Newton's First Law

"Every body continues in its state of rest, or of uniform motion with constant speed in a straight line, unless it is compelled to change that state by forces impressed on it by the surrounding bodies." Such forces are called external forces - divided into two groups: Body & Contact forces.

The state of uniform motion or of rest is basically a state of zero acceleration, with respect to an inertial observer. *All laws of Physics are valid for inertial observers only. At our level, any observer standing still on the Earth, or moving with a constant speed in a straight line, is an inertial observer.* Strictly speaking, this is not correct since the Earth is also moving plus rotating. In advanced situations demanding more accuracy, a reference frame fixed to the Sun can be taken as an inertial reference frame (better still, a frame fixed to a massive star, much bigger than our Sun). But it should be clear that it is not possible to identify a 'perfect' inertial frame in this Universe!

The Newton's First Law implies that the vector sum of all the external forces acting on a body must be zero if the body is at rest (the state of equilibrium) or in an un-accelerated state, w.r.t. an inertial observer.

$$\sum \overrightarrow{F_{ext}} = 0$$
$\Sigma F_x = 0 \quad \Sigma F_y = 0$
(equilibrium state)

Newton's Second Law (a mathematical definition of force)

"The resultant external force acting on a body is equal to its mass multiplied by its acceleration, which is seen by an inertial observer."

Thus, we define the S.I. unit of force 1 newton as the force required to cause a 1 kg mass to accelerate at 1 m/s^2, w.r.t. an inertial observer.

$$\sum \overrightarrow{F_{ext}} = m.\vec{a}$$
$\Sigma F_x = ma_x$
$\Sigma F_y = ma_y$

Newton's Third Law

If a body exerts a force '**F**' on another body, the second body exerts a force on the first one too, which is equal in magnitude to F. The forces of magnitude F acting on the two bodies are in opposite directions. They are called – "Action and Reaction forces". Any one can be called 'action', the other is then called the 'reaction'. "Thus, to every action, there is an equal and opposite reaction." Their source is the same, but they act on different bodies.

Newton's laws should be applied to a body only after drawing its free body diagram (FBD)→ in which a separate diagram of the body is drawn and all external forces are shown at the correct points of applications, and in correct directions. Note that both action and reaction forces can never appear in the same FBD.

Drawing the Free Body Diagram (FBD) of a body

- Isolate the body from its surrounding bodies/objects and draw a separate diagram of it.
- Show all 'body forces' and 'contact forces' acting on the body due to surrounding bodies. The body forces can be exerted by other bodies that are even far away, while the contact forces are exerted by bodies that are actually in physical contact with the body. The forces should be shown at their correct points of application, along with their directions.

In addition to the above, one should show a set of x-y coordinate axes in the FBD in such a way that most of the forces are parallel to x or y directions. This saves the trouble of resolving many forces into their x, y components.

For equilibrium in 2-D (NON-ROTATIONAL STATICS): $\Sigma F_x = 0 \quad \Sigma F_y = 0$

For accelerated motion in 2-D (DYNAMICS): $\Sigma F_x = ma_x \quad \Sigma F_y = ma_y$

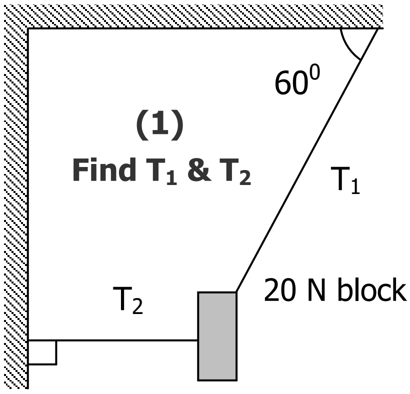
For inertial observer only

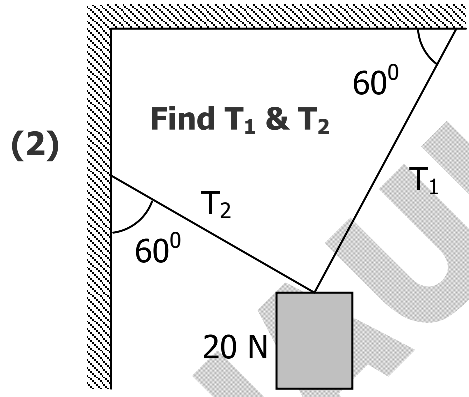
See lectures for:

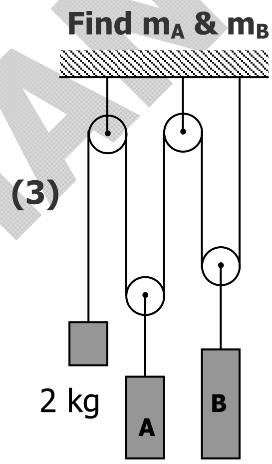
- **Normal reaction and Friction (static and kinetic). Angle of friction.**
- **Three common units of force → 1 N, 1 dyne and 1 kgf.**
- **Application of Newton's second law of motion by a non-inertial observer, by using the concept of pseudo force (D' Alembert's principle).**

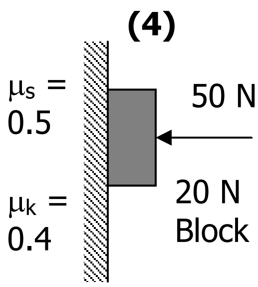
Static Systems

PROBLEMS (all strings & pulleys are ideal. Take $g = 10\ m/s^2$)

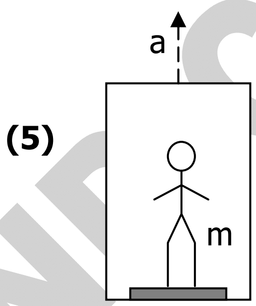




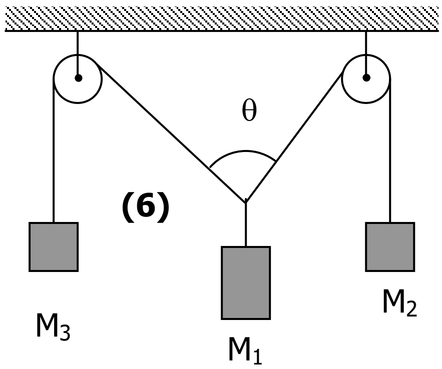




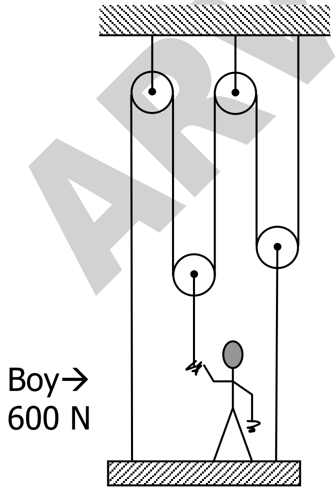
Find friction force acting on block.



Find apparent weight of the man in the accelerating Lift



Find the value of θ at equilibrium.



(7)

In the figure shown on left, with what force should the boy pull down on the rope to keep the entire system static?

(8)

A person is standing on a weighing machine inside an elevator, which is coming down with acceleration = $2\ m/s^2$.

The machine reads '64 kgf'. What is the actual 'weight' of the person.

9. A block of mass m_1 is connected through a string to another block of mass m_2 (> m_1). The string passes over a fixed pulley. Find the acceleration of the two blocks.

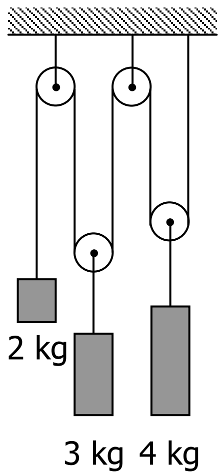
10. Repeat the previous problem if the center of the pulley is fixed to the ceiling of an elevator, which is accelerating upwards with acceleration 'a_0' .

11. A block is imparted some initial velocity up a 30^0 incline. The block travels some distance up the incline and then comes down. The time taken to come down is double the time taken to climb. Find the coefficient of kinetic friction μ (which is given to be < $1 \div \sqrt{3}$).

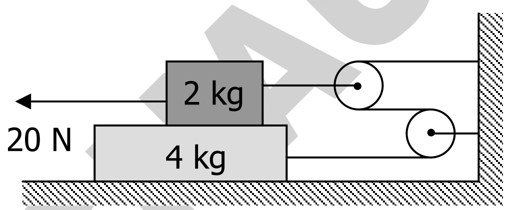
12. A tiny bob of mass 'm' is tied to a string of length L. The upper end of the string is tied to a fixed point O to form a simple pendulum. The bob is now pulled aside until the taut string makes an angle = 60^0 with the vertical, and released from rest. Discuss the motion of the bob by applying Newton's 2nd law in centripetal and tangential directions.

13. A 2 kg block is tied to a 6 kg block through a rope of mass 2 kg. A force of 120 N is applied to the upper 2 kg block to pull the system upwards with some acceleration. Find the tension in the midpoint of the rope.

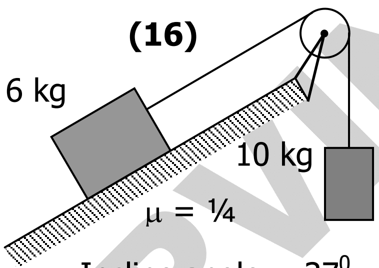
14. The figure om right shows three blocks, connected through massless and frictionless pulleys, with massless and inextensible threads. Find their accelerations.



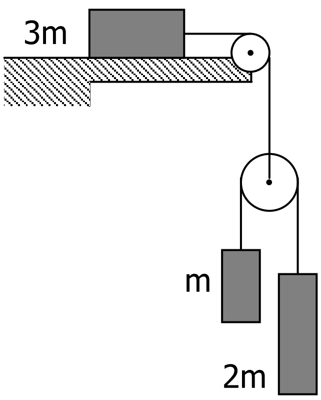
15. In the figure shown, find the accelerations of the two blocks. The coefficient of kinetic friction between all contact surfaces is 0.2 and the pulleys are massless and frictionless.



In problems 16 – 19, find the accelerations of the bodies involved.

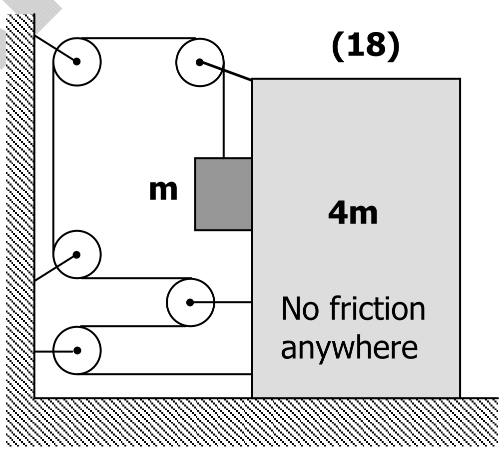


Incline angle = 37^0



(17)

Table is smooth.



No friction anywhere

(19)