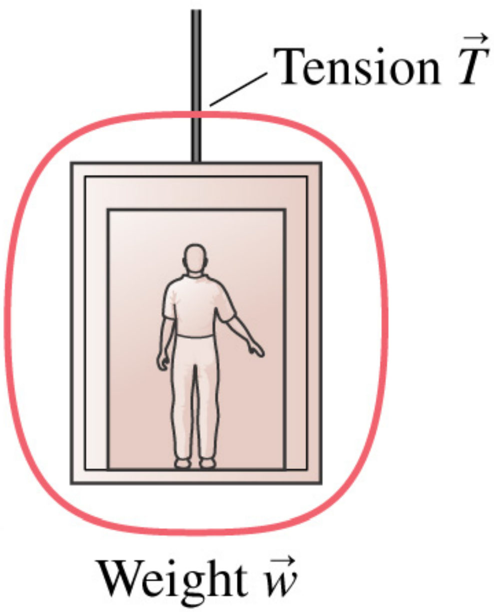
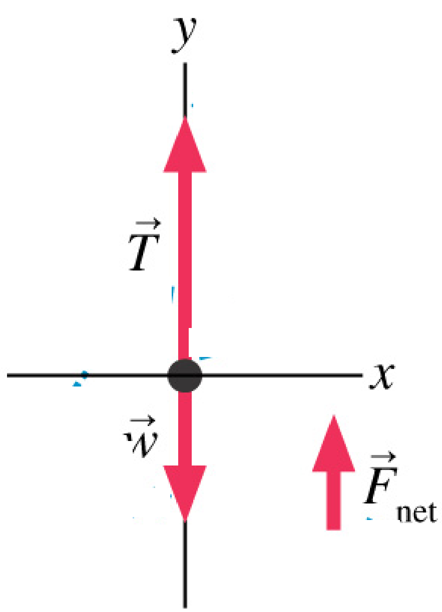
Newton's Second Law:

Motion Along a Line

Readings: Chapter 6 (2nd edition)

1) Object – as a particle
2) Identify all the forces
3) Find the net force (vector sum of all individual forces)
4) Introduce convenient co-ordinate system
5) Find the acceleration of the object (second Newton's law)
6) With the known acceleration find kinematics of the object



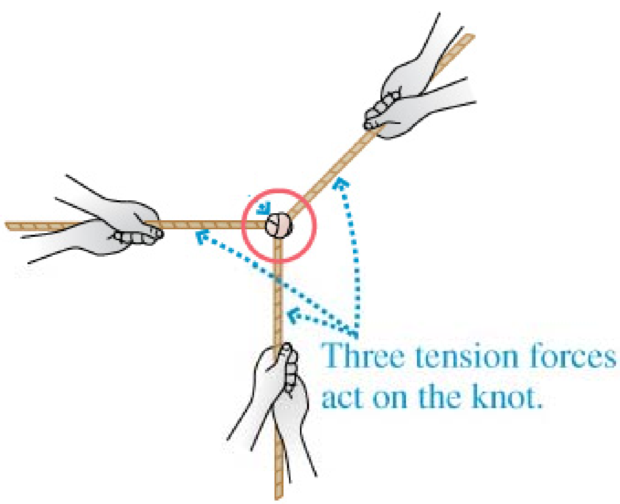


The First Class of Problems: Equilibrium

1. **Static Equilibrium: no motion (velocity = 0, then acceleration = 0)**
2. **Dynamical Equilibrium: no acceleration (velocity = constant)**

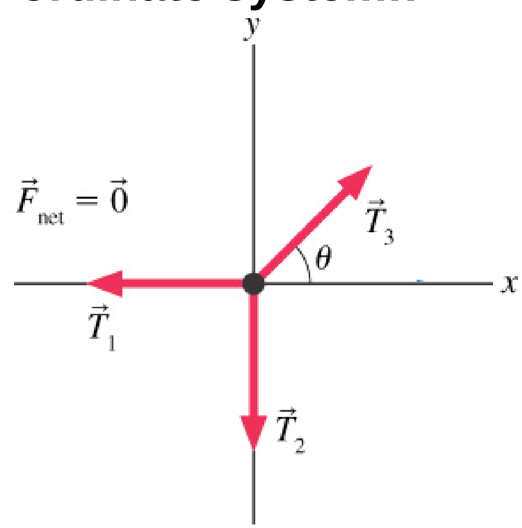
- **In both cases acceleration = 0**
- **Second Newton's Law – Net Force = 0**

Static Equilibrium:



Identify forces.

Convenient co-ordinate system!!



Draw free-body diagram.

$$\vec{F}_{net} = \vec{T}_1 + \vec{T}_2 + \vec{T}_3 = 0$$

$$-T_1 + T_3 \cos\theta = 0$$

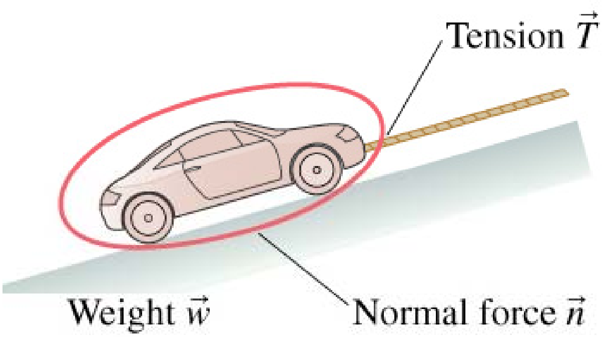
$$-T_2 + T_3 \sin\theta = 0$$

The First Class of Problems: Equilibrium

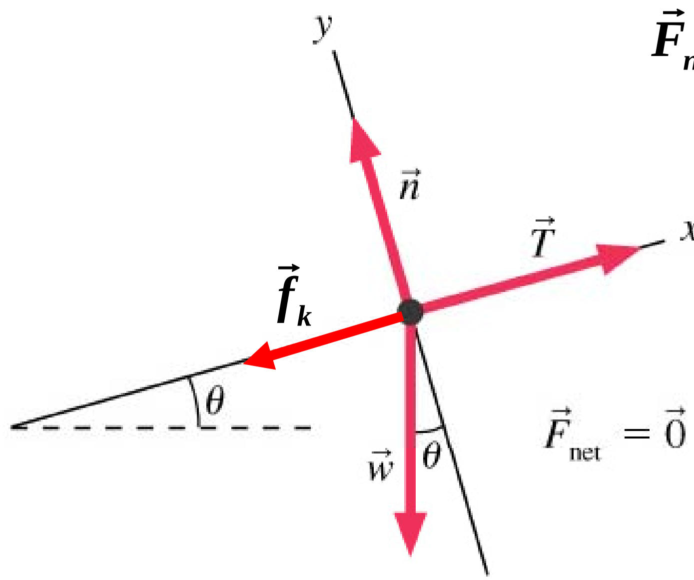
1. **Static Equilibrium: no motion (velocity = 0, then acceleration = 0)**
2. **Dynamical Equilibrium: no acceleration (velocity = constant)**

Dynamic Equilibrium:

Convenient co-ordinate system!!



Kinetic friction



$$\vec{F}_{net} = \vec{n} + \vec{T} + \vec{w} + \vec{f}_k = 0$$

$$T - f_k - w\sin\theta = 0$$

$$n - w\cos\theta = 0$$

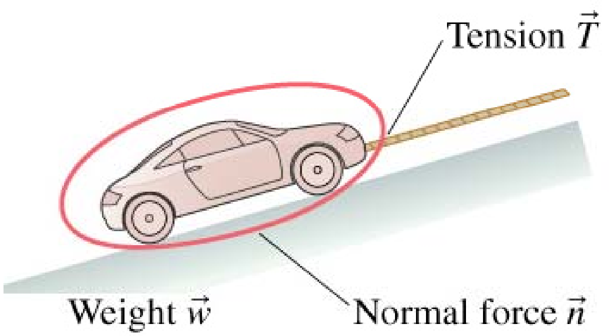
The Second Class of Problems: Find Acceleration

Important:

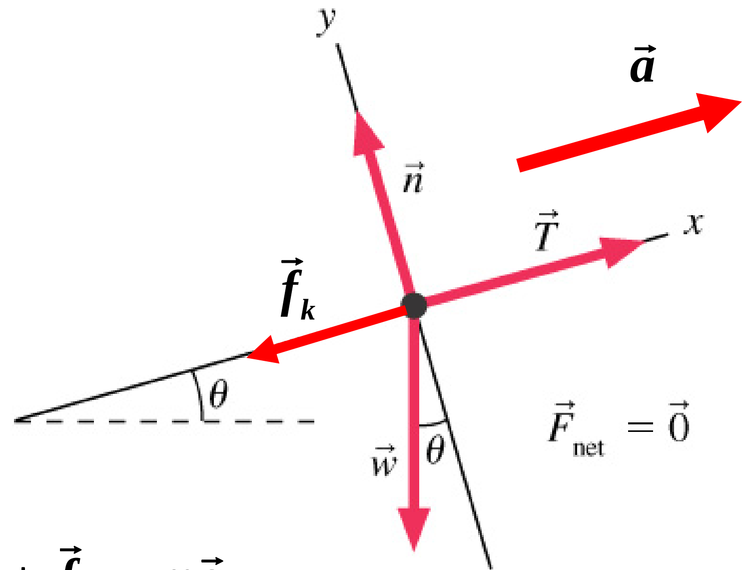
- Introduce convenient co-ordinate system!!

- Understand what the direction of acceleration is!!

$$\vec{a} = \frac{\vec{F}_{net}}{m}$$



Kinetic friction

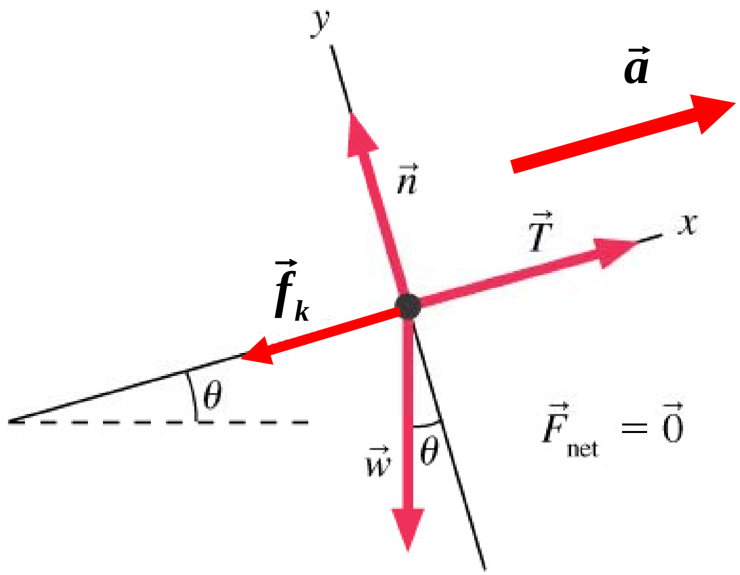


$$\vec{F}_{net} = \vec{n} + \vec{T} + \vec{w} + \vec{f}_k = m\vec{a}$$

$$T - f_k - w\sin\theta = ma$$

$$n - w\cos\theta = 0$$

The Second Class of Problems: Find Acceleration



$$\vec{a} = \frac{\vec{F}_{net}}{m}$$

$$\vec{F}_{net} = \vec{n} + \vec{T} + \vec{w} + \vec{f}_k = m\vec{a}$$

$$T - f_k - w\sin\theta = ma$$

$$n - w\cos\theta = 0$$

$T = 20N$ **is given**

$m = 1kg \Rightarrow w = mg \approx 10N$ **is given**

$\theta = 30^0$ **is given**

Then:

$$n = w\cos\theta = 10\cos 30^0 = 8.7N$$

?

$$a = \frac{T - f_k - w\sin\theta}{m} = \frac{20 - f_k - 5}{1}$$

Friction

Static friction: $f_s \leq f_{s,\max} = \mu_s n$

μ_s - coefficient of static friction (it is usually given in the problem)

n - normal force

Kinetic friction: $f_k = \mu_k n$

μ_k - coefficient of kinetic friction (it is usually given in the problem)

Rolling friction: $f_r = \mu_r n$

μ_r - coefficient of rolling friction (it is usually given in the problem)

Usually: $\mu_s > \mu_k > \underbrace{\mu_r}_{\text{very small}}$

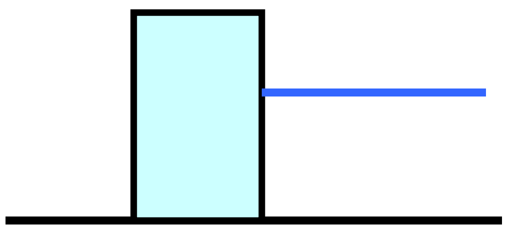
Friction

Static friction: $f_s \le f_{s,\max} = \mu_s n$

μ_s - coefficient of static friction

n - normal force

Find the maximum tension, $T_{\max}$



weight,

friction

tension

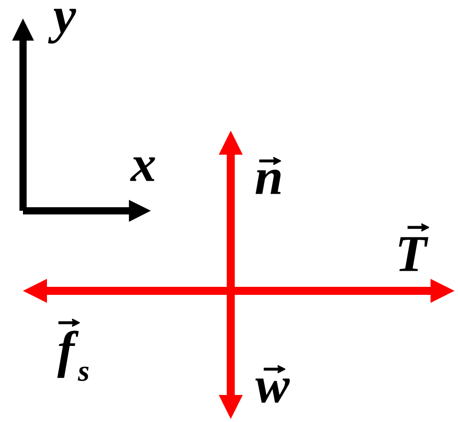
normal

Equilibrium:

$$\vec{F}_{net} = \vec{n} + \vec{w} + \vec{T} + \vec{f}_s = 0$$

$$n - w = 0$$

$$-f_s + T = 0$$



$$n = w$$

$$f_{s,\max} = \mu_s n = \mu_s w$$

$$f_s = T \le f_{s,\max}$$

Condition of equilibrium: $T \le \mu_s w$

$$T_{\max} = \mu_s w$$

Friction

Static friction: $f_s \le f_{s,\max} = \mu_s n$

μ_s - coefficient of static friction

n - normal force

Find the maximum tension, $T_{\max}$

Equilibrium:

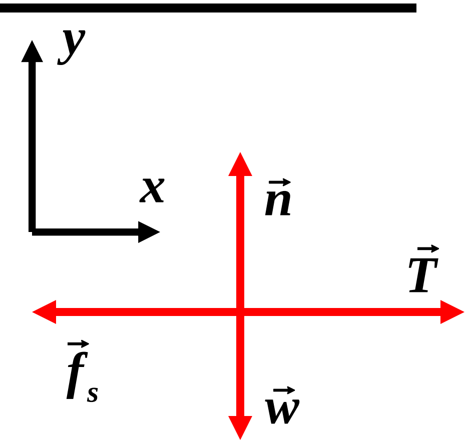
$$\vec{F}_{net} = \vec{n} + \vec{w} + \vec{T} + \vec{f}_s = 0$$

$$n - w = 0$$

$$-f_s + T = 0$$

$$f_{s,\max} = \mu_s n = \mu_s w$$

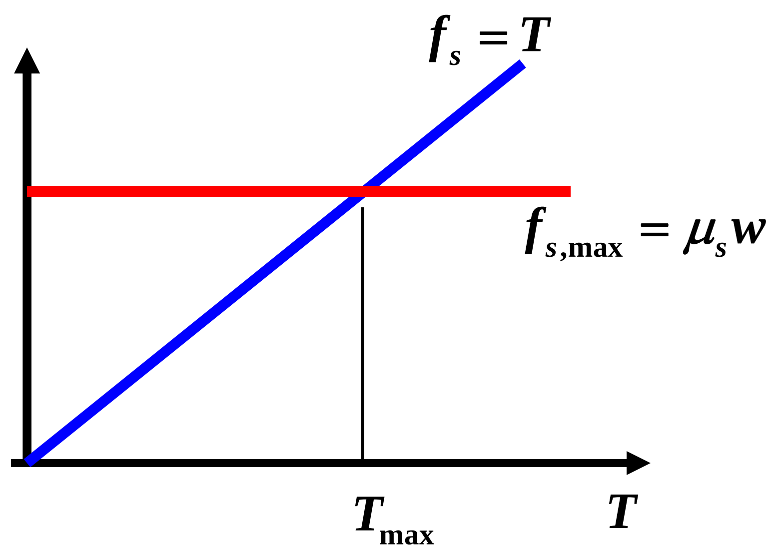
$$f_s = T \le f_{s,\max}$$



Condition of equilibrium:

$$T \le \mu_s w$$

$$T_{\max} = \mu_s w$$



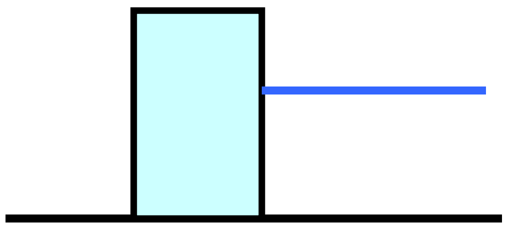
Friction

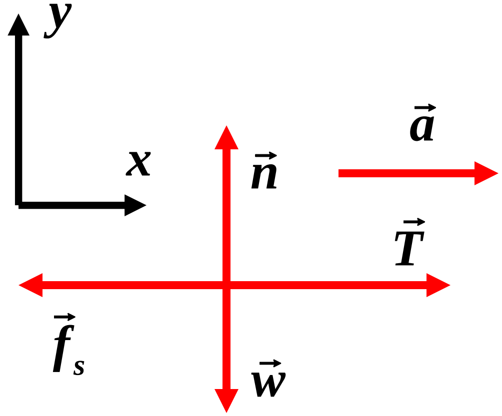
<u>Kinetic friction:</u> $f_k = \mu_k n$

μ_k - coefficient of kinetic friction

n - normal force

Find acceleration, $(T > T_{\max})$





$$\vec{F}_{net} = \vec{n} + \vec{w} + \vec{T} + \vec{f}_k = m\vec{a}$$
$$n - w = 0$$
$$-f_k + T = ma$$

weight,

friction

tension

normal

$n = w$ then $f_k = \mu_k n = \mu_k w$

$$a = \frac{T - f_k}{m} = \frac{T - \mu_k w}{m} = \frac{T}{m} - \mu_k g$$

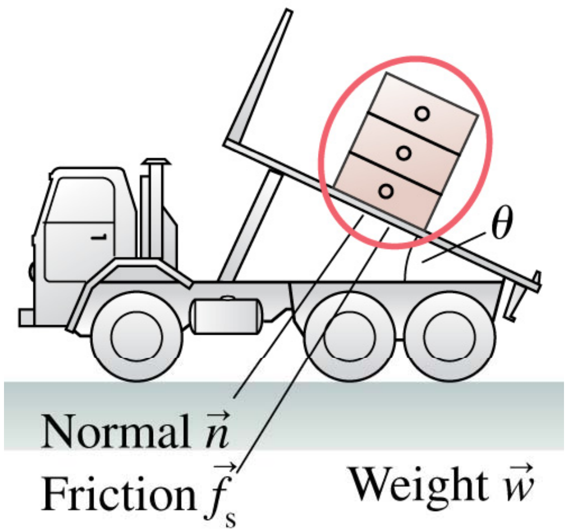
Friction

Static friction: $f_s \le f_{s,\max} = \mu_s n$

μ_s - coefficient of static friction

n - normal force

Find the maximum angle, $\theta_{\max}$

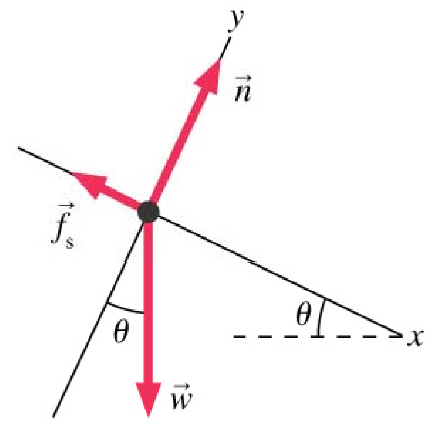


Equilibrium:

$$\vec{F}_{net} = \vec{n} + \vec{w} + \vec{f}_s = 0$$

$$n - w\cos\theta = 0$$

$$-f_s + w\sin\theta = 0$$



$$n = w\cos\theta \qquad f_{s,\max} = \mu_s n = \mu_s w\cos\theta$$

$$f_s = w\sin\theta \le f_{s,\max}$$

Condition of equilibrium: $w\sin\theta \le \mu_s w\sin\theta$

$$\tan\theta \le \mu_s$$

$$\tan\theta_{\max} = \mu_s$$

Friction

<u>Static friction:</u> $f_s \le f_{s,\max} = \mu_s n$

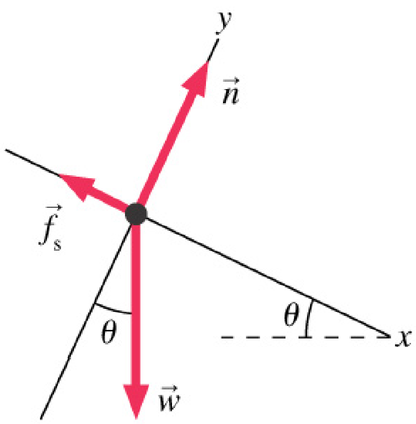
μ_s - coefficient of static friction

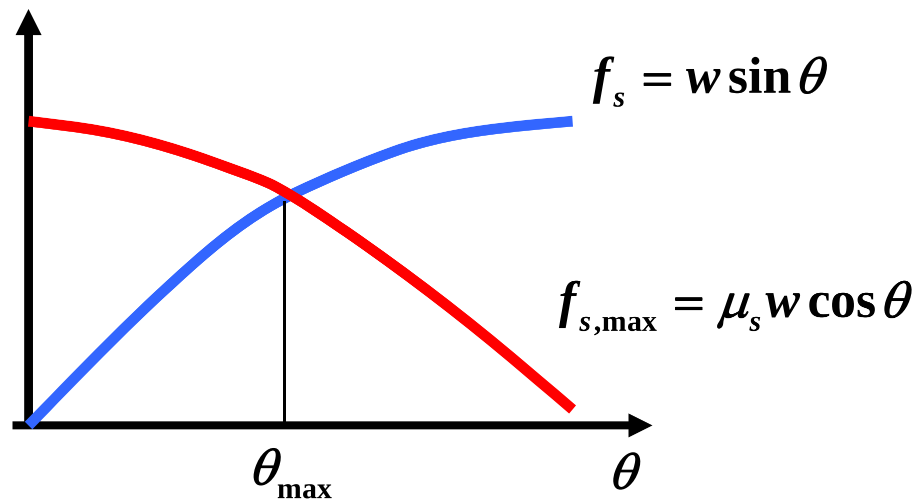
n - normal force

Find the maximum angle, $\theta_{\max}$

$$f_{s,\max} = \mu_s n = \mu_s w \cos\theta$$

$$f_s = w \sin\theta \le f_{s,\max}$$





Condition of equilibrium: $\tan\theta \le \mu_s$

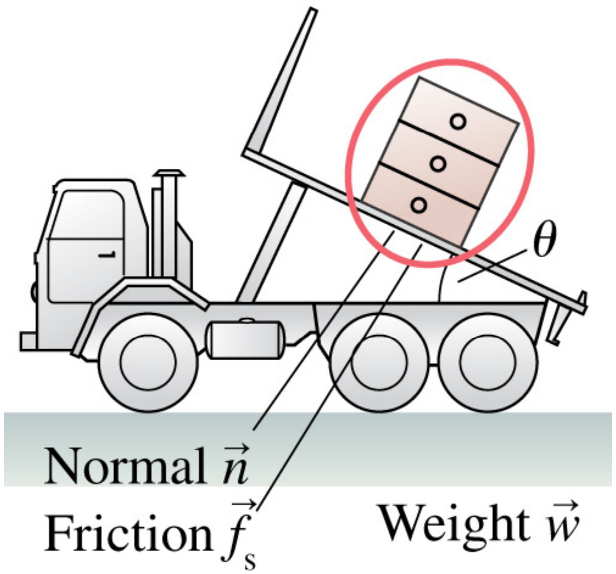
Friction

Kinetic friction: $f_k = \mu_k n$

μ_k - coefficient of kinetic friction

n - normal force

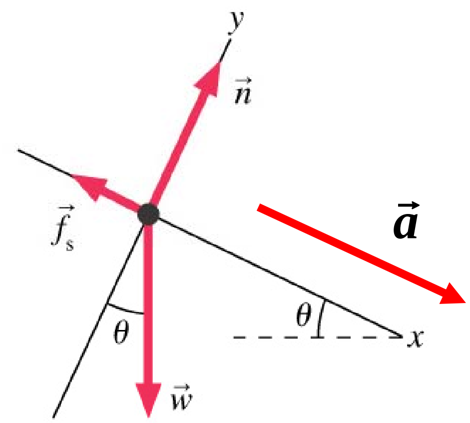
Find acceleration $(\theta > \theta_{\max})$



$$\vec{F}_{net} = \vec{n} + \vec{w} + \vec{f}_k = m\vec{a}$$

$$n - w\cos\theta = 0$$

$$-f_k + w\sin\theta = ma$$



$n = w\cos\theta$ then $f_k = \mu_k n = \mu_k w\cos\theta$

$$a = \frac{-f_k + w\sin\theta}{m} = \frac{-\mu_k w\cos\theta + w\sin\theta}{m} = g(\sin\theta - \mu_k\cos\theta)$$

Weight and Apparent Weight

Weight – gravitational force - pulls the objects down

$$\vec{w} = m\vec{g}$$

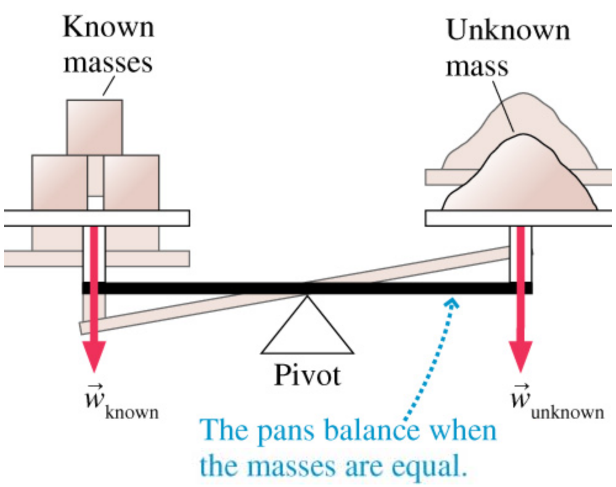
m - mass of the object (the same on all planets)

$g = 9.8\frac{m}{s^2}$ - free-fall acceleration (different on different planets)

How can we measure weight?

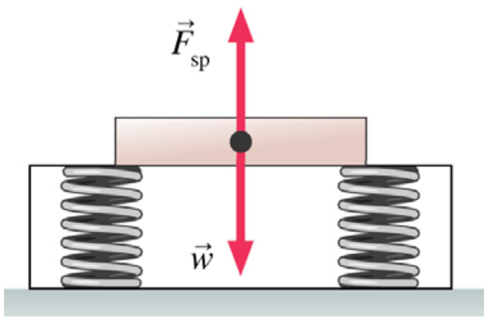
1. We can measure mass by comparing with the known mass

$$m_{unknown} = m_{known}$$

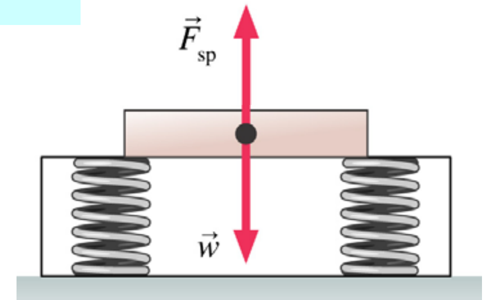


2. We can measure the weight by comparing with the known force

$$w = F_{spring}$$



Weight and Apparent Weight



Apparent Weight – reading of the scale

(or the normal force)

In equilibrium:

$$\vec{F}_{net} = 0 \quad \text{then} \quad F_{spring} = w$$

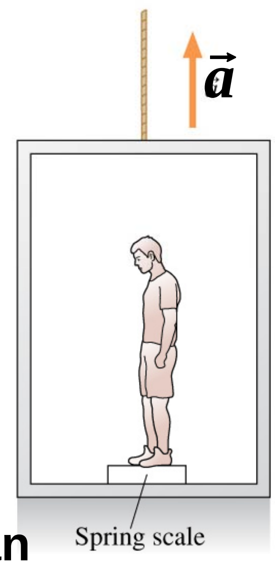
Motion with acceleration:

$$\vec{F}_{net} = m\vec{a}$$

$$F_{spring} - w = ma$$

then

$$F_{spring} = m(g + a)$$



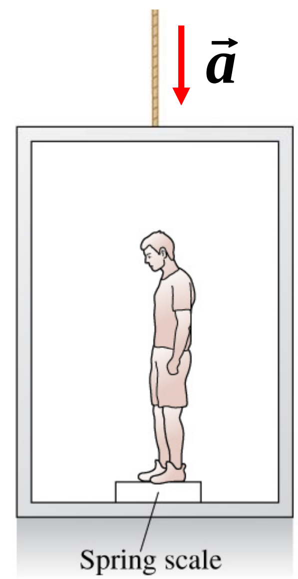
The man feels heavier than normal while accelerating upward

$$\vec{F}_{net} = m\vec{a}$$

$$F_{spring} - w = -ma$$

then

$$F_{spring} = m(g - a)$$



The man feels lighter than normal while accelerating upward