Physics I
Lecture05- the laws of motion-I

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CONTENTS

NEWTON'S LAW

What's the mechanism for the motion?

Newton's 1st Law:

An object at rest stays at rest unless acted by an external force.

An object in motion continues to travel with constant velocity unless acted by an external force.

Newton's 2nd Law:

The direction of the acceleration of an object is in the direction of the net external force acting on it.

$\vec{F}_{net} = m\vec{a}, \vec{F}_{net} = \sum \vec{F_i}$

Newton's 3rd Law:

Forces always occur in equal and opposite pairs and on two different objects.

https://sites.google.com/a/jeffcoschools.us/holland-s-earth/physical-science/unit-2-linear-motion-newton-s-laws

1. THE CONCEPT OF FORCE

Distortion, Compression

Changing The State of Motion

Anti-Gravitation Lifting

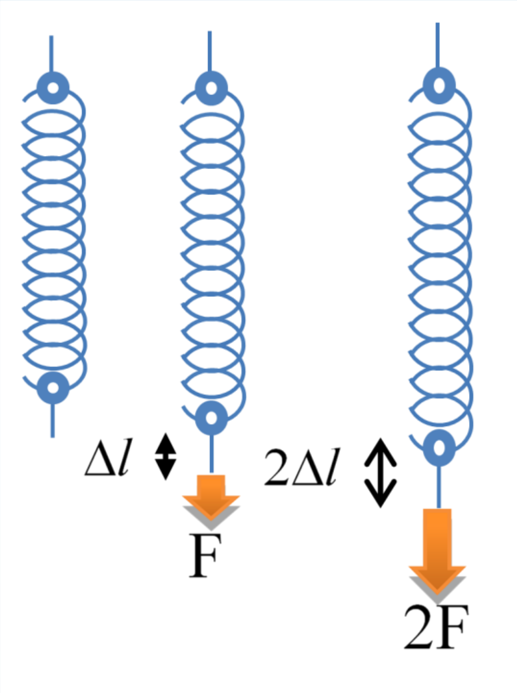
Fighting

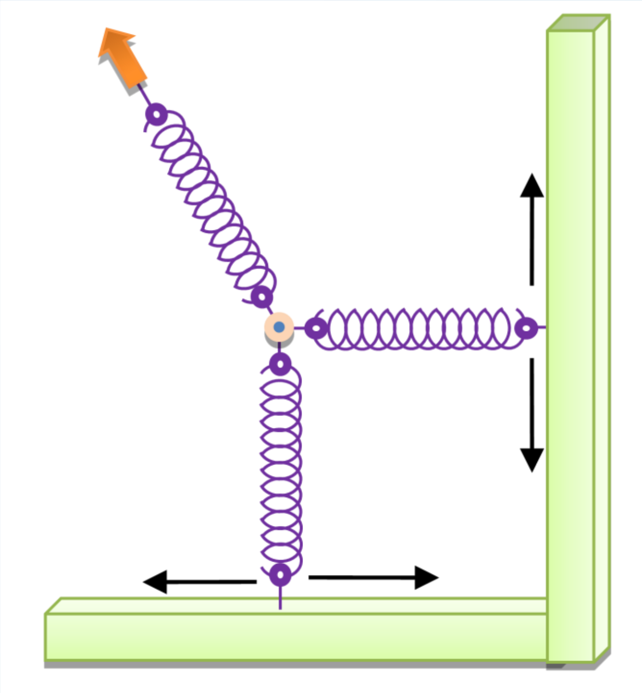
https://giphy.com/gifs/movie-baseball-ball-3ohzAo5FkZizHXsACc
https://giphy.com/gifs/mtv-ridiculousness-rob-dyrdek-yTIo9AfHLSL6M

https://giphy.com/gifs/law-newton-finest-m9BK5yCFrBjIA

1. THE CONCEPT OF FORCE

1. Stretching springs
2. Vector nature of force





2. INERTIA FRAMES AND NEWTON'S 1ST LAW

Newton's 1st Law – Inertia Law:

In the absence of an external force, an object remains at rest when it is initially at rest. Otherwise, it continues to move with a constant velocity if it is initially in motion.

Inertia Frame:

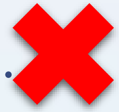
1. It is the one in which Newton's 1st law is valid.
2. Any reference frame moves with a constant velocity relative to an inertia frame is also an inertia frame.
3. If an object is acted by zero force, the acceleration of the object is zero in the inertia frame.

Non-inertia Frame:

In the train when it is in the acceleration motion

On the rotational Earth

3. MASS

Previous Image: Mass is weight. 

After learning the concept of force, it is found that the same force give different motional behavior when pushing on objects of different mass.

Inertia Mass: Mass is the measure of an object's resistance to a change in motion in response to an external force.

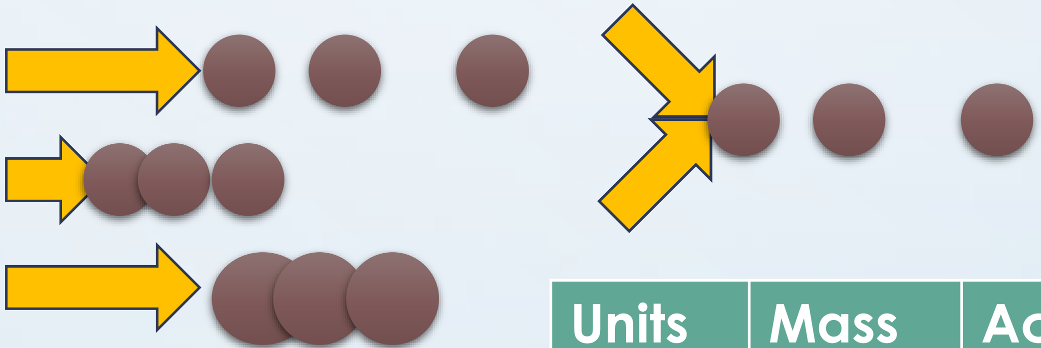
The same force on two objects of different mass gives different acceleration.

$$\frac{m_1}{m_2} = \frac{a_2}{a_1}$$

Mass is an inherent property of an object and it is independent of the surrounding and the method used to measure it.

4. NEWTON'S 2^{ND} LAW

The acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass.



$$\vec{a} = \frac{\sum_{i=1}^{N} \vec{F}_i}{m}$$

Units	Mass	Acceleration	Force
SI	Kg	m/s^2	$kg\ m/s^2$
US	slug	ft/s^2	$slug\ ft/s^2$

$1(slug) \times 1(ft/s^2) = 1(lbf)$ $\quad$ $1(slug) \times 0.3048(m/s^2) = 0.454(kgw)$

$1(slug) \times 0.3048(m/s^2) = 4.45(N)$ $\quad$ $1(slug) = 14.593(kg)$

4. NEWTON'S 2ND LAW

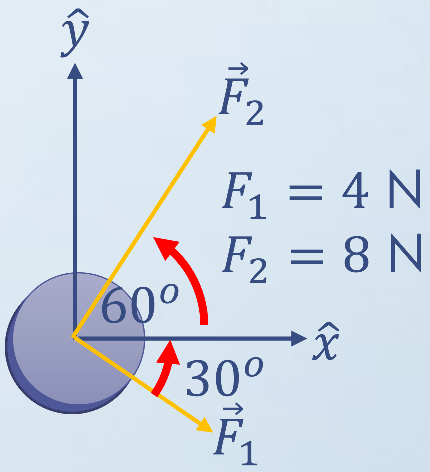
Example: A 0.3 kg hockey puck slides on the horizontal frictionless surface of an ice rink. It is struck simultaneously by two different hockey sticks. The forces are shown in the figure. Determine the acceleration of the puck.

$$\vec{F}_{net} = \left(4\cos(30^0) + 8\cos(60^0)\right)\hat{\imath} + \left(-4\sin(30^0) + 8\sin(60^0)\right)\hat{\jmath}$$

$$\vec{F}_{net} = 7.46\hat{\imath} + 4.93\hat{\jmath}$$

$$\vec{a} = \frac{7.46\hat{\imath} + 4.93\hat{\jmath}}{0.3} = 24.9\hat{\imath} + 16.4\hat{\jmath}\ (\text{m/s}^2)$$

$$|\vec{a}| = 29.8\ (\text{m/s}^2)$$



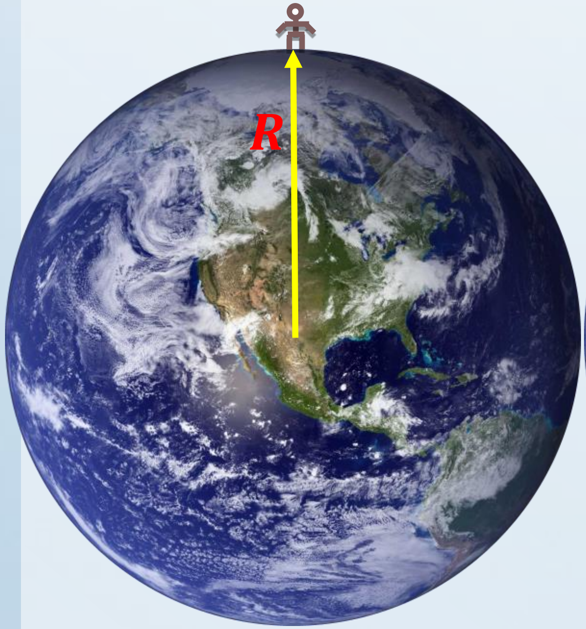
5. GRAVITATION FORCE AND WEIGHT

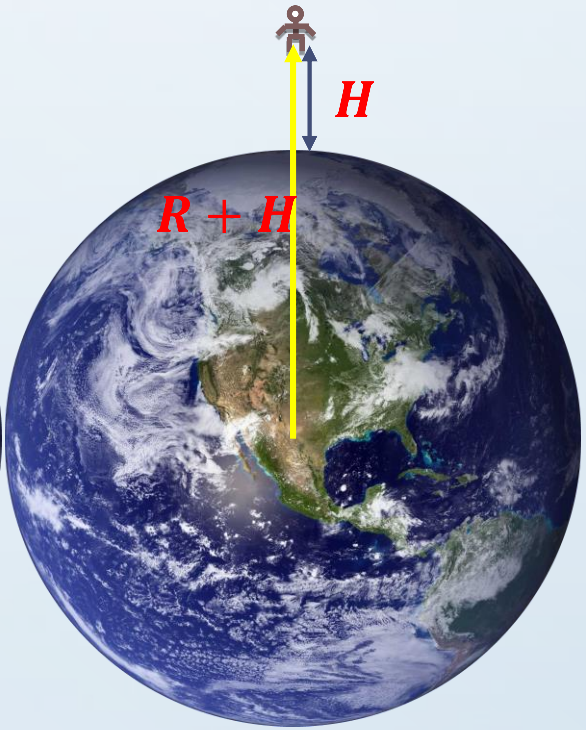
The gravitational force of an object is the its weight.

$$\vec{F}_g = m\vec{g}$$

Objects weigh less at higher altitudes than at sea level.

$$F_g = mg_0 = m\frac{GM}{R^2}$$





$$F = m\frac{GM}{(R+H)^2} = mg(H)$$

$$g(H) = \frac{g_0 R^2}{(R+H)^2}$$

5. GRAVITATION FORCE AND WEIGHT

Space Elevator ref:http://www.obayashi.co.jp/english/special/2014110424.html

The required tensile strength of the cable is 150 G Pa.

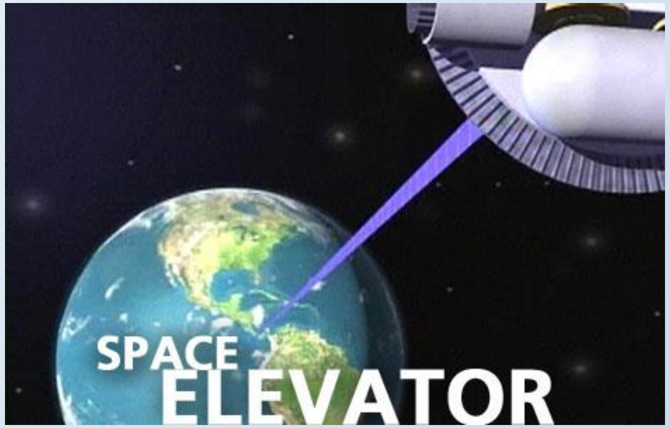
Example: Assume that the cable sectional area is 1 m^2 and its mass per unit length is 1 kg/m. The radius of the Earth R_E is 6.4×10^6 (m). If the cable is constructed along the radial direction and from the Earth surface to a height of R_E, please calculate the pressure given by the cable on the Earth surface.

$\lambda = 1$ (kg/m), $dM = \lambda dy$

$$F = \int_0^{R_E} g(y)dM = \int_0^{R_E} \frac{g_0 R^2}{(R+y)^2}\lambda dy = \frac{\lambda g_0 R}{2}$$

$$F \cong 3.14 \times 10^7$$

Pressure: $F/A = 3.14 \times 10^7$ (Pa)



Carbon nanotubes show such high tensile strength.

6. NEWTON'S 3RD LAW

Forces always occur in pairs.
The action force is equal in magnitude to the reaction force and opposite in direction.

The two forces in an action-reaction pair always act on two different objects.

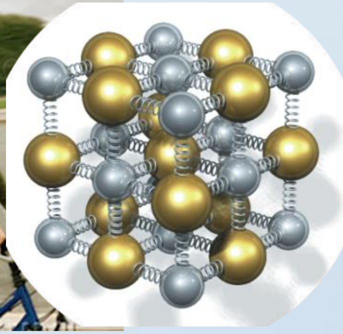
https://giphy.com/gifs/law-newton-finest-m9BK5yCFrBjIA

7. THE FUNDAMENTAL FORCES

1. The Gravitational Forces – the force between objects
2. The Electromagnetic Forces – the force between electric charges
3. The Strong Nuclear Forces – the force between subatomic particles
4. The Weak Nuclear Forces – the force during certain radioactive decay process

Action At a Distance



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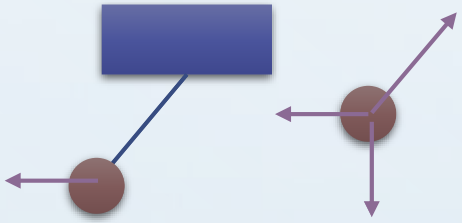
8. APPLICATION OF NEWTON'S LAW

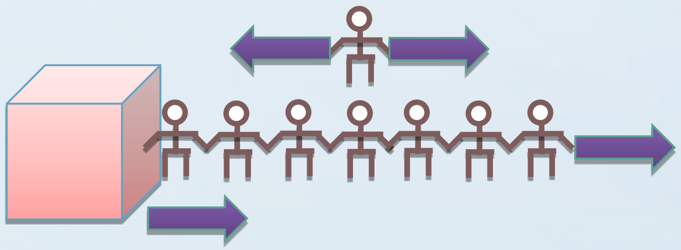
If the acceleration of an object is zero, the particle is in equilibrium. It is either in constant velocity motion or at rest.

$$\vec{a} = 0 \Rightarrow \sum_{i=1}^{N} \vec{F}_i = 0 \Rightarrow \sum_{i=1}^{N} F_{ix} = \sum_{i=1}^{N} F_{iy} = \sum_{i=1}^{N} F_{iz} = 0$$

Free-Body Diagram

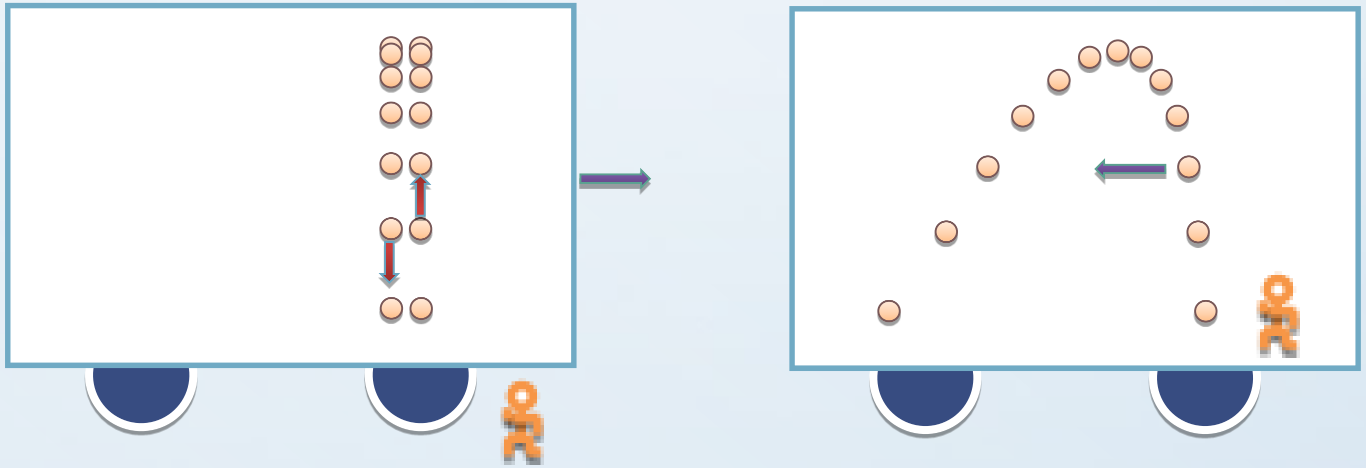


Tension in String



8. APPLICATION OF NEWTON'S LAW

Drawing physical phenomena – solving physics problems by drawing.

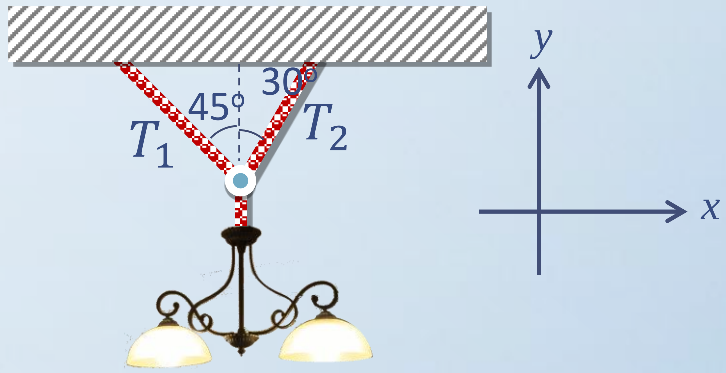


8. APPLICATION OF NEWTON'S LAW

Example: A main light in the living room weighing 100 N hangs from a cable tied to two other cables fastened to a support as that shown in the figure. Please calculate tension force in the cables.

$$\vec{W} = -100\hat{j}$$

$$\vec{T}_1 = -\frac{T_1}{\sqrt{2}}\hat{\imath} + \frac{T_1}{\sqrt{2}}\hat{j} \qquad \vec{T}_2 = \frac{T_2}{2}\hat{\imath} + \frac{\sqrt{3}T_2}{2}\hat{j}$$



$$\vec{F}_{net} = \left(\frac{T_2}{2} - \frac{T_1}{\sqrt{2}}\right)\hat{\imath} + \left(\frac{T_1}{\sqrt{2}} + \frac{\sqrt{3}T_2}{2} - 100\right)\hat{j} = 0$$

$$T_2 = \sqrt{2}T_1,\ T_1 = 100\sqrt{2}/(1+\sqrt{3}) = 51.8\ (\text{N})$$

$$T_2 = 73.3\ (\text{N})$$

8. APPLICATION OF NEWTON'S LAW

Example: As your high-speed train speeds up, you decide to determine its acceleration, so you take out your yo-yo and note that when you suspend it, the string makes an angle of 5° with the vertical.
(a) What is the acceleration of the train?
(b) If the mass of the yo-yo is 40 g, what is the tension in the string?

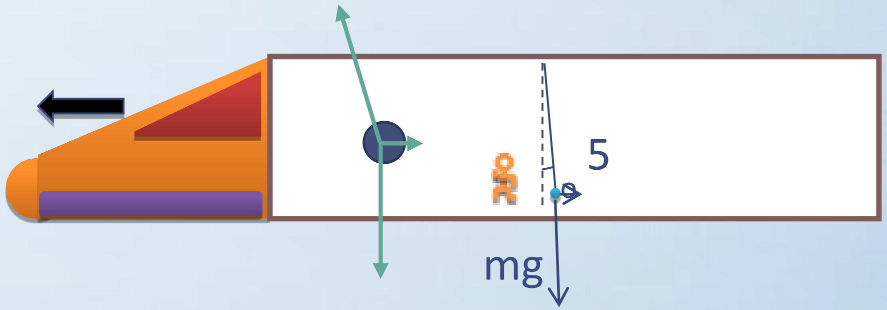
$$\vec{W} = -mg\hat{j} \quad \vec{F}_h = ma\hat{i}$$

$$\vec{T} = -T\sin(5^0)\,\hat{i} + T\cos(5^0)\,\hat{j}$$

$$\vec{F}_{net} = (ma - T\sin(5^0))\hat{i} + (T\cos(5^0) - mg)\hat{j} = 0$$

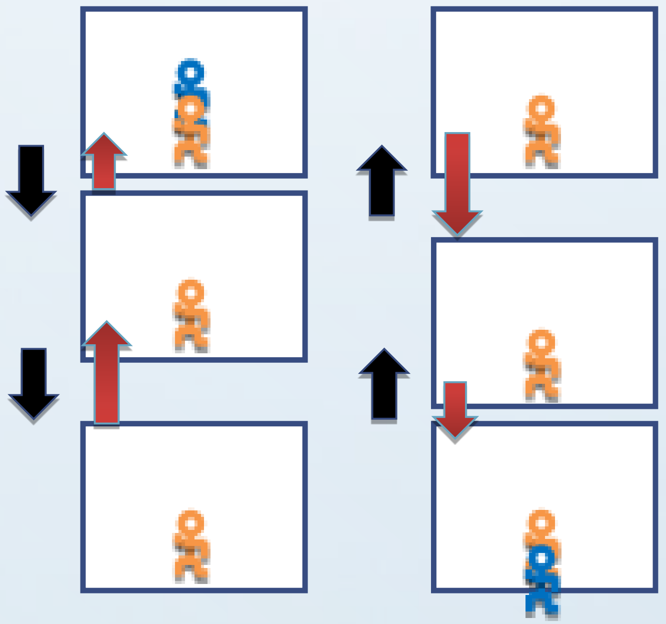
$$a = g\tan(5^0) = 0.857 \ (\text{m/s}^2)$$

$$T = \frac{0.04 \times 9.8}{\cos(5^0)} = 0.393 \ \ (\text{N})$$



8. APPLICATION OF NEWTON'S LAW

Example: A person weighs himself on a scale in the ceiling of an elevator. Show that if the elevator accelerates either upward or downward, the spring scale gives a reading that is different from the real weight.

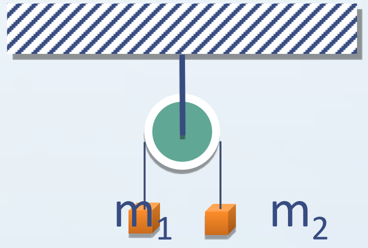


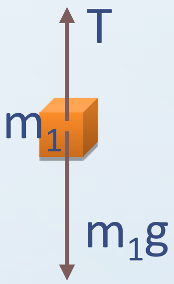
8. APPLICATION OF NEWTON'S LAW

Example: The Atwood machine is assembled as that shown in the figure. Please calculate the acceleration of the system.

$$m_1 g - T = m_1 a$$

$$T - m_2 g = m_2 a$$

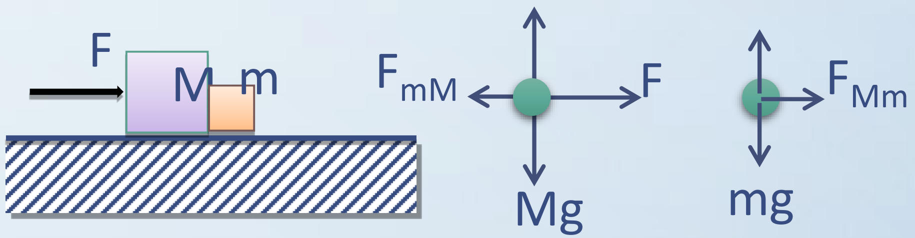




$$a = \frac{m_1 - m_2}{m_1 + m_2} g$$

8. APPLICATION OF NEWTON'S LAW

Example: A constant F is applied on two blocks with mass M and m, respectively. Determine the action and reaction forces between them.



$$a = \frac{F}{(M+m)} \qquad \vec{a} = \frac{F}{(M+m)}\hat{\imath}$$

$$F - F_{mM} = Ma \Rightarrow F_{mM} = F - \frac{MF}{(M+m)}$$

$$F_{mM} = \frac{mF}{(M+m)} \Rightarrow \vec{F}_{mM} = -\frac{mF}{(M+m)}\hat{\imath}$$

$$\vec{F}_{Mm} = m\vec{a} = \frac{mF}{(M+m)}\hat{\imath}$$

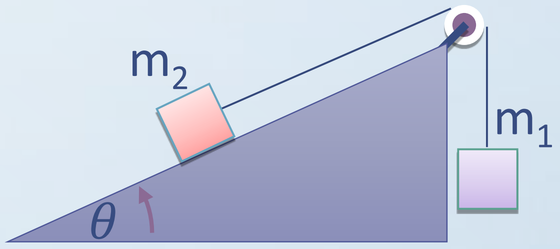
8. APPLICATION OF NEWTON'S LAW

Example: Two blocks of mass m_1 and m_2 are attached by a lightweight cord that passes through a frictionless pulley of negligible mass. The block m_2 lies on a frictionless incline of angle θ. Assume that the m_1 block is lifted, find the magnitude of the acceleration of the two objects and the tension in the cord.

$$a = \frac{m_2 g \sin\theta - m_1 g}{m_1 + m_2}$$

$$T = m_1 a + m_1 g = \left(\frac{m_1 m_2 \sin\theta - m_1^2}{m_1 + m_2} + m_1\right) g$$

$$T = \left(\frac{m_1 m_2 (\sin\theta + 1)}{m_1 + m_2}\right) g$$



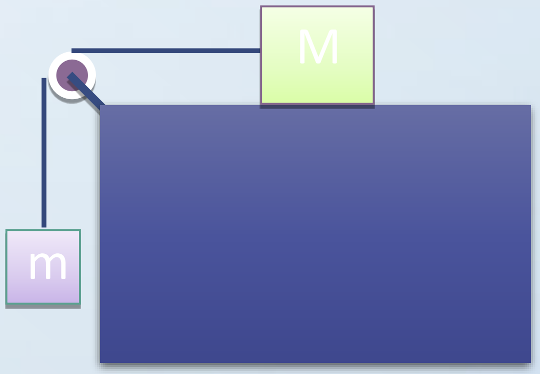
8. APPLICATION OF NEWTON'S LAW

Example: The figure shows two blocks with mass M and m, connected by a cord. The block is free to move on frictionless surface. The cord wraps over a frictionless pulley. The cord and pulley have negligible masses. The hanging block falls as the sliding block accelerates to the left. Find

(a) the acceleration of the sliding block
(b) the acceleration of the hanging block, and
(c) the tension in the cord.

$$a = \frac{mg}{M + m}$$

$$T = Ma = \frac{Mm}{M + m} g$$



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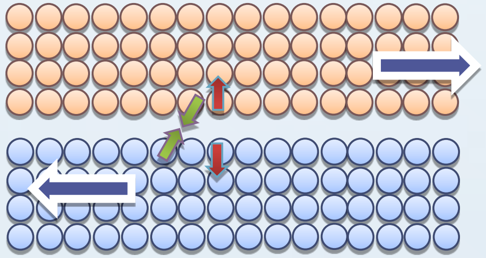
9. FRICTIONAL FORCES

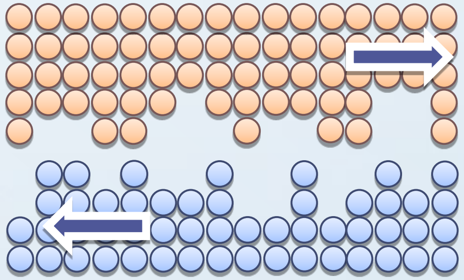
Notmal Force: $\vec{N}$, $\vec{F}_N$

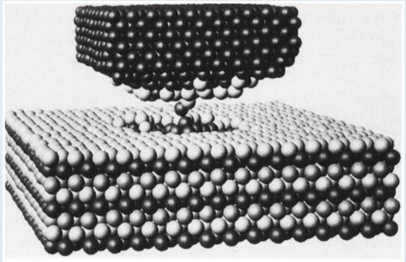
Static Friction: $F_s < F_{s,MAX}$, $F_{s,MAX} = \mu_s N$

Kinetic Friction: $F_k = \mu_k N$

Rolling Friction: $F_r = \mu_r N$







$\mu_{N,car} \cong 1.00$, $\mu_{r,car} \cong 0.014$

http://hpwizard.com/tire-friction-coefficient.html

9. FRICTIONAL FORCES

Example: Suppose a block is placed on a rough surface inclined relative to the horizontal. (a) How is the coefficient of static friction related to the critical angle θ_c at which the block begins to move? (b) How could we find the coefficient of kinetic friction?

(a) $mg\sin\theta_c = \mu_s mg\cos\theta_c$

$$\mu_s = \tan(\theta_c)$$

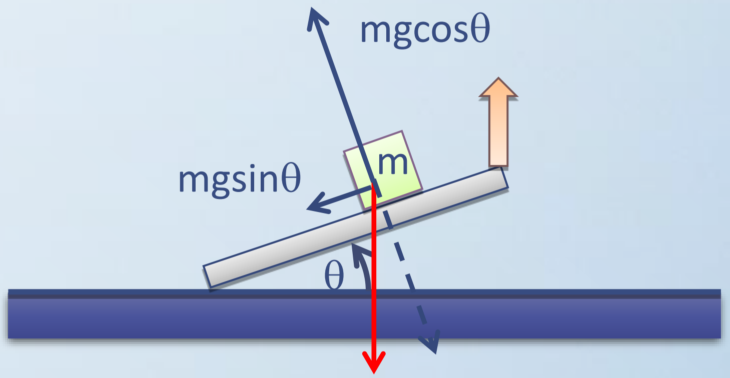
(b) $\theta > \theta_c$

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

Measure the required time T for traveling a length L

$$a = 2L/T^2$$

$$\mu_k = \frac{g\sin\theta - 2L/T^2}{g\cos\theta}$$

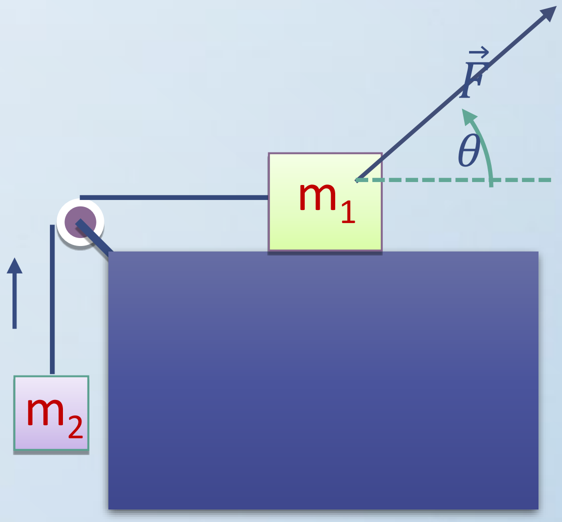


9. FRICTIONAL FORCES

Example: A block of mass m_1 on a rough, horizontal surface is connected to a ball of mass m_2 by a lightweight cord over a lightweight, frictionless pulley. A force of magnitude F at an angle of θ with the horizontal is applied to the block as shown. The coefficient of kinetic friction between the block and surface is μ_k. Determine the magnitude of the acceleration of the two objects.

$$f_k = (m_1 g - F\sin\theta)\mu_k$$

$$a = \frac{F\cos\theta - m_2 g - (m_1 g - F\sin\theta)\mu_k}{m_1 + m_2}$$



9. FRICTIONAL FORCES

Example: A cargo box of mass m sits on a truck of mass M, which drives on the road without resistance. The truck is pulled with a horizontal force F. The coefficients of static and kinetic sliding friction between the cargo and the truck are μ_s and μ_k. (a) Find the maximum value of F for which the cargo will not slide relative to the truck. (b) Find the acceleration of the truck and the cargo when F is greater than this value.

(a)

Maximum acceleration for the cargo: $g\mu_s$

$$F = (M + m)g\mu_s$$

(b)

Truck: $F - mg\mu_k = Ma_M \quad a_M = \dfrac{F - mg\mu_k}{M}$

Cargo: $mg\mu_k = ma_m \;\; a_m = g\mu_k$

ACKNOWLEDGEMENT

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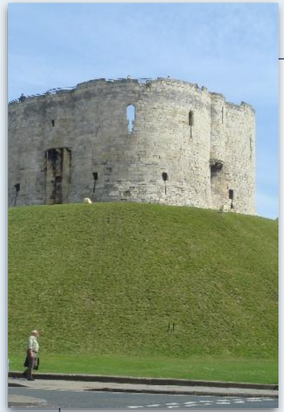

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