Some Basic Information

When Newton's laws are applied, *external forces* are only of interest!!

Why? Because, as described in Newton's first law, an object will keep its current motion unless non-zero net external force is applied.

Normal Force, **n**: Reaction force that reacts to gravitational force due to the surface structure of an object. Its direction is perpendicular to the surface.

Tension, **T**: The reactionary force by a stringy object against an external force exerted on it.

Free-body diagram: A graphical tool which is a **diagram of external forces on an object** and is extremely useful analyzing forces and motion!! Drawn only on an object.

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Free Body Diagrams

- Diagrams of vector forces acting on an object
- A great tool to solve a problem using forces or using dynamics
- Select a point on an object and w/ information given
- Identify all the forces acting only on the selected object
- Define a reference frame with positive and negative axes specified
- Draw arrows to represent the force vectors on the selected point
- Write down net force vector equation
- Write down the forces in components to solve the problems
- No matter which one we choose to draw the diagram on, the results should be the same, as long as they are from the same motion

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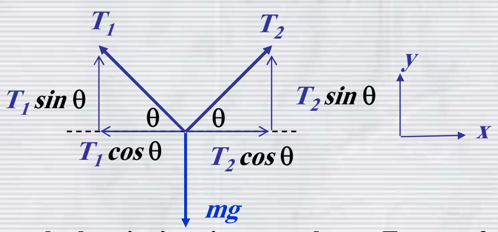
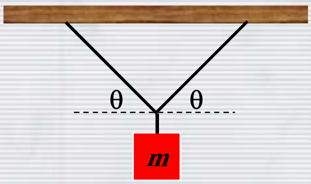
SOME APPLICATIONS OF NEWTON'S LAWS

Example: Tension and Angles

A box is suspended from the ceiling by two ropes making an angle θ with the horizontal. What is the tension in each rope?

Draw a FBD:





Since the box isn't going anywhere, $F_{x,NET} = 0$ **and** $F_{y,NET} = 0$

$$\Sigma F_x = T_2 \cos\theta - T_1 \cos\theta = 0 \quad \Rightarrow \quad T_1 = T_2$$

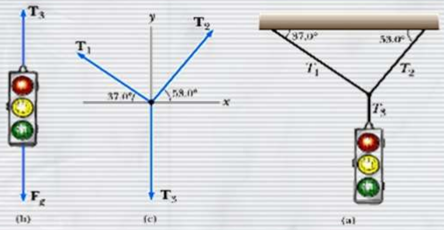
$$\Sigma F_y = T_1 \sin\theta + T_2 \sin\theta - mg = 0 \quad \Rightarrow \quad T_1 = T_2 = \frac{mg}{2\sin\theta}$$

Example 5.4

A traffic light weighing 125 N hangs from a cable tied to two other cables fastened to a support as shown in the figure. Find the tension in the three cables.

Newton's 2nd law $\sum \vec{F} = m \cdot \vec{a}$

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



x-comp. of net force

$$\sum F_x = 0 \Rightarrow -T_1 \cos(37^\circ) + T_2 \cos(53^\circ) = 0 \quad \therefore T_1 = \frac{\cos(53^\circ)}{\cos(37^\circ)} T_2 = 0.754\, T_2$$

y-comp. of net force

$$\sum F_y = 0 \Rightarrow T_1 \sin(37^\circ) + T_2 \sin(53^\circ) - m g = 0$$

$$T_2 \left[\sin(53^\circ) + 0.754 \times \sin(37^\circ) \right] = 1.25\, T_2 = 125\ N$$

$$T_2 = 100\ N; \quad T_1 = 0.754\ T_2 = 75.4\ N$$

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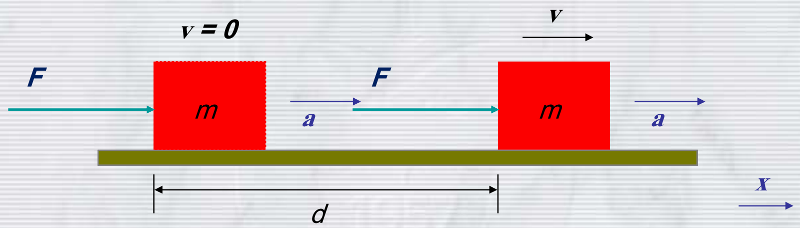
Example: Pushing a Box on Ice.

A skater is pushing a heavy box (mass m = 100 kg) across a sheet of ice (horizontal & frictionless). He applies a force of 50 N in the x direction. If the box starts at rest, what is its speed v after being pushed a distance d = 10 m ?



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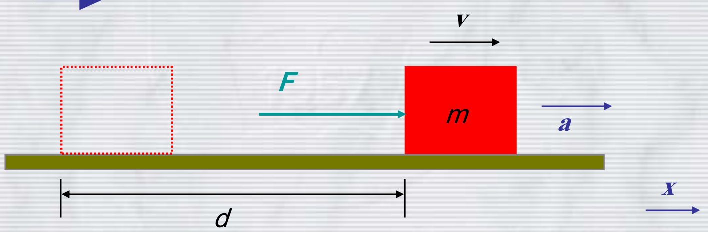
- Start with $F = ma$.
  - ➡ $a = F / m$.
  - Recall that $v^2 = v_0^2 + 2ax$
  - So $v = 2Fd / m$ ➡ $v = \sqrt{\dfrac{2Fd}{m}}$

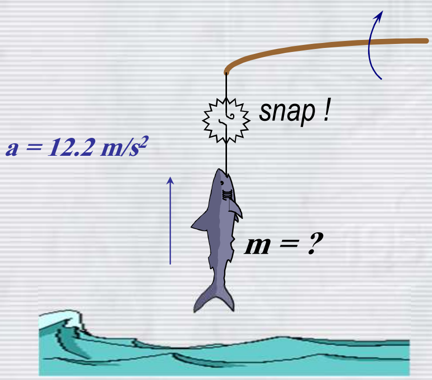
Plug in $F = 50$ N, $d = 10$ m, $m = 100$ kg:

➡ **$v = 3.2$ m/s.**

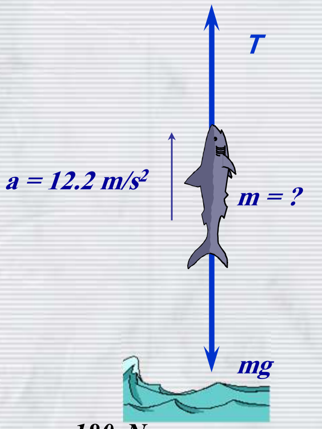


Example

A fish is being yanked upward out of the water using a fishing line that breaks when the tension reaches *180 N*. The string snaps when the acceleration of the fish is observed to be is *12.2 m/s²*. What is the mass of the fish?



- **Draw a Free Body Diagram**



Use Newton's 2nd law in the upward direction:

$$\Sigma F = ma$$

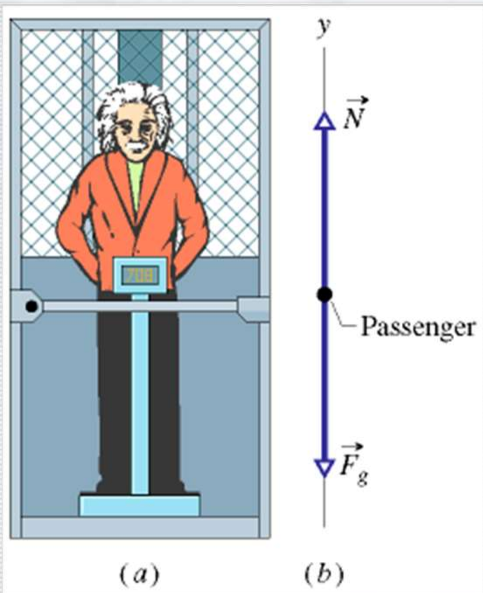
$$T - mg = ma$$

$$T = ma + mg = m(g+a)$$

$$\Rightarrow \quad m = \frac{T}{g+a} \quad \Rightarrow \quad m = \frac{180\ N}{(9.8 + 12.2)\ m/s^2} = 8.2\ kg$$

EXAMPLE APPERENT WEIGHT

In the Figure shown, a passenger of mass m = 72.2 kg stands on a platform scale in an elevator cab. We are concerned with the scale readings when the cab is stationary, and when it is moving up or down. (a) Find a general solution for the scale reading, whatever the vertical motion of the cab.



SOLUTION:

$$N - mg = ma$$
$$N = m(g + a)$$

Positive direction for a is up

(b) What does the scale read if the cab is stationary or moving upward at a constant 0.50 m/s?

$$N = (72.2\ kg)(9.8\ m/s^2 + 0) = 708\ N$$

(c) What does the scale read if the cab accelerates upward at 3.20 m/s^2 and downward at 3.20 m/s^2?

$$N = (72.2\ kg)(9.8\ m/s^2 + 3.20\ m/s^2) = 939\ N$$
$$N = (72.2\ kg)(9.8\ m/s^2 - 3.20\ m/s^2) = 477\ N$$

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(d) During the upward acceleration in part (c), what is the magnitude F_{net} of the net force on the passenger, and what is the magnitude $a_{p,cab}$ of the passenger's acceleration as measured in the frame of the cab? *Does* $\vec{F}_{net} = m\vec{a}_{p,cab}$ *?*

$$F_{net} = N - F_g = 939\ N - 708\ N = 231\ N$$

The acceleration $a_{p,cab}$ of the passenger relative to the frame of the cab is zero. Thus, in the noninertial frame of the accelerating cab, F_{net} is not equal to $ma_{p,cab}$, and Newton's second law does not hold

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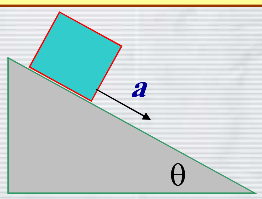
ELEVATOR

APPERENT WEIGHT

Example

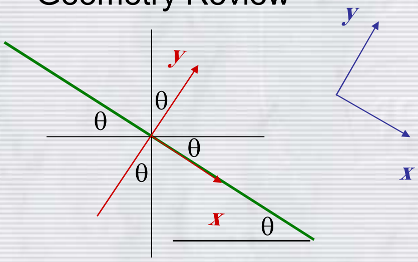
A block of mass *m* slides down a frictionless ramp that makes angle θ with respect to the horizontal. What is its acceleration ***a*** ?

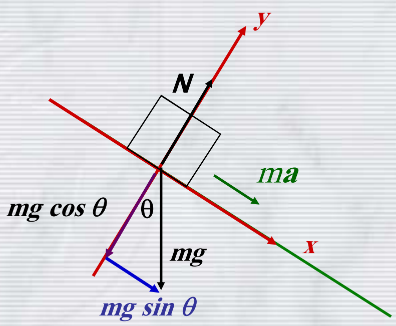


Define convenient axes parallel and perpendicular to plane:

Acceleration *a* is in *x* direction only.

Geometry Review





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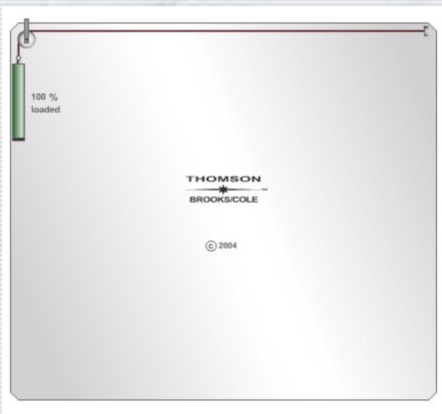
Consider x and y components separately:

- x: $mg \sin\theta = ma$. $a = g \sin\theta$
- y: $N - mg \cos\theta = 0$. $N = mg \cos\theta$



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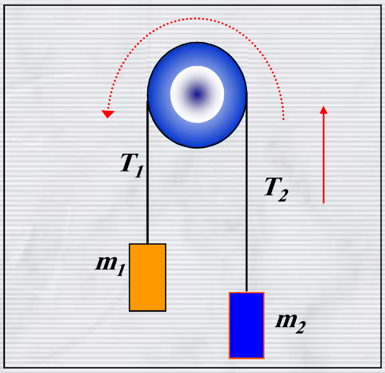
Atwood's Machine:

Masses m_1 and m_2 are attached to an ideal massless string and hung as shown around an ideal massless pulley.
Find the accelerations, of the masses.
What is the tension in the string T?

Assume $m_1 > m_2$: the direction of Motion is shown



- Draw free body diagrams for each object
- Define the acceleration direction
- Applying Newton's Second Law:

  For m_1

  $m_1 g - T_1 = m_1 a$

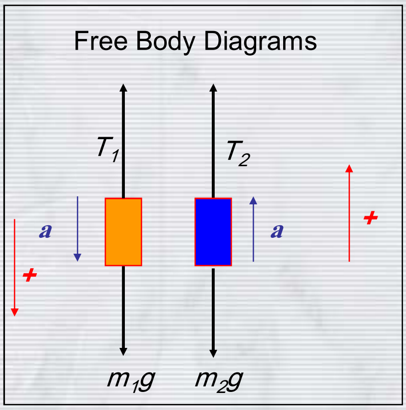
  For m_2

  $T_2 - m_2 g = m_2 a$

- But $T_1 = T_2 = T$ since pulley is ideal

  $m_1 g - T = m_1 a$ (a)

  $T - m_2 g = m_2 a$ (b)



- Two equations & two unknowns
  - we can solve for both unknowns (T and a).

- ***add (b) + (a):***

  $(m_1 - m_2)\,g = (m_1 + m_2)\,a$

  $$a = \frac{(m_1 - m_2)}{(m_1 + m_2)} g$$

- ***Substitute the value of a in eq. (b) , we obtained;***

  $T = 2m_1 m_2 / (m_1 + m_2)\, g$

Is the result reasonable? Check limiting cases!

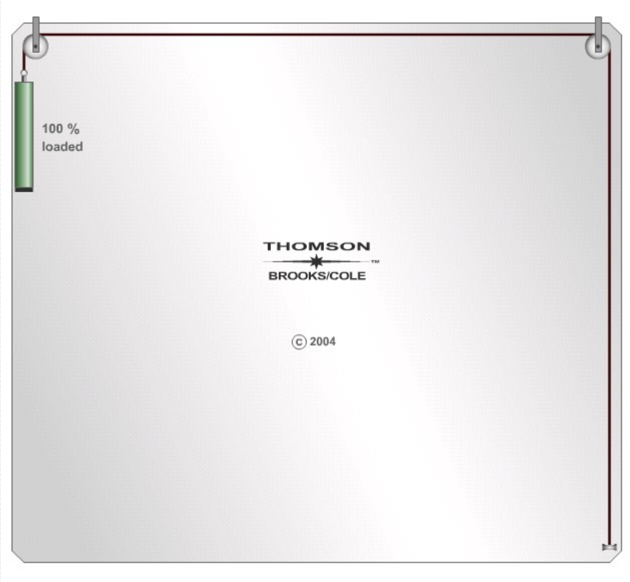
Special cases:

i.) $m_1 = m2 = m$ ⇨ $a = 0$ and $T = mg$. **OK!**

ii.) m_2 or $m_1 = 0$ ⇨ $|a| = g$ and $T = 0$. **OK!**

- Atwood's machine can be used to determine g (by measuring the acceleration a for given masses).

ATWOOD MACHINE



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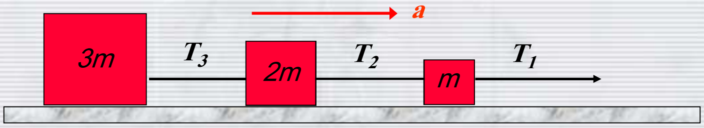
Two-body dynamics

Three blocks of mass *3m*, *2m*, and *m* are connected by strings and pulled with constant acceleration *a*. What is the relationship between the tension in each of the strings?

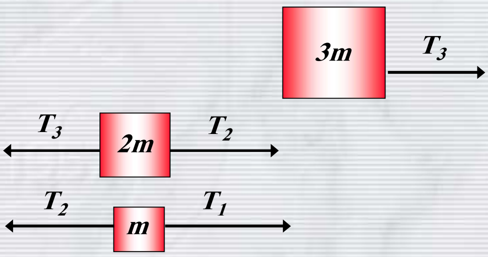


(a) $T_1 > T_2 > T_3$ (b) $T_3 > T_2 > T_1$ (c) $T_1 = T_2 = T_3$

Solution

- *Draw free body diagrams!!*

$T_3 = 3ma$



$T_2 - T_3 = 2ma$

$T_2 = 2ma + T_3 > T_3$

$T_1 - T_2 = ma$

$T_1 = ma + T_2 > T_2$

$T_1 > T_2 > T_3$

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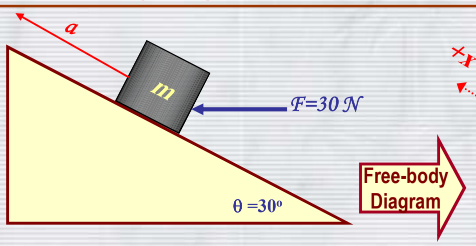
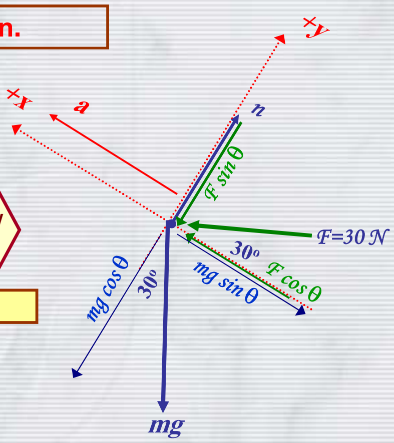
Example;

A 5 kg block is placed on a frictionless inclined plane of angle 30º and pushed up the plane with a horizontal force of magnitude 30 N.

Draw a free-body diagram for this motion.





What are the direction and magnitude of block's acceleration?

x comp.

$$\sum F_x = ma$$

$$F\cos\theta - mg\sin\theta = ma$$

$$\therefore \quad a = \frac{F\cos\theta - mg\sin\theta}{m} = 0.3 \ m/s^2$$

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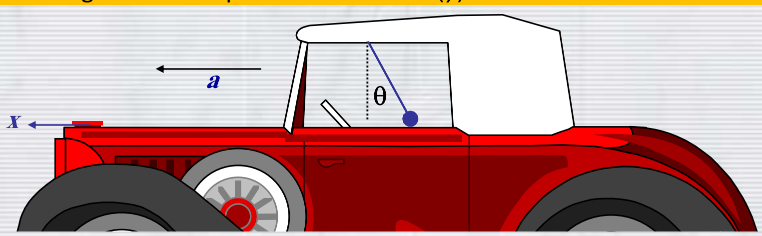
Example: Accelerometer

A weight of mass *m* is hung from the ceiling of a car with a massless string. The car travels on a horizontal road, and has an acceleration *a* in the *x* direction. The string makes an angle θ with respect to the vertical (*y*) axis. Solve for θ in terms of *a* and *g*.



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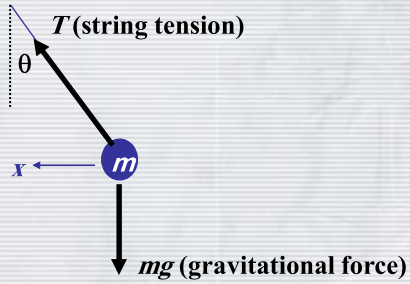
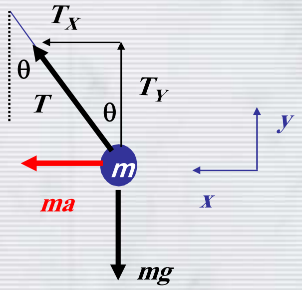
Draw a free body diagram for the mass:
What are all of the forces acting?





- **Using components**

x: $F_X = T_X = T \sin\theta = ma$

y: $F_Y = T_Y - mg$

$= T \cos\theta - mg = 0$

- **Eliminate** T:

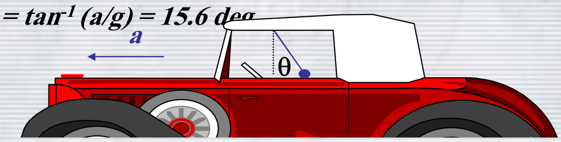
$$\frac{T\sin\theta}{T\cos\theta} = \frac{ma}{mg}$$

$$\tan\theta = \frac{a}{g}$$

Accelerometer

$$\tan\theta = \frac{a}{g}$$

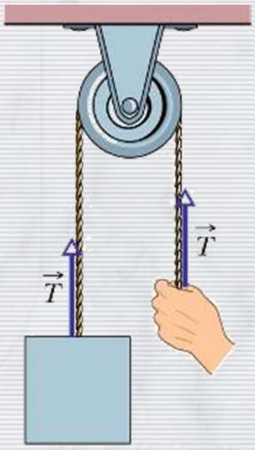
- **Let's put in some numbers:**
- **Say the car goes from 0 to 60 mph in 10 seconds:**
  - $60\ mph = 60 \times 0.45\ m/s = 27\ m/s.$
  - Acceleration $a = \Delta v/\Delta t = 2.7\ m/s^2$.
  - So $a/g = 2.7 / 9.8 = 0.28$.
  - $\theta = tan^{-1}(a/g) = 15.6\ deg$



READ EXAMPLES 5.5 to 5.10

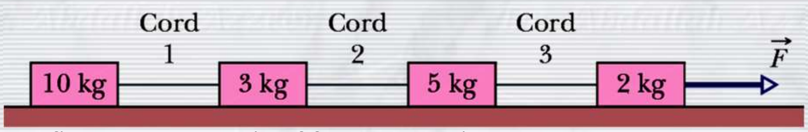
More questions

The body that is suspended by a rope in the figure has a weight of 75N.
Is *T* equal to, greater than or less than 75N when the body is moving downward at...



(a) increasing speed
1. less than
2. equal to
3. greater than

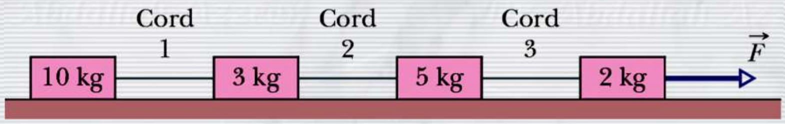
(b) decreasing speed
1. less than
2. greater than
3. equal to



The figure shows a train of four block being pulled across a frictionless floor by force *F*. What total mass is accelerated to the right by...

(a) Force *F*
1. 20
2. 2
3. 7
4. 10

(b) cord 3
1. 8
2. 20
3. 3
4. 18



cord 1
1. 20
2. 13
3. 18
4. 10

(d) Rank the blocks according to their accelerations, greatest first.
1. all tie
2. 1,2,3,4
3. 1,3,2,4
4. 4,3,2,1

(e) Rank the cords according to their tensions, greatest first.
1. all tie
2. 3,2,1
3. 1,3,2
4. 1,2,3

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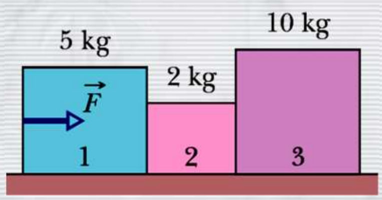
The figure shows a group of three blocks being pushed across a frictionless floor by a horizontal force *F*. What total mass is accelerated to the right ...

(a) by force *F*
1. 17
2. 5
3. 12
4. 7



(b) by force F_{21} on block 2 from block 1
1. 5
2. 2
3. 7
4. 12

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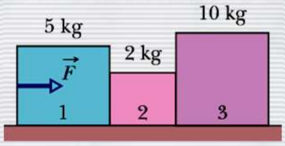

(c) by force F_{32} on block 3 from block 2
1. 17
2. 12
3. 2
4. 10

(d) Rank the blocks according to the magnitude of their accelerations, greatest first.
1. 3,2,1
2. 1,2,3
3. all tie
4. 2,1,3

(e) Rank forces F, F_{21} and F_{32} according to their magnitude, greatest first.
1. all tie
2. F_{32}, F_{21}, F
3. F_{21}, F, F_{32}
4. F, F_{21}, F_{32}

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