NEWTON'S LAWS (POINT OBJECTS).

FIRST OBJECTS DO NOT CHANGE THEIR STATE OF MOTION (Vel. $\underset{\to}{v}$ FOR NOW) SPONTANEOUSLY

DEFINES INERTIA

Examples: SEAT BELTS, STUMBLE,

SECOND a) EVERY OBJECT HAS AN INTRINSIC PROPERTY CALLED INERTIAL MASS (M)

b) AN OBJECT OF MASS M CAN HAVE A NON-ZERO ACCELERATION IF AND ONLY IF THERE IS A FORCE $\underset{\to}{F}$ PRESENT SUCH THAT

$$\boxed{M \underset{\to}{a} = \underset{\to}{F}}$$

COROLLARIES: (i) IF AN OBJECT IS IN EQUILIBRIUM ($\equiv m$) ($\underset{\to}{a} = 0$), THE VECTOR SUM OF ALL THE FORCES ACTING ON IT MUST BE ZERO

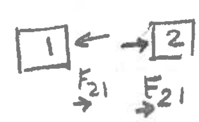
$$\underset{\to}{F_1} + \underset{\to}{F_2} + \underset{\to}{F_3} \cdots = 0$$

Object does not have to be at rest, it must not change $\underset{\to}{v}$.

(ii) IF $\underset{\to}{a} \neq 0$ at a SPACE POINT AT A TIME t, THERE MUST BE A FORCE ACTING AT THAT PT AT THAT TIME.

THIRD WHEN TWO OBJECTS INTERACT THE FORCES ACTING ON THEM FORM ACTION-REACTION PAIRS ($\underset{\to}{F_{21}}$ acts on object 1, $\underset{\to}{F_{12}}$ on object 2)

$$\underset{\to}{F_{21}} = -\underset{\to}{F_{12}}$$



FORCES

In order to use Newton's Laws we need the Forces that occur in various physical systems. For our discussion in 121 we deal with Mechanical Forces only. Also, we donot discuss in detail the origin of the force in Every Case.

I WEIGHT Near Earth Every unsupported object has an acceleration

$$\underset{\rightarrow}{a} = -9.8 m/s^2 \hat{y} = -g\hat{y}$$

so it must experience a force

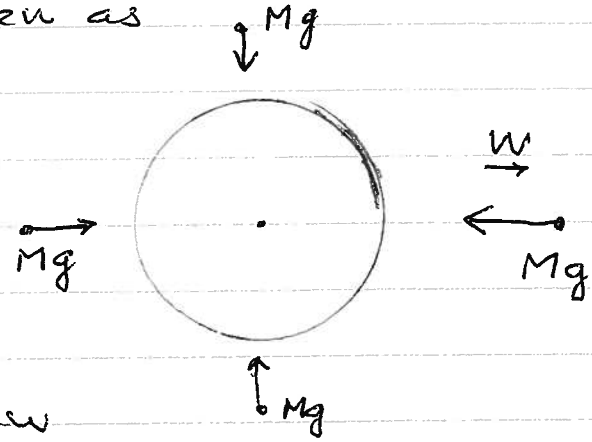
$$\underset{\rightarrow}{W} = -9.8 M \hat{y} = -Mg\hat{y}$$

where M is its mass. This force is weight and is a vector perpendicular to the Earth's surface directed toward the center of the Earth.

More precisely, Since the Earth is a sphere this force should be written as

$$\underset{\rightarrow}{W} = -9.8 M \hat{r}$$

where $\hat{r}$ is a unit vector along the radius.

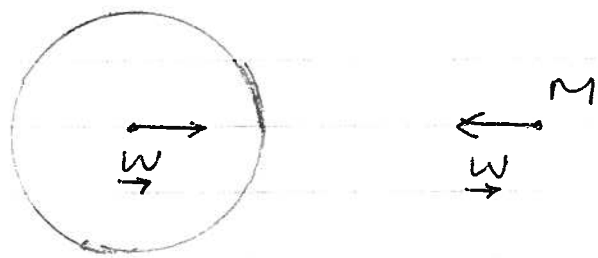


It is a manifestation of Newton's universal law of Gravitation (discussed in detail later)

$$\vec{F}_G = - \frac{G M_E M}{R_E^2} \hat{r}$$

where M_E = Mass of Earth
R_E = Radius of Earth
$G = 6.7 \times 10^{-11} \frac{N\text{-}m^2}{(kg)^2}$

By Newton's 3rd law it follows that the reaction force to $\vec{W}$ acts at the center of the Earth

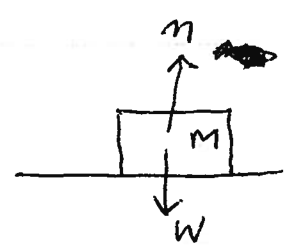


SO EARTH PULLS ON M, M Pulls on EARTH with an Equal and oppsite force.

II CONTACT FORCE OR NORMAL FORCE: Comes into play when an object is in contact with the surface of a Solid. It acts perpendicular to surface of the solid: hence Normal Force. (N_R)

It comes about b/c the atoms/molecules of a solid oppose the attempt by any foreign object to enter the solid.

For example, put the Mass M of the above discussion on the Earth. Now M is in $\equiv$m so the sum of the forces

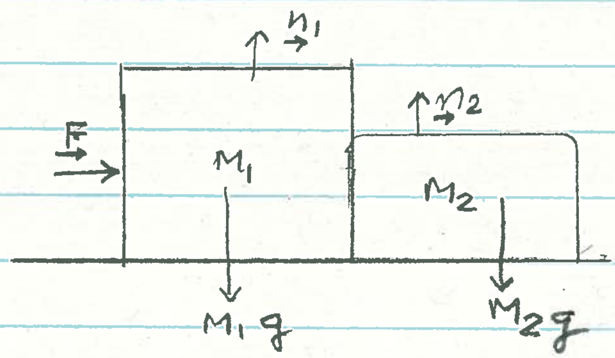


acting on it must be zero

$$\vec{n} = n\hat{y} \qquad \vec{W} = -Mg\hat{y}$$

$$\vec{n} + \vec{W} = 0$$

$$\vec{n} = +Mg\hat{y}$$



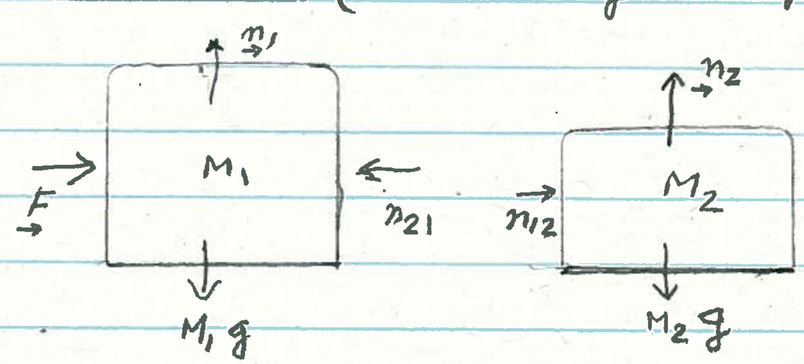
Ex 2 M_1 and M_2 are lying on a smooth horizontal surface. Apply a force $\vec{F} = F\hat{x}$ to M_1 as shown. Both M_1 and M_2 acquire an acceleration

$$\vec{a} = a\hat{x}$$

Question: Which force causes M_2 to accelerate?

Answer: Contact force between between M_1 and M_2.

Let us draw all the forces acting on each mass (Free Body diagrams)



So

$\vec{F}$ pushes on M_1

M_1 pushes on M_2 with $\vec{n}_{12}$

M_2 pushes back on M_1 with $\vec{n}_{21}$

By the 3rd law $\vec{n}_{12} + \vec{n}_{21} = 0$

$$(n_{12} - n_{21})\,\hat{x} = 0$$

To calculate $\vec{a}$ we must use force acting at that mass at that time so

$$M_1\,\vec{a} = \vec{F} + \vec{n}_{21} = F\hat{x} - n_{21}\hat{x}$$

$$M_2\,\vec{a} = \vec{n}_{12} = n_{12}\hat{x}$$

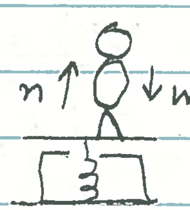
add

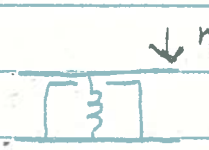
$$(M_1 + M_2)\,\vec{a} = F\hat{x} + (n_{12} - n_{21})\,\hat{x}$$

$$= F\hat{x}$$

$$\vec{a} = \left(\frac{F}{M_1 + M_2}\right)\hat{x}$$

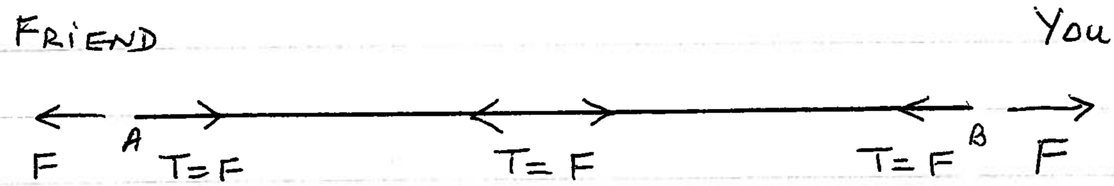
Ex 3 To weigh yourself you stand on a weighing machine. You have two forces acting on you $\vec{W} = -Mg\hat{y}$ and $\vec{n} = n\hat{y}$ the normal force which the machine exerts on you. You are in Ξm so $n = Mg$. You push down on machine with $\vec{n} = -n\hat{y}$ so machine records n and hence W.





Ex 4 If the surface is not horizontal $\vec{n}$ will have to adjust so that there is Ξm perpendicular (normal) to the surface while there is acceleration g since down the ramp. The force picture is

III TENSION IN A MASSLESS, INEXTENSIBLE STRING.



You are holding one end of a light string. Your friend catches hold of the other end. Suppose she pulls on it with a force $\vec{F} = -F\hat{x}$, toward the left. In order to keep it in ≡m you have to pull on the right with $\vec{F} = +F\hat{x}$. How come? Well, when she applied $-F\hat{x}$ at A and the string wants be in ≡m it must develop $+F\hat{x}$ at A, again to keep ≡m everywhere inside it needs $\vec{F}$'s at every point balancing each other out until point B is reached where string pulls to the left. So for ≡m at B you must pull with $+F\hat{x}$. A force $\vec{F}$ applied at one end of the string causes a tension $T=F$ to appear in the string such that at the ends T acts toward the middle and at the middle $\vec{T}$ is directed toward the ends.

IV **Spring Force (Hooke's law)**

We already used this in establishing a measure for Force b/c we used a SPRING BALANCE.

This force appears if you stretch a spring or squeeze it. The spring resists the change in its length so this force always opposes the stretch (or squeeze). For small changes in length the force is proportional to the change in length hence we write

$$\vec{F}_{sp} = -k(\Delta x)\hat{x}$$

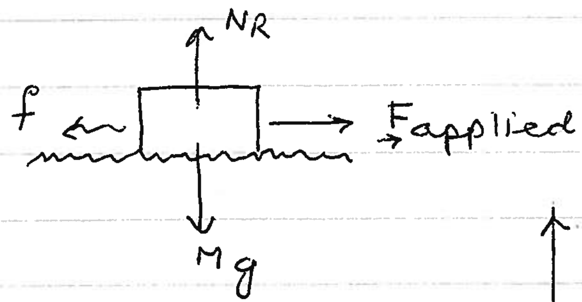
where $\Delta x =$ change in length
$k =$ spring constant

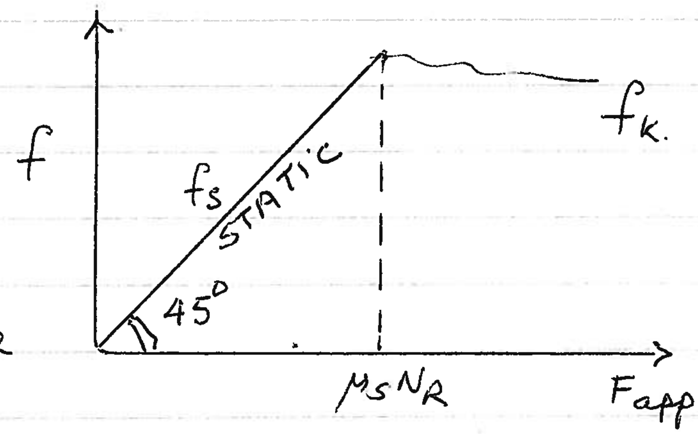
Minus sign ensures that $\vec{F}_{sp}$ is opposite to $\vec{\Delta x} = \Delta x\,\hat{x}$.

So if $k = 10^4 N/m$, it will cost you 10N of force to change its length by 1mm.

V **FRICTION**: This force arises b/c surfaces of solids are never totally smooth so when two surfaces are made to slide past one another they resist it by developing the force of friction. Indeed, as we showed in class if the applied force is less than a certain value no motion occurs and we talk of static friction (f_s).

Note: friction always opposes motion





Recall the Expt. we did in class. We slowly increased F_{app} and since no motion occurred we said $\vec{f}_s = -\vec{F}_{app}$. That means that as long as there is no motion f vs F_{app} forms a st. line of slope 1. Finally, sliding starts b/c f_s has a maximum value. That is

$$f_s \leq (\mu_s N_R) \qquad \vec{f}_s \perp \vec{N}_R$$

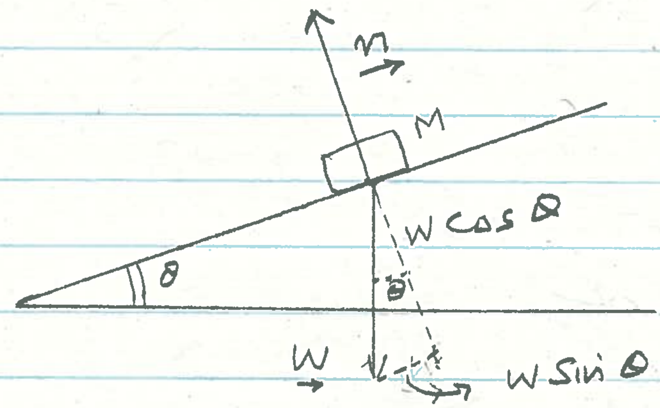
where μ_s is called coefficient of static friction. μ_s is determined by the properties of the two surfaces.

If $f_{app} > \mu_s N_R$, sliding begins but frictional force is <u>Not</u> zero. It is given by

$$f_k = \mu_k N_R.$$

μ_k is called coeff. of kinetic friction.

<u>Note</u> $\vec{f} \perp N_R$, $\vec{f}$ always opposes $\vec{F}_{applied}$



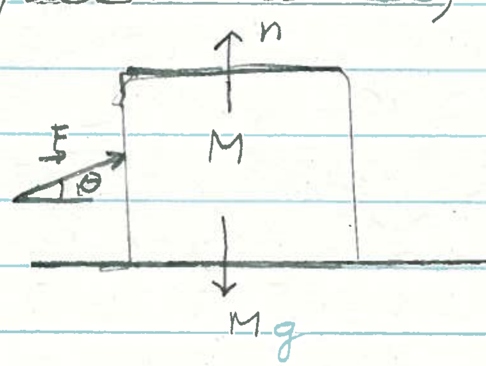
$\perp$ to surface there is Ξm so

$$n - Mg\cos\theta = 0 \; ; \quad n = Mg\cos\theta$$

$\parallel$ to surface there is acceleration caused by $Mg\sin\theta$

Not surprisingly $\vec{n}$ is maximum when $\theta = 0$. (horizontal surface) and goes to zero when $\theta = \pi/2$ (surface is vertical)

Ex5 Another way to chang n is to apply a force $\vec{F}$ at an angle θ above the X-axis. Now for Ξm along Y we have



$$n + F\sin\theta - Mg = 0$$

$$\text{so} \quad n = Mg - F\sin\theta$$

while along x there is acceleration given by

$$M\vec{a} = F\cos\theta\,\hat{x}$$