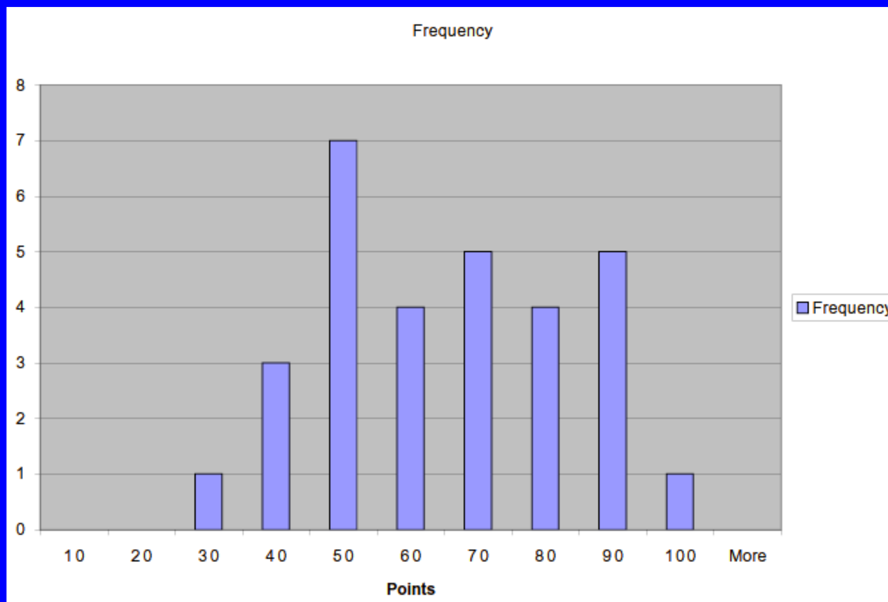
Quiz 1

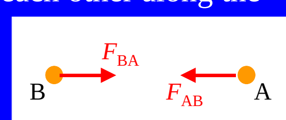


Types of Forces

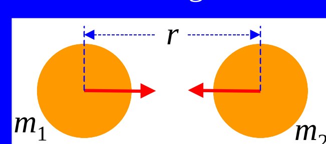
Newton's Law of Universal Gravitation

- Gravitational force is one of the fundamental forces (others are electromagnetic force, weak and strong nuclear forces).
- Other types of forces covered in this chapter (normal force, frictional forces, tension force) and some others (forces coming from machines or muscles, etc) are non-fundamental.
- The gravitational force between two particles with masses m_1 and m_2, separated by a distance r, is attractive to each other along the line joining the two, and with a magnitude

$$F = G\frac{m_1 m_2}{r^2}$$



- G = universal gravitational constant = 6.67×10^{-11} Nm^2/kg^2
- Can also be applied to forces between uniform spheres.



Types of Forces

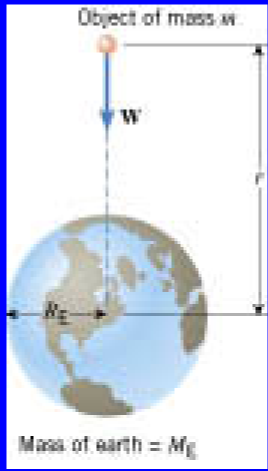
Weight

• The weight of an object is gravitational force exerted on it.

• Near the Earth, the weight of an object with mass *m*, at a distance *r* away from the center of the Earth, has a magnitude of

$$W = G\frac{M_E m}{r^2}$$

with a direction pointing to the center of the Earth.



• Mass is a constant. Weight is a vector with a value depending on its location.

• The SI unit of weight is a N.

Types of Forces

Gravitational acceleration (g)

• Gravitational acceleration **g** is a vector defined by the weight of an object divided by its mass. So its magnitude *g* satisfies

$$W = G\frac{M_E m}{r^2} = mg\,,\ \text{or,}\quad g = G\frac{M_E}{r^2}$$

with a direction pointing to the center of the Earth.

• **g** is independent of mass of the object --- recovers Galileo Galilei's discovery.

• Near the Earth, $g = G\frac{M_E}{R_E^2} \approx 9.8\ \text{m/s}^2$.

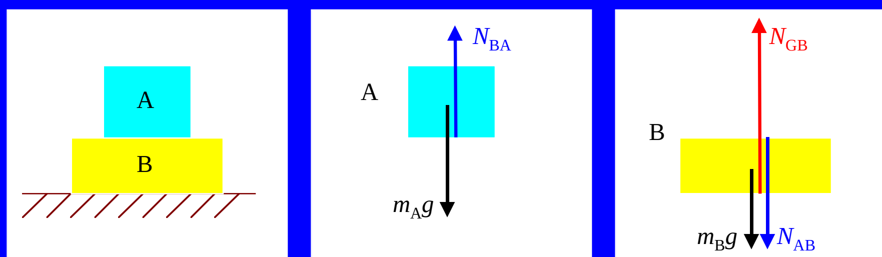
• Can use this to measure the mass of the Earth.

Do 4.CQ.009, 011, 014

Types of Forces

Normal force

• When a surface of an object is in contact with a surface of another object that blocks the movement of the first object due to a net force acting on it, there is a normal force in between the two objects with a direction perpendicular (normal) to the surface.

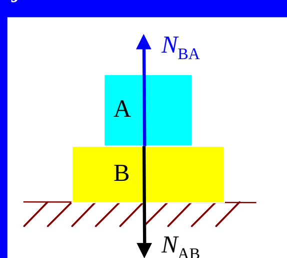


Types of Forces

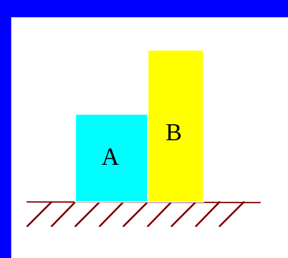
Normal force

• When a surface of an object is in contact with a surface of another object that blocks the movement of the first object due to a net force acting on it, there is a normal force in between the two objects with a direction perpendicular (normal) to the surface.

• Objects in contact with each other can have no normal force.



Normal force between A and B

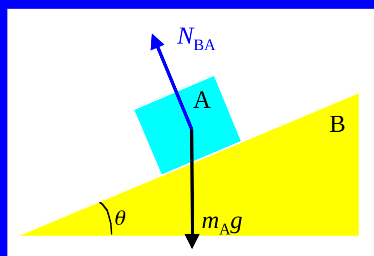


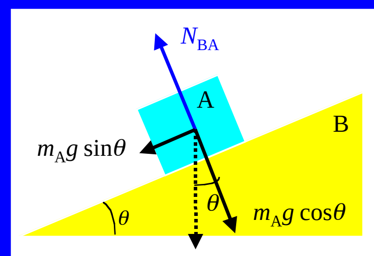
No normal force between A and B

Types of Forces

Normal force on an incline

• The normal force between an object on an incline has a direction perpendicular to the surface, and a magnitude that balances the perpendicular component of the weight of the object.





• Or, the magnitude of the normal force is $N_{BA} = m_A g \cos\theta$.

Types of Forces

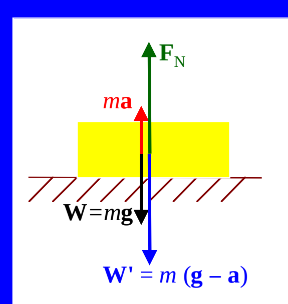
Apparent Weight

• In an inertial reference frame, weight $\mathbf{W} = m\,\mathbf{g}$

• In a non-inertial reference frame (i.e. a reference frame accelerating relative to an inertial reference frame with an acceleration $\mathbf{a}$, e.g., an accelerating elevator), apparent weight $\mathbf{W'} = m\,(\mathbf{g} - \mathbf{a})$.

• Near the surface of the Earth, $\mathbf{g} = -g\hat{\mathbf{y}}$, $\mathbf{W'} = -W'\,\hat{\mathbf{y}}$, if $\mathbf{a} = a\,\hat{\mathbf{y}}$, then $W' = m\,(g + a)$.

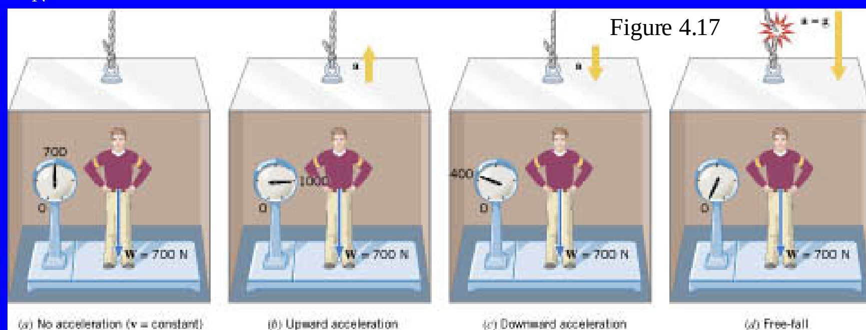
• If there is a horizontal floor providing a normal force $\mathbf{F}_N = F_N\,\hat{\mathbf{y}}$ that support the weight, then $\mathbf{F}_N = -\mathbf{W'}$, or $F_N = W' = m\,(g + a)$.



Types of Forces

Apparent Weight

• $F_N = W' = m(g + a)$.



$F_N = W = 700$ N $F_N = W' = 1000$ N $F_N = W' = 400$ N $F_N = W' = 0$ N

Do 4.CQ.017

Types of Forces

Static frictional force (friction)

• When a surface of an object is in contact with a surface of another object and that there is a normal force in between the two objects, it is possible to have a static frictional force $\mathbf{f}_s$ parallel to the surface.

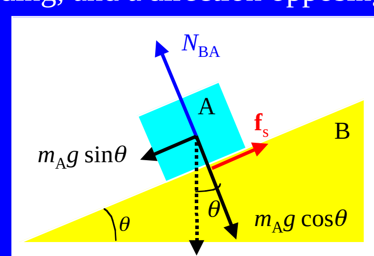
• Static friction has a magnitude just enough to keep the two surfaces of the two objects in contact without sliding, and a direction opposing the force that try to move the object.

• Static friction has a maximum value

$$f_s \le f_s^{MAX} = \mu_s F_N$$

• μ_s is the coefficient of static friction

• For an incline, the maximum angle that can still keep an object from sliding down is $\theta \le \tan^{-1}\mu_s$.



Types of Forces

Kinetic frictional force (friction)

• When a surface of an object is sliding while in contact with a surface of another object and that there is a normal force in between the two objects, it is possible to have a kinetic frictional force $\mathbf{f}_k$ parallel to the surface.

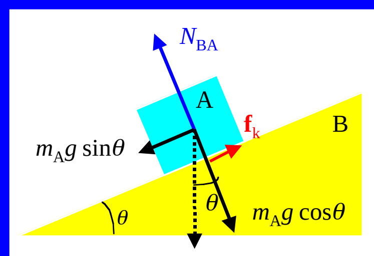
• kinetic friction always has a direction opposing the relative movement between the two objects.

• kinetic friction has a value

$$f_k = \mu_k F_N$$

• μ_k is the coefficient of kinetic friction

• For an incline, if an object slide down with $\theta < \tan^{-1}\mu_k$, it will be slowed not by the kinetic friction, otherwise, it can speed up.



• $\mu_k < \mu_s$ usually.

Do 4.CQ.018, 020

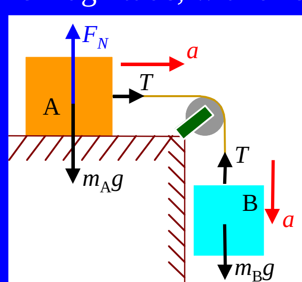
Types of Forces

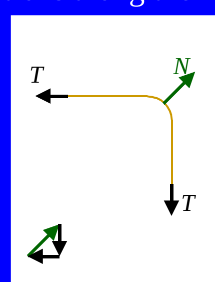
Tension force (tension)

• A tension force T is applied through a cable or a rope with very small mass (massless).

• The tension forces applied to the two objects connected to the two ends of a rope are of the same magnitude, with directions along the rope pulling inside.

• A frictionless pulley that changes the direction of the rope will not change the magnitude of the tension, although it does apply a normal force to the rope.





• Objects connected by a rope will move with the same magnitude of velocity or acceleration, although may be with different directions.

Do 4.CQ.021, 026

Types of Forces

Equilibrium and Non-equilibrium applications of Newton's Law

- "An object is in equilibrium when it has zero acceleration" (can have non-zero constant velocity).
- Condition for equilibrium: $\Sigma\mathbf{F} = 0$, or in components,
  $\Sigma F_x = 0$, and $\Sigma F_y = 0$.
- When an object is not in equilibrium (non-equilibrium), it has an acceleration **a** satisfying $\Sigma\mathbf{F} = m\,\mathbf{a}$, or in components,
  $\Sigma F_x = m\,a_x$, $\Sigma F_y = m\,a_y$
- Remember to apply these conditions for each object (each free-body diagram).