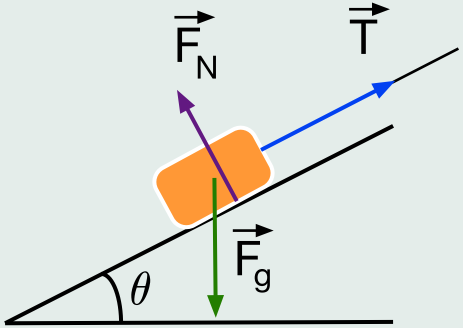
- **Normal force:** $\vec{F}_N$ stops the object from falling through; always perpendicular to the surface

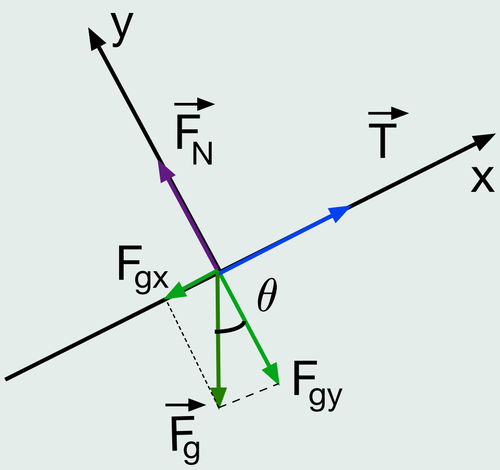


$$\vec{F}_N + \vec{F}_g = m\vec{a} \Rightarrow (F_N)_y + (F_g)_y = m a_y \Rightarrow F_N = m(g + a_y)$$

a_y vertical acceleration of table + block

- **Example:** box pulled up a frictionless inclined plane by an ideal cord





$$\vec{F}_{\text{net}} = m\vec{a} \qquad \vec{F}_{\text{net}} = \vec{F}_g + \vec{F}_N + \vec{T}$$

$$T - mg\sin\theta = ma_x \qquad F_N - mg\cos\theta = ma_y$$

$$a_y = 0 \text{ (no motion along y axis)} \Rightarrow F_N = mg\cos\theta.$$

$$a_x = (T - mg\sin\theta)/m$$

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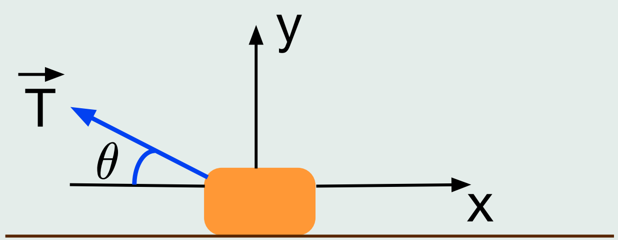
A box of mass m is pulled along a frictionless table as shown below. What is the horizontal component a_x of the accleration of the box?



A) $a_x = 0$

B) $a_x = -(T/m)\cos\theta$

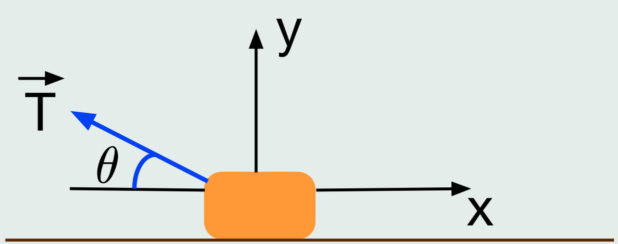
C) $a_x = T/m$

D) $a_x = (T/m)\sin\theta$

E) $a_x = -T/m$

Answer

A box of mass m is pulled along a frictionless table as shown below. What is the horizontal component a_x of the accleration of the box?



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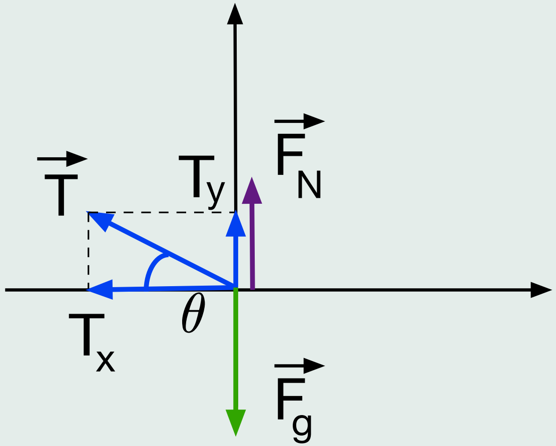


$$\vec{F}_{\text{net}} = m\vec{a}$$

$$\vec{F}_{\text{net}} = \vec{T} + \vec{F}_g + \vec{F}_N$$

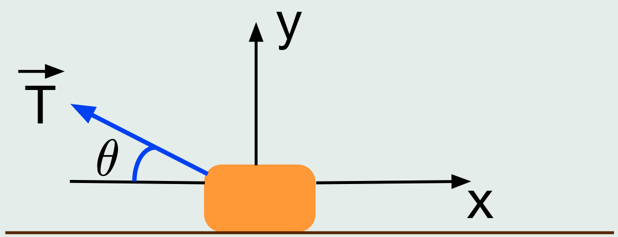
$$(F_{\text{net}})_x = T_x = -T\cos\theta$$

$$ma_x = -T\cos\theta$$

$$a = -(T/m)\cos\theta$$

i-Clicker

A box of mass m is pulled along a frictionless table as shown below. For which values of T, m, θ will the box remain on the table?



$A)$ For all values of T, m, θ

$B)$ $T\sin\theta > mg$

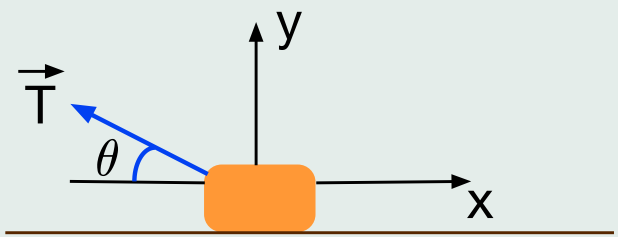
$C)$ $T\sin\theta \leq mg$

$D)$ $T\cos\theta < mg$

$E)$ None one the above

Answer

A box of mass m is pulled along a frictionless table as shown below. For which values of T, m, θ will the box remain on the table?



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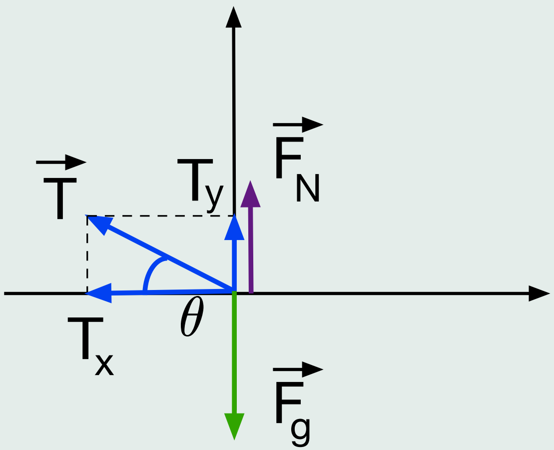


$$\vec{F}_{\text{net}} = m\vec{a}$$
$$\vec{F}_{\text{net}} = \vec{T} + \vec{F}_g + \vec{F}_N$$
$$(F_{\text{net}})_y = T\sin\theta + F_N - mg$$
$$ma_y = T\sin\theta + F_N - mg$$

The condition for the box to stay on the table is

$$a_y = 0 \;\Rightarrow T\sin\theta + F_N - mg = 0.$$

Note that $F_N \geq 0$ since it is the magnitude of $\vec{F}_N$. Hence

$$T\sin\theta \leq mg$$

Home Page

Title Page

◀◀ ▶▶

◀ ▶

Go Back

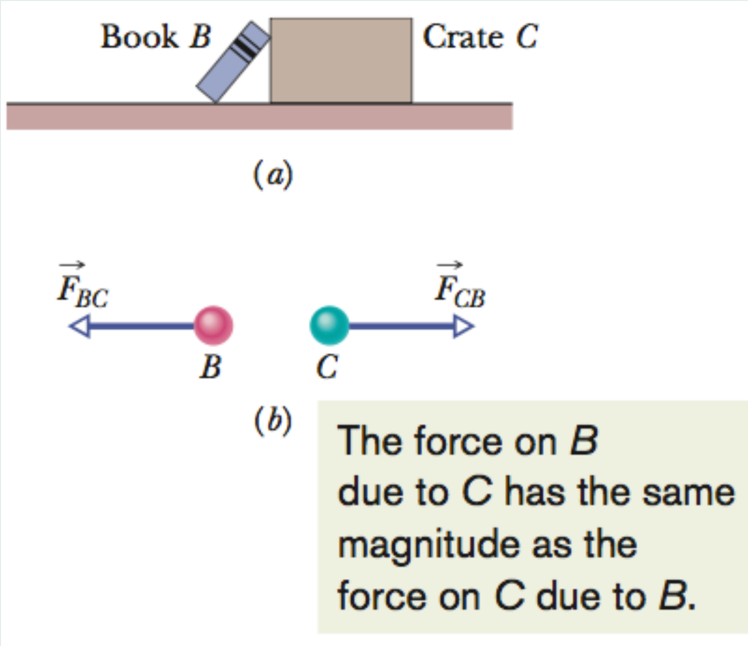
Full Screen

Close

Quit

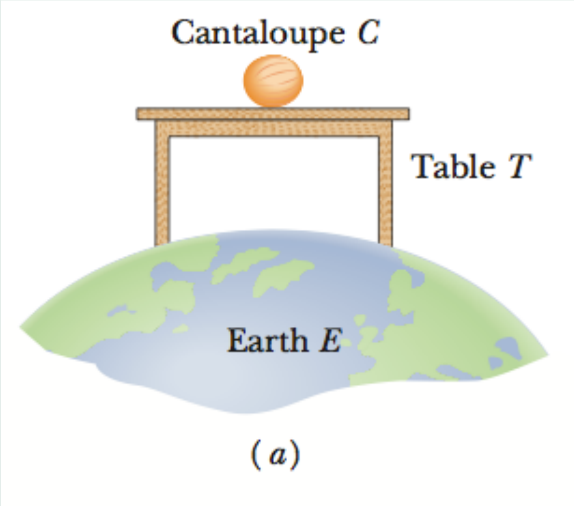
Newton's Third Law

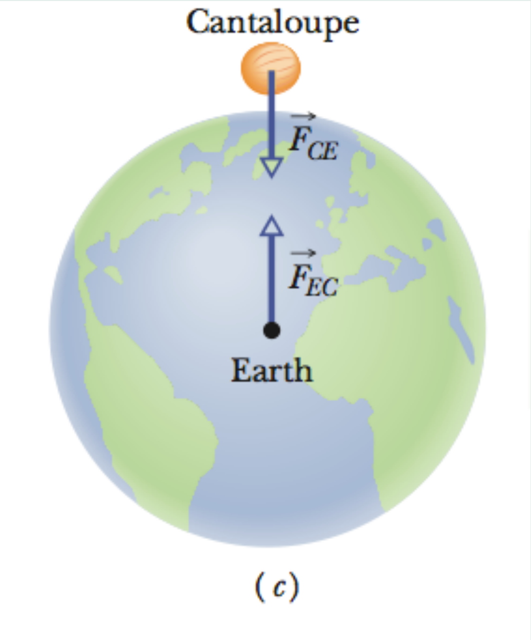
When two bodies interact, the forces on the bodies from each other are always equal in magnitude and opposite in direction.

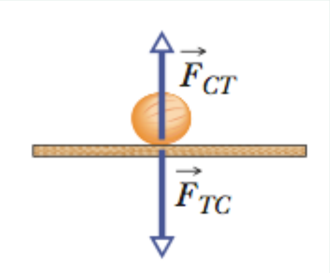


$$\vec{F}_{BC} + \vec{F}_{CB} = 0$$

$$F_{BC} = F_{CB}$$

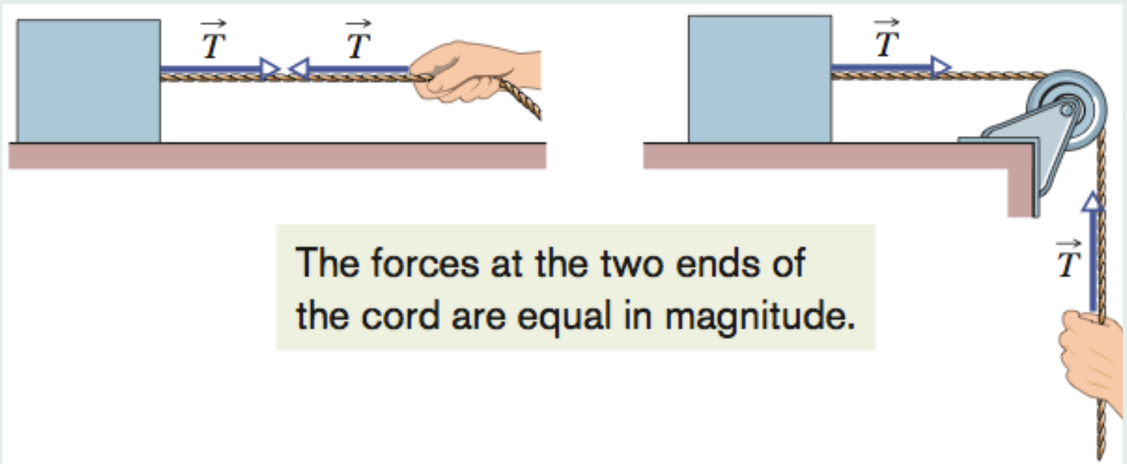


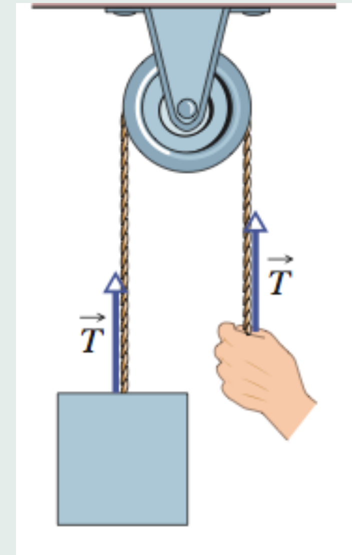




$$\vec{F}_{CE} + \vec{F}_{EC} = 0$$
$$\vec{F}_{CT} + \vec{F}_{TC} = 0$$

- Tension, cords, pulleys



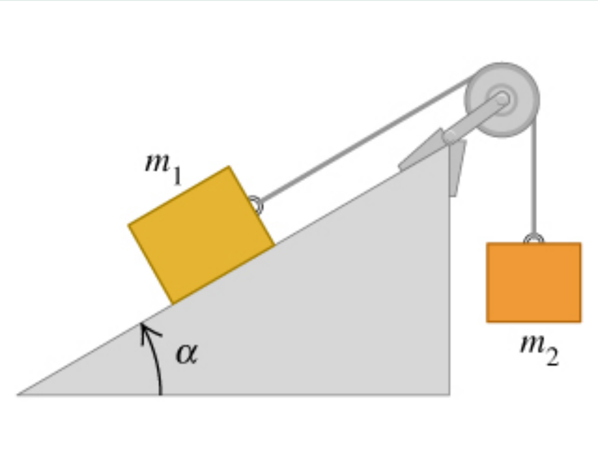


Ideal cord: massless, unstretchable

Ideal pulley: massless, frictionless

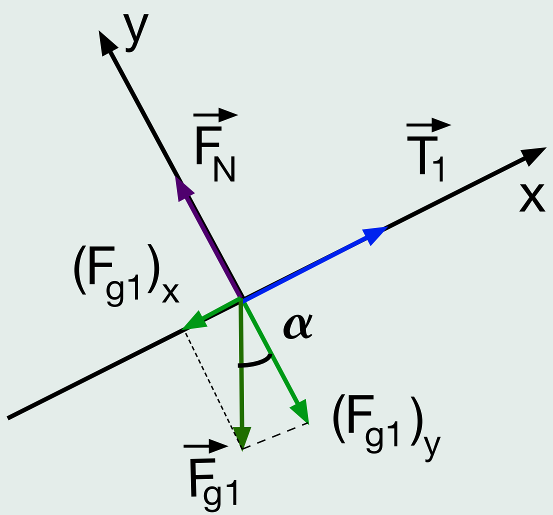
The forces at the two ends are always equal in magnitude.

- **Example:**



- The object of mass m_2 hangs at the end of an ideal cord tied to the object of mass m_1.
- The object of mass m_1 is placed on a frictionless inclined plane.
- The cord is wrapped around an ideal pulley attached to the plane.
- Find the acceleration $\vec{a}_2$.

Step 1: free body diagram for object 1



$$\vec{F}_{\text{net1}} = m_1\vec{a}_1$$

$$\vec{F}_{\text{net1}} = \vec{T}_1 + \vec{F}_{g1} + \vec{F}_N$$

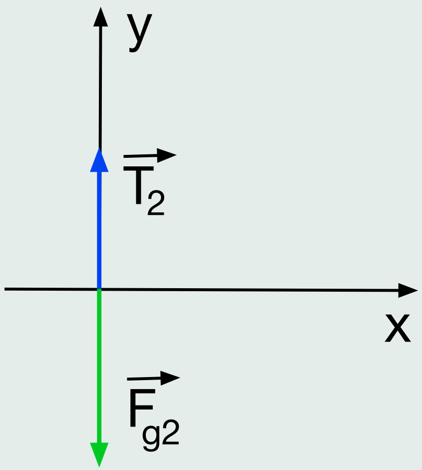
$$(F_N)_x = 0, \quad (F_{g1})_x = -m_1 g\sin\alpha$$

$$T_1 - m_1 g\sin\alpha = m_1 a_{1x}$$

$$a_{1y} = 0 \text{ (no motion } \perp \text{ to plane)}$$

$$m_1 a_{1x} = T_1 - m_1 g\sin\alpha$$

Step 2: free body diagram for object 2



$$\vec{F}_{\text{net2}} = m_2\vec{a}_2$$
$$\vec{F}_{\text{net2}} = \vec{T}_2 + \vec{F}_{g2}$$
$$(F_{\text{net2}})_x = 0 \qquad (F_{\text{net2}})_y = T_2 - m_2 g$$
$$m_2 a_{2x} = 0 \qquad m_2 a_{2y} = T_2 - m_2 g$$

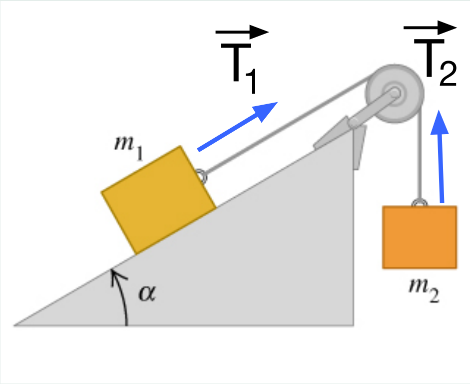
Step 3: put equations together

$$m_1 a_{1x} = T_1 - m_1 g \sin\alpha$$

Can we solve?

$$m_2 a_{2y} = T_2 - m_2 g$$

Need extra conditions!



$$T_1 = T_2$$

$$(\Delta x)_1 = -(\Delta y)_2 \text{ at all times}$$

$$\Downarrow$$

$$a_{1x} = -a_{2y}$$

$$m_1 a_{1x} = T_1 - m_1 g \sin\alpha$$

Can we solve?

$$m_2 a_{2y} = T_2 - m_2 g$$

Yes!

$$T_1 = T_2$$

$$a_{1x} = -a_{2y}$$

$$(m_1 + m_2) a_{2y} = m_1 g \sin\alpha - m_2 g$$

$$a_{2y} = \frac{m_1 g \sin\alpha - m_2 g}{m_1 + m_2}$$

Which way will box 2 move? Up or down?

$$a_{2y} = \frac{m_1 g \sin\alpha - m_2 g}{m_1 + m_2}$$

$$a_{2y} > 0 \iff m_1 \sin\alpha > m_2 \quad \text{Up}$$

$$a_{2y} < 0 \iff m_1 \sin\alpha < m_2 \quad \text{Down}$$

$$a_{2y} = 0 \iff m_1 \sin\alpha = m_2 \quad \text{No motion (if initial velocity is 0)}$$