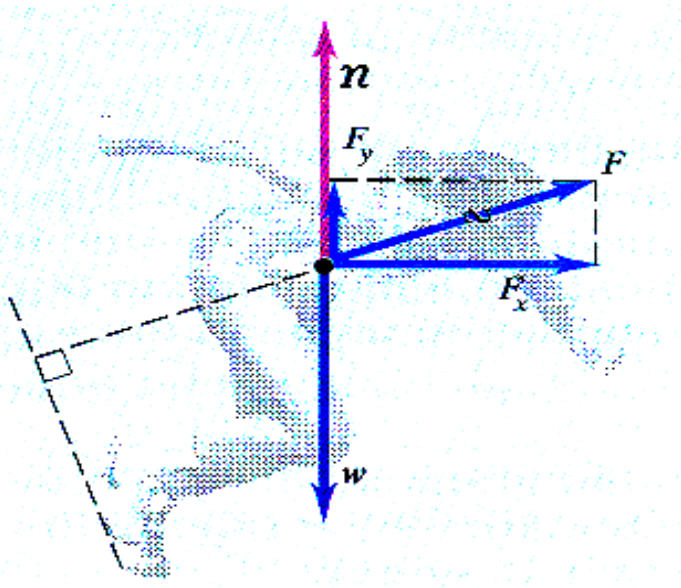
Ch 03 Force



Movement of massive object ⟷ **Force** ⟷ Velocity, acceleration

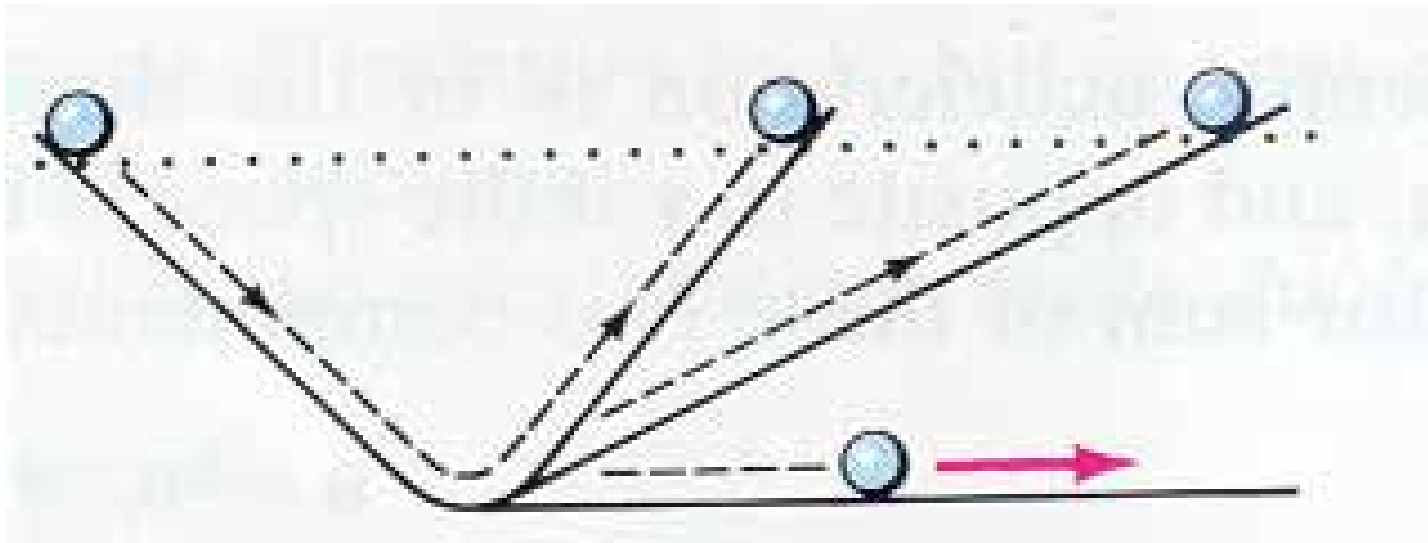
Source of the move

1 평(坪) = ? m^2

~ 3.305 m^2

~ 1.82 m x 1.82 m

Newton's First Law

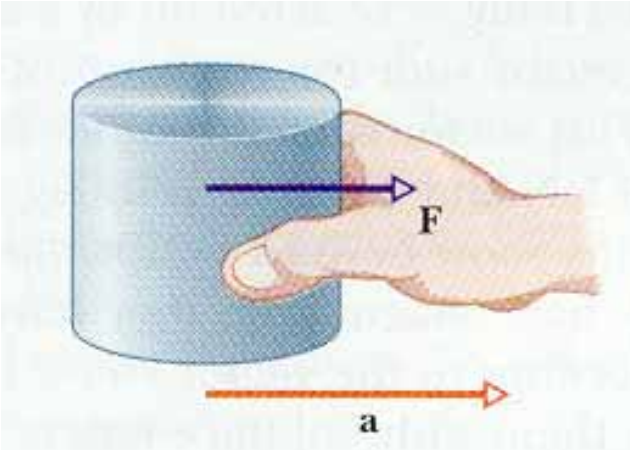


Law of Inertia (mass)

Any body will remain at rest of in motion in a straight line with a constant velocity unless acted upon by an outside force

If the net force is zero, there is a reference frame with zero acceleration

Newton's Second Law



Law of Motion

If a force is applied, the state of motion is changed

$$\mathbf{F} = \left[\frac{d\mathbf{p}}{dt} = \frac{d}{dt}(m\mathbf{v}) = m\frac{d\mathbf{v}}{dt} \right] = m\mathbf{a}$$

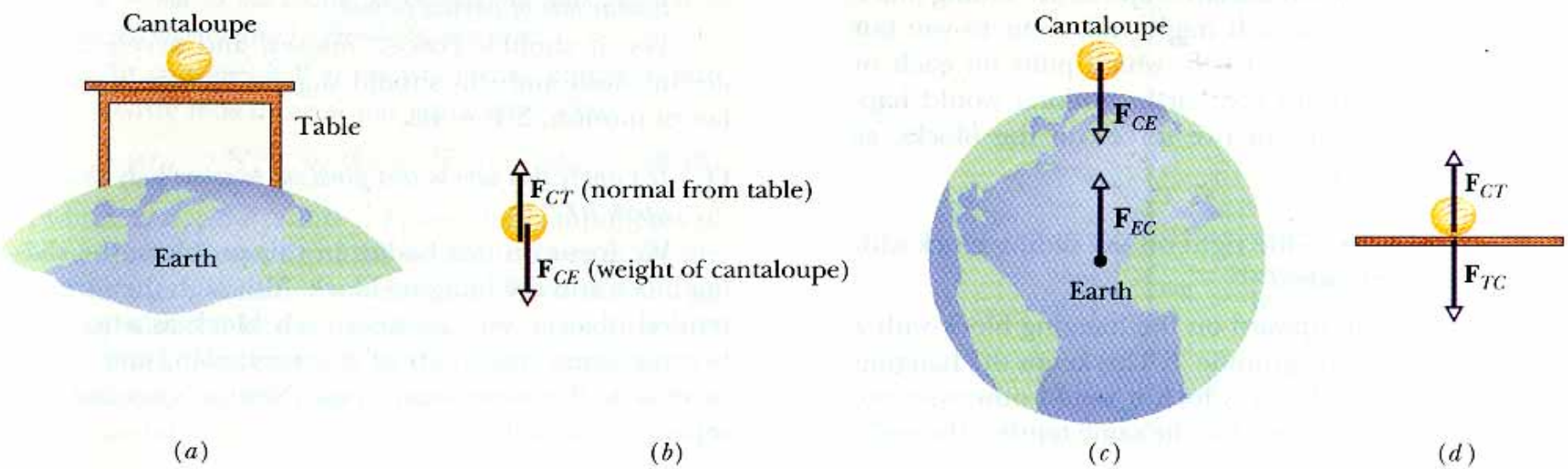
$$\text{newton} \Rightarrow [\mathrm{N} = \mathrm{kg} \cdot \mathrm{m/s^2}]$$

Newton's Third Law

Action-Reaction Law

Whenever one body exerts a force on a second body, the second body exerts a force back on the first that is equal in magnitude and opposite in direction

$$\mathbf{F}_{AB} = -\mathbf{F}_{BA}$$



Example 3.1

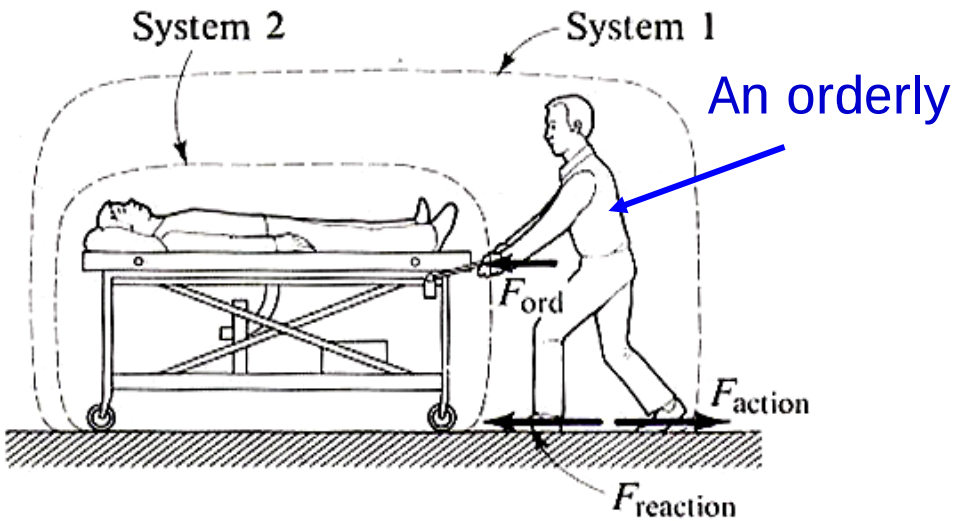
A 440-g can of food on a frictionless level surface is observed to accelerate at a rate of 1.5 m/sec². What is the force on the can?

$$F_{net,ext} = ma$$

$$= (0.440\,\mathrm{kg})(1.5\,\mathrm{m/s^2}) = 0.66\,\mathrm{kg\cdot m/s^2}$$

$$F_{net,ext} = 0.66\,\mathrm{N}$$

Example 3.2



The orderly exerts a backward force of 100 N on the floor. What acceleration is produced, assuming the friction in the wheels is negligible?

(question on the system I)

An orderly $m_o = 85\text{kg}$

Gurney $m_g = 20\text{kg}$

Patient $m_p = 50\text{kg}$

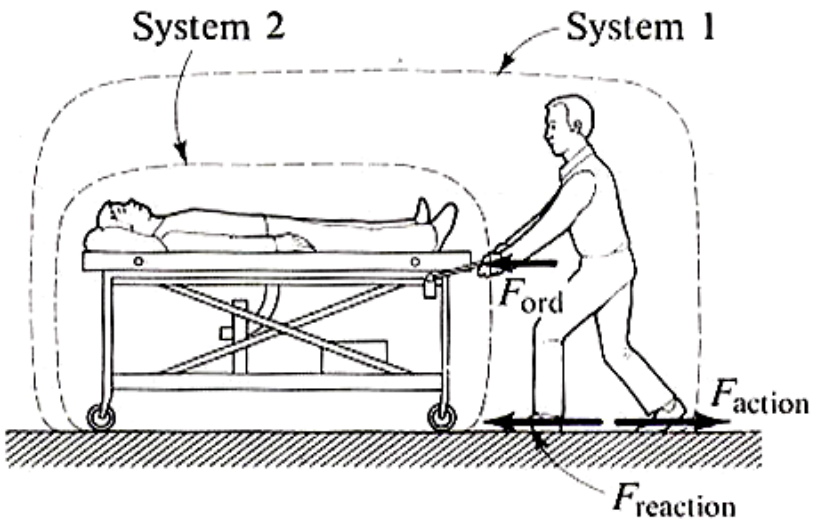
Force that the orderly exerts $F_a = 100\text{N}$

Acceleration

$$a = \frac{F_t}{m_t} = \frac{F_a}{m_o + m_g + m_p}$$

$$= \frac{100}{85 + 20 + 50} = 0.645\text{m/s}^2$$

Example 3.3



Calculate the force the orderly exerts on the gurney in Example 3.2

(Question on system 2)

An orderly $m_o = 85\text{kg}$

Gurney $m_g = 20\text{kg}$

Patient $m_p = 50\text{kg}$

Force that the orderly exerts $F_a = 100\text{N}$

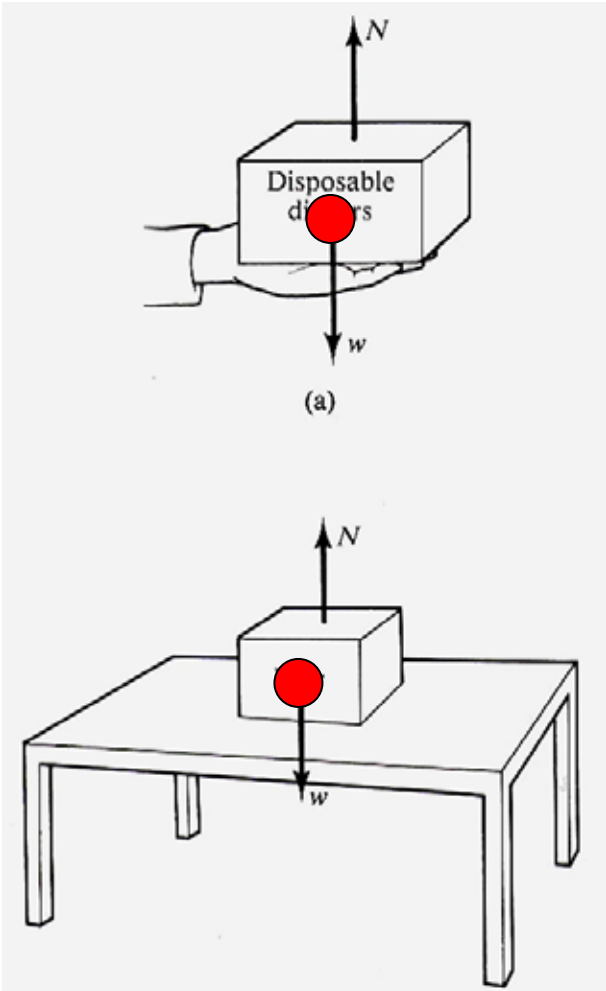
Force

$$F_o = ma = (m_g + m_p)a$$

$$= (20+50)(0.645)$$

$$= 45.2\text{kgm/s}^2 = 45.2\text{N}$$

Weight and normal force



weight

$$\mathbf{F} = m\mathbf{a}$$

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

Normal force

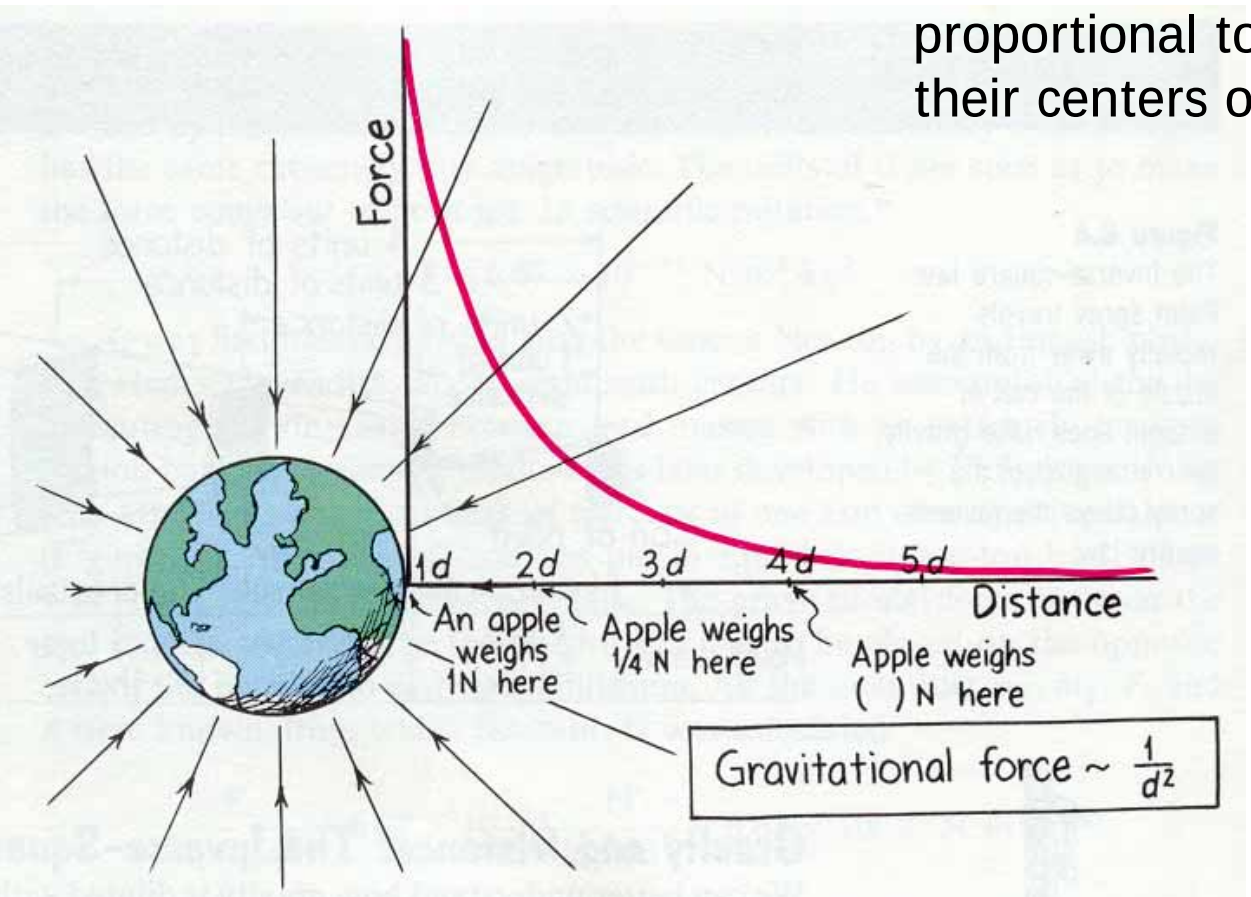
$$\mathbf{F}_t = \mathbf{0}$$

$$N - w = 0 \quad \Rightarrow \quad N = w$$

Newton's Universal Law of Gravitation

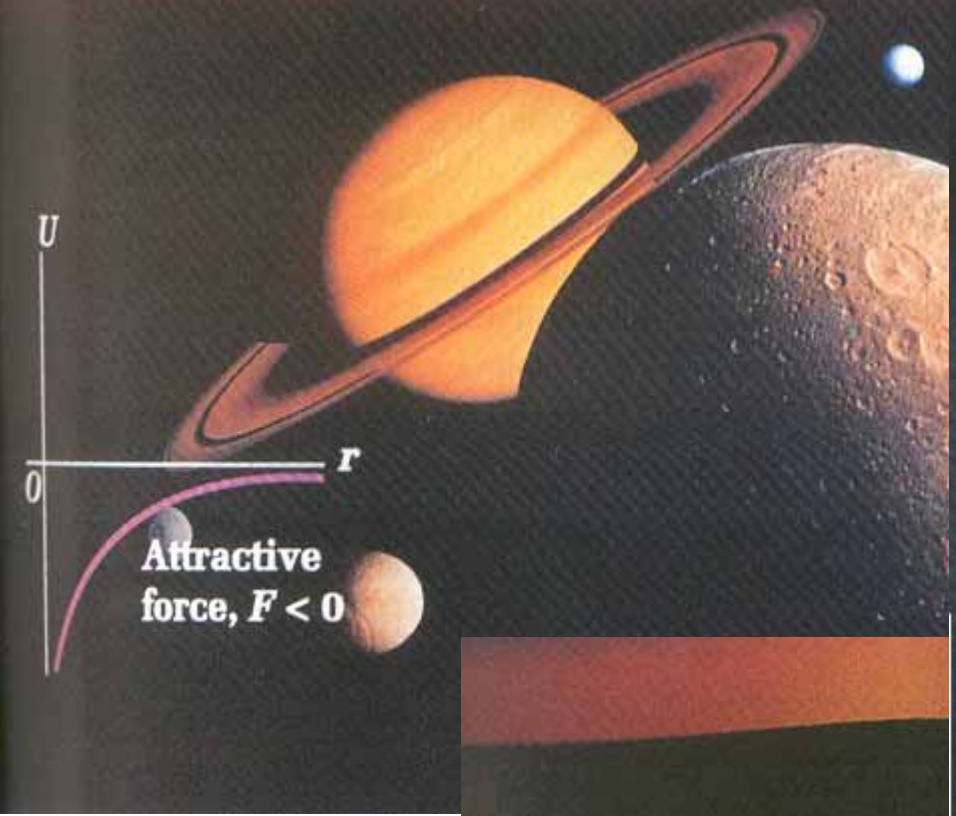
$$F = G\frac{mM}{r^2}$$

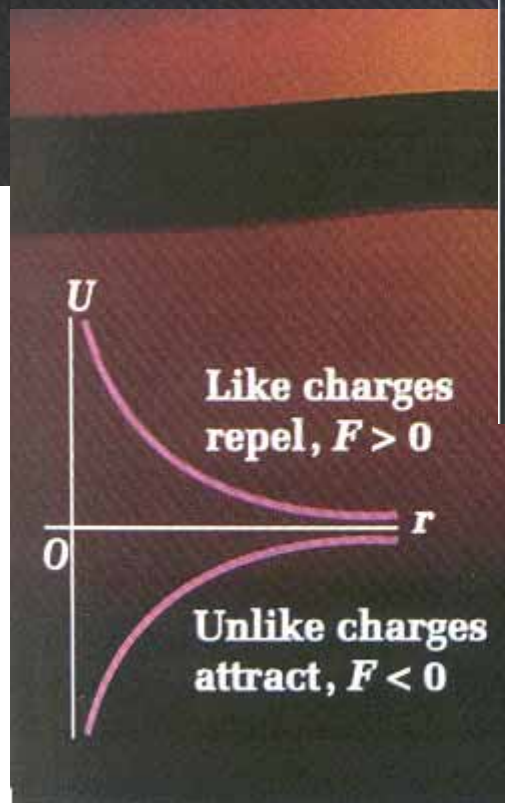
: there is a force of attraction between any two masses that is proportional to the product of the masses and inversely proportional to the distance between their centers of mass

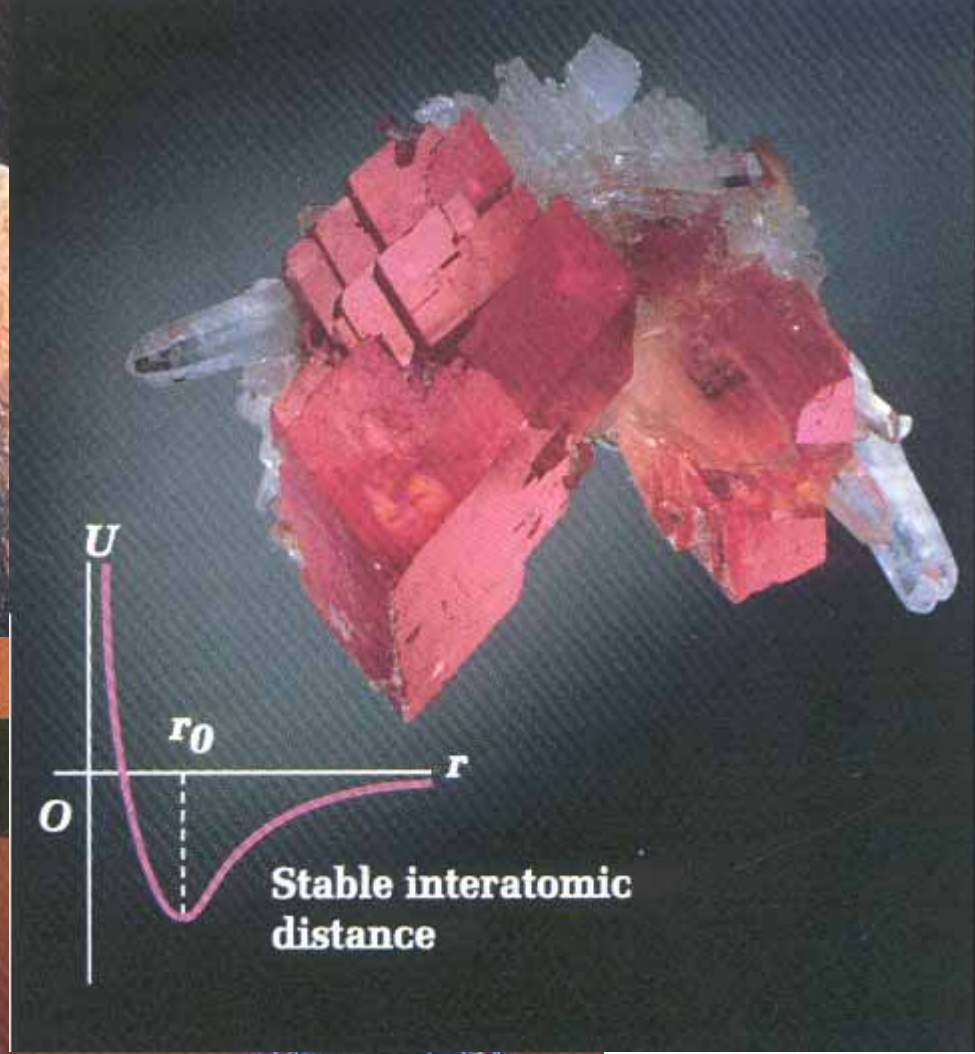


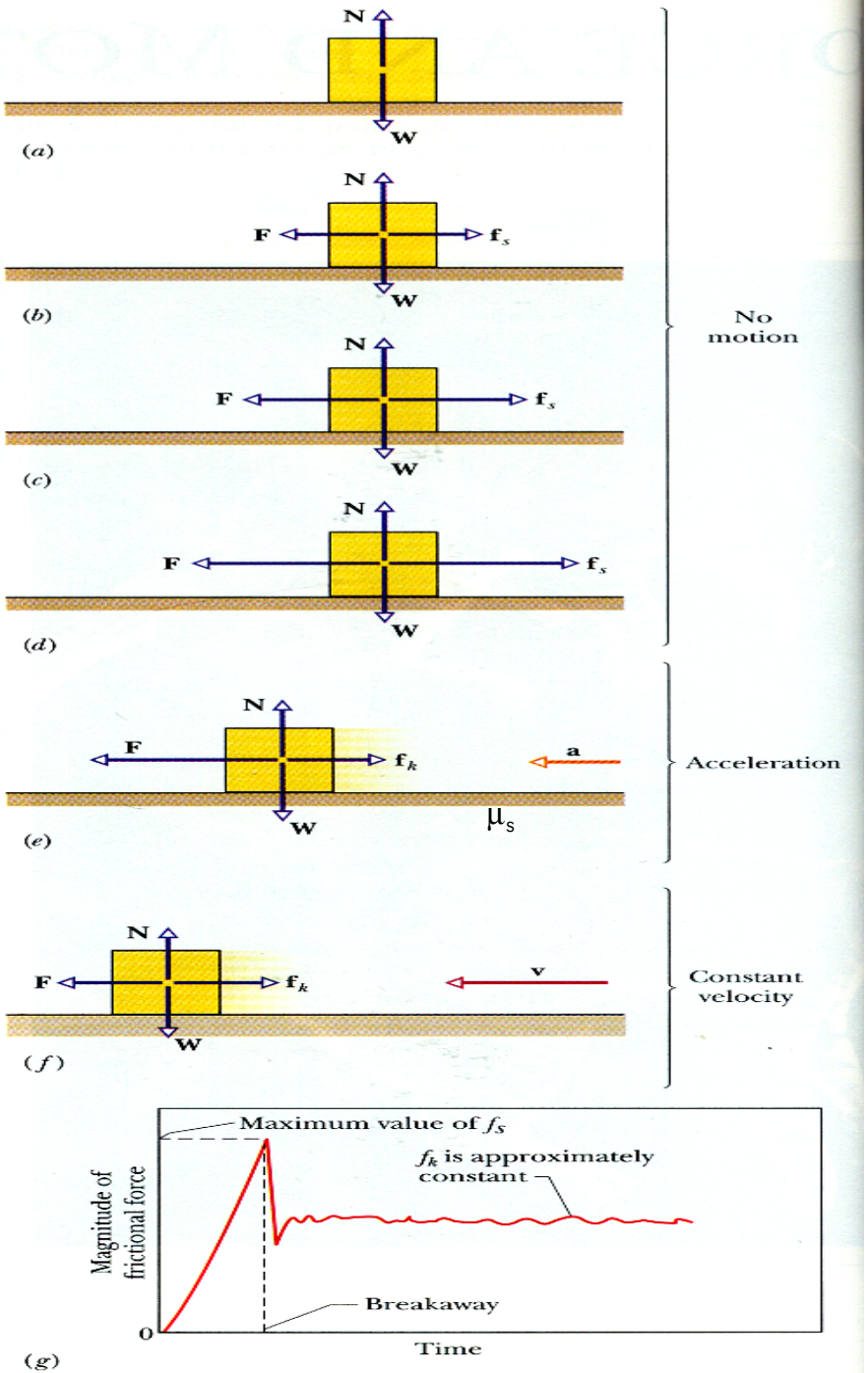
$$w = mg \Leftrightarrow G\frac{mM}{r^2}$$

$$g = \frac{GM}{r^2}$$


U
r
0
Attractive
force, F < 0


U
Like charges
repel, F > 0
r
0
Unlike charges
attract, F < 0


U
r0
r
0
Stable interatomic
distance



Friction

: proportional to the normal force

Static Friction

$$f_s = \mu_s N$$

Kinetic Friction

$$f\,(=f_k) = \mu_k N$$

$$f \le f_s$$

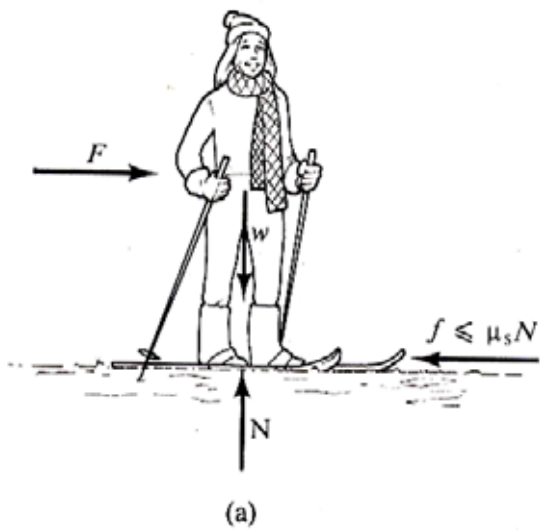
μ_s : coefficient of static friction

μ_k : coefficient of kinetic friction

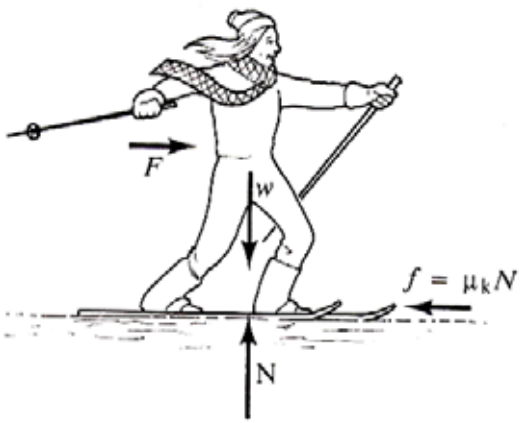
Friction

Coefficients of friction		
	Kinetic	Static
Rubber on dry concrete	0.7	1.0
Rubber on wet concrete	0.5	0.7
Wood on Wood	0.3	0.5
Waxed wood on wet snow	0.1	0.14
Metal on wood	0.3	0.5
Steel on steel (dry)	0.3	0.6
Steel on steel (oiled)	0.03	0.05
Teflon on steel	0.04	0.04
Bone lubricated with synovial fluid (활액)	0.015	0.016
Shoes on wood	0.7	0.9
Shoes on ice	0.05	0.1
Ice on ice	0.03	0.1
Steel on ice	0.02	0.4

Example 3.4



(a)



(b)

A 70-kg cross-country skier is on level ground in wet snow wearing waxed wooden skis. (a) What is the maximum force that can be exerted on the skier in a horizontal direction without causing her to move? (b) Once the skier is moving, what horizontal force is necessary to keep her moving at a steady velocity?

$$w = mg = (70\,\text{kg})(9.8\,\text{m/s}^2) = 686\,\text{N}$$

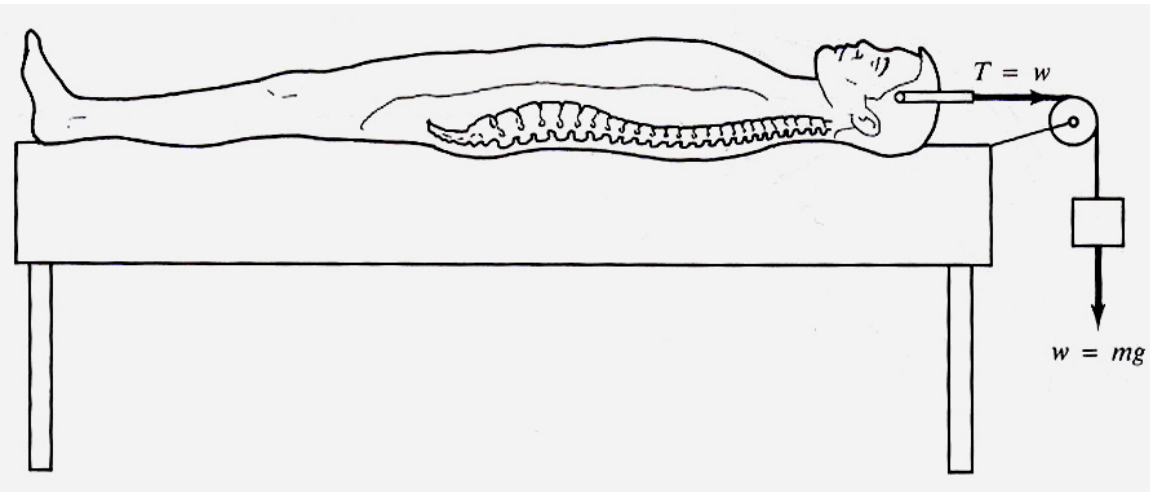
$$f = \mu_s N$$
$$= (0.14)(686\,\text{N}) = 96\,\text{N}$$

$$F_{net,ext} = 0 \Rightarrow F - f = 0$$

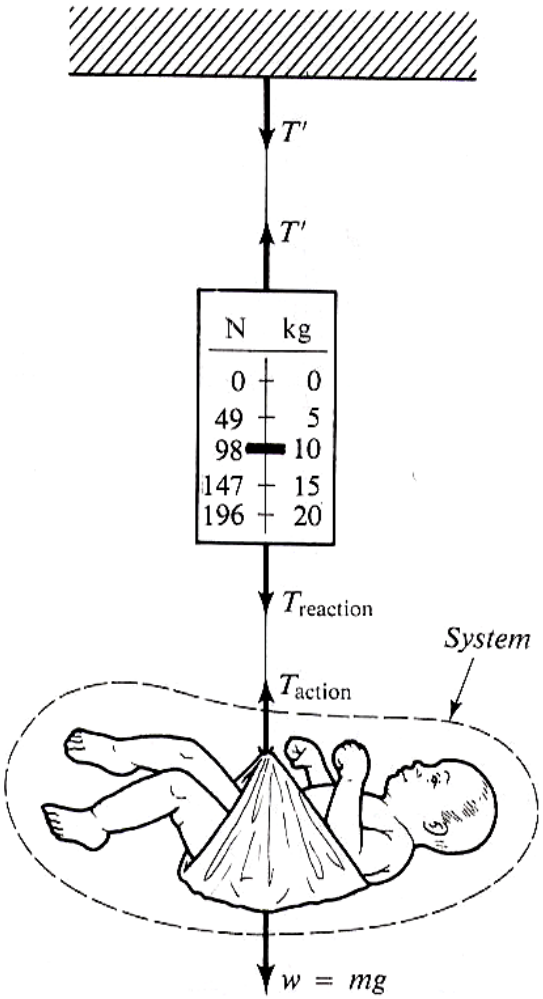
$$F = f = \mu_k N$$
$$= (0.1)(686\,\text{N}) = 68.6\,\text{N}$$

Tension

A tension is any force carried by a flexible string, rope, cable, chain etc



Example 3.5



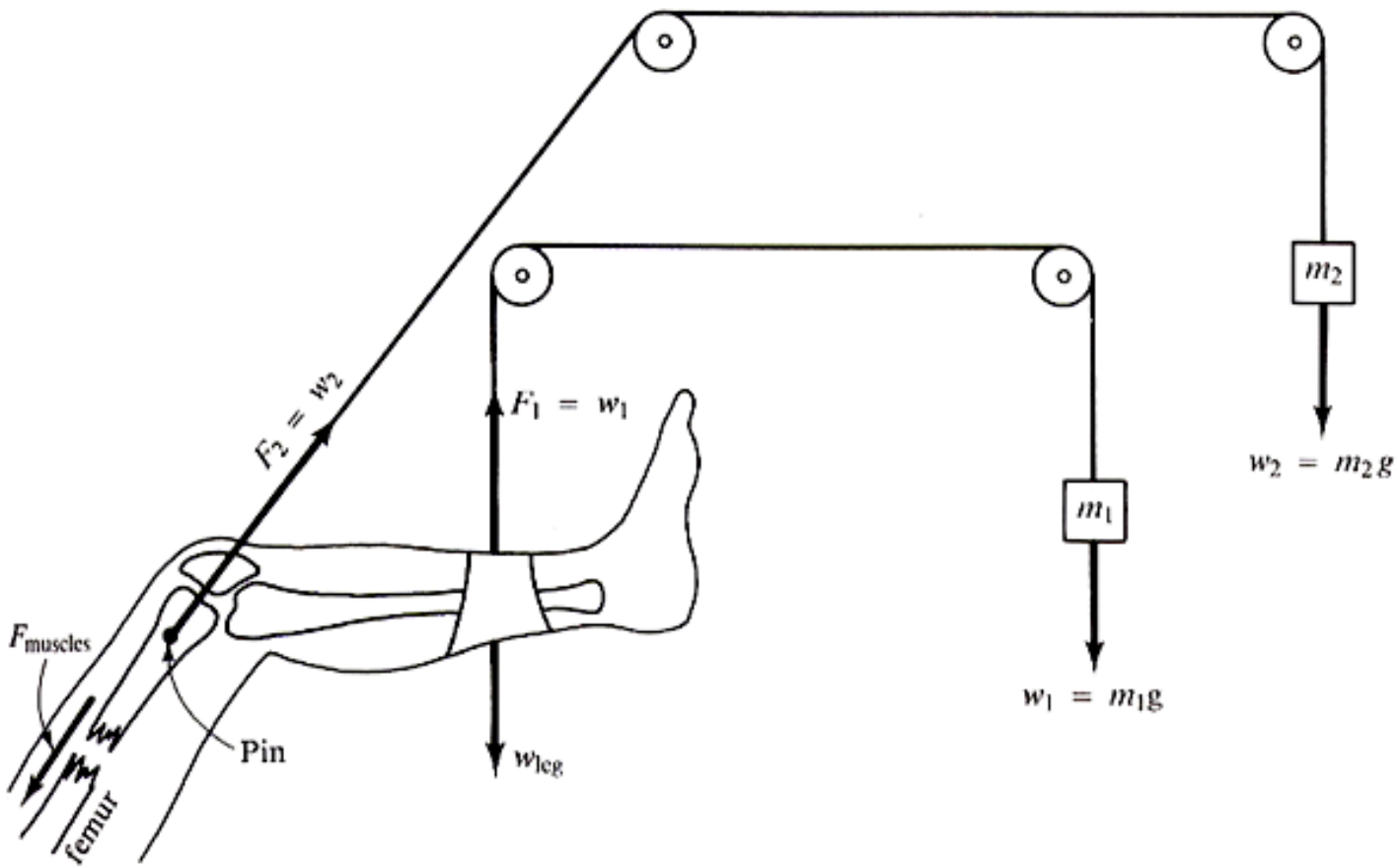
A child and basket with a total mass of 10 kg are suspended from a scale by a cord. Calculate the tension in the cord.

$$F_{net,ext} = T - w = 0$$

$$T = w = mg$$

$$= (10\,\text{kg})(9.8\,\text{m/s}^2) = 98\,\text{N}$$

Tensions of a patient



Vector

1. Vectors have direction & magnitude

$\{\vec{a}, \mathbf{a}\}, \quad a = |\mathbf{a}|$

2. Two vectors are identical if both direction and magnitude are same

$\mathbf{a} = \mathbf{b}$

3. Negative vector.

$-\mathbf{a}$

4. Zero vector.

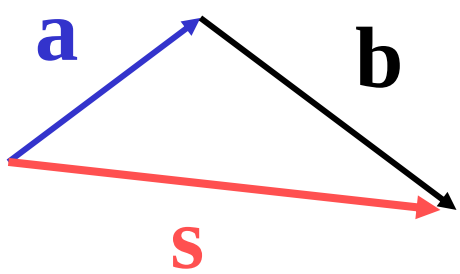
$\mathbf{0}$

5. Unit vector.

$\hat{\mathbf{e}} \Rightarrow |\hat{\mathbf{e}}| = 1$

Vector analysis

$$\mathbf{a}+\mathbf{b}=\mathbf{s}$$



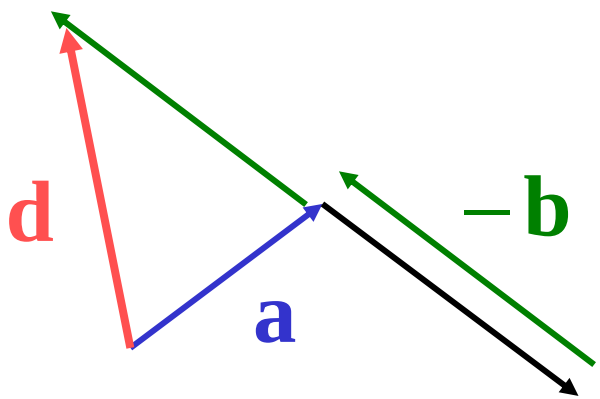
$$\mathbf{a}+\mathbf{b}=\mathbf{b}+\mathbf{a}$$

$$\mathbf{a}+(\mathbf{b}+\mathbf{c})=(\mathbf{a}+\mathbf{b})+\mathbf{c}$$

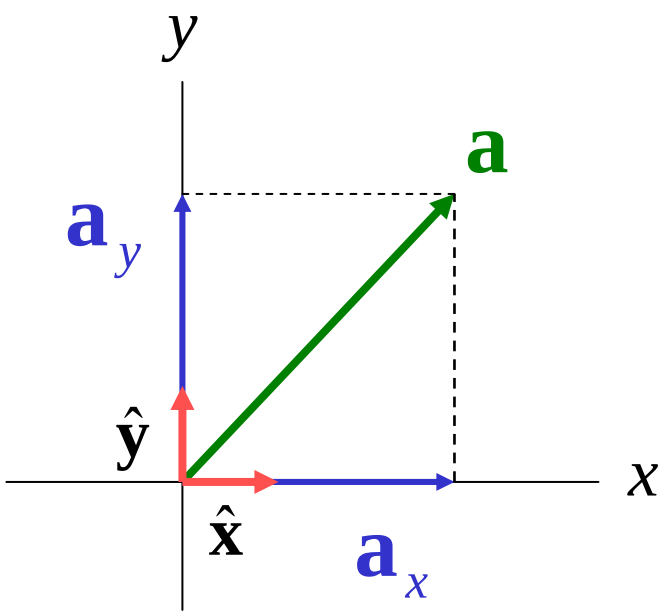
$$\mathbf{a}+(-\mathbf{a})=\mathbf{0}$$

$$\mathbf{a}+\mathbf{0}=\mathbf{a}$$

$$\mathbf{a}-\mathbf{b}=\mathbf{d}$$



Components of Vectors



$$\hat{\mathbf{x}} = \mathbf{i} = (1,0,0)$$

$$\hat{\mathbf{y}} = \mathbf{j} = (0,1,0)$$

$$\mathbf{a} = \mathbf{a}_x + \mathbf{a}_y + \mathbf{a}_z$$
$$= a_x\hat{\mathbf{x}} + a_y\hat{\mathbf{y}} + a_z\hat{\mathbf{z}}$$

$$\mathbf{a}+\mathbf{b} = (a_x\mathbf{i}+a_y\mathbf{j})+(b_x\mathbf{i}+b_y\mathbf{j})$$
$$= (a_x+b_x)\mathbf{i}+(a_y+b_y)\mathbf{j}$$

$$\mathbf{a}+\mathbf{b} = \mathbf{s} = s_x\mathbf{i}+s_y\mathbf{j}$$

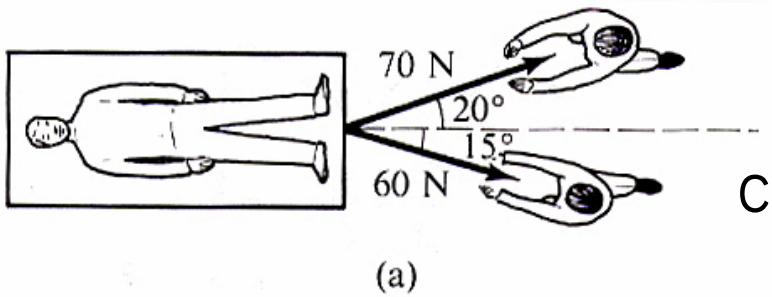
$$s_x = a_x + b_x$$

$$s_y = a_y + b_y$$

$$a_x = a\cos\theta, \quad a_y = a\sin\theta$$

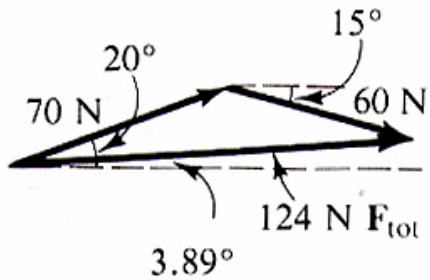
$$\theta = \tan^{-1}\left(\frac{a_y}{a_x}\right)$$

Example 3.6



(a)

Calculate the total force exerted on a gurney



(b)

$$\mathbf{F_t} = \mathbf{F_1} + \mathbf{F_2}$$

$$\mathbf{F_1} = F_{1x}\mathbf{i} + F_{1y}\mathbf{j}$$

$$\mathbf{F_2} = F_{2x}\mathbf{i} + F_{2y}\mathbf{j}$$

$$\mathbf{F_t} = (F_{1x} + F_{2x})\mathbf{i} + (F_{2y} + F_{2y})\mathbf{j}$$

$$F_{1x} = F_1 \cos 20° = 70(0.939) = 65.78$$

$$F_{1y} = F_1 \sin 20° = 70(0.342) = 23.94$$

$$F_{2x} = F_2 \cos 15° = 60(0.966) = 57.95$$

$$F_{2y} = F_2 \sin 15° = 60(0.259) = 15.53$$

$$F_{tx} = F_{1x} + F_{2x} = 123.73$$

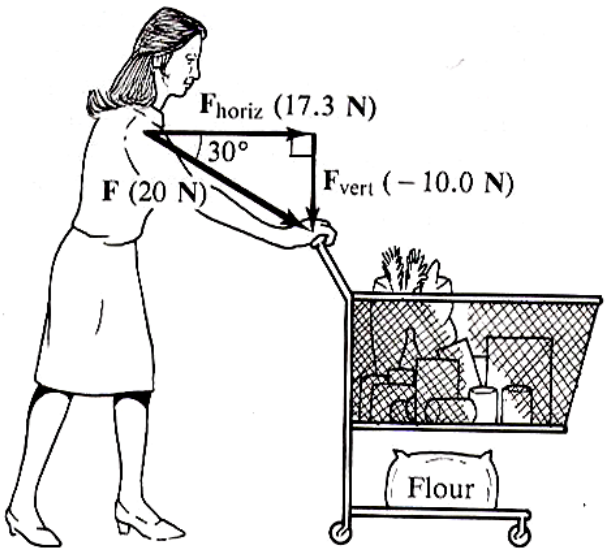
$$F_{ty} = F_{2y} - F_{2y} = 8.41$$

$$F_t = \sqrt{F_{tx}^{\,2} + F_{ty}^{\,2}} = 124.01$$

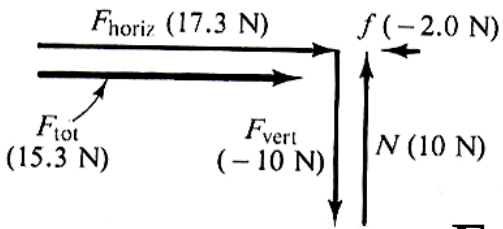
$$\theta = \tan^{-1}\left(F_{ty} / F_{tx}\right) = 3.89°$$

Example 3.7 / 3.8

Calculate the acceleration (cart+stuff=25 kg, frictional force=2.0 N)



(a)



(b)

Acceleration of the cart

$$F_n = F_h - f = 17.3 - 2.0 = 15.3$$

$$a = \frac{F_n}{m} = \frac{15.3}{25} = 0.61 \text{m/s}^2$$

Normal Force

$$\mathbf{F_y = 0}$$

$$N - w - F_v = 0$$

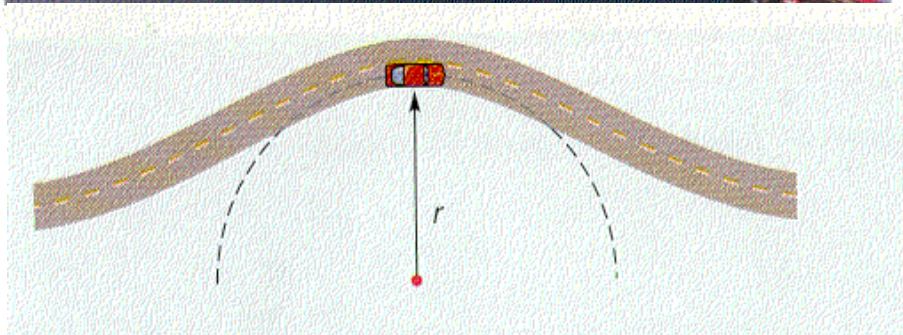
$$N = w + F_v = mg + F_v$$

$$= (25)(9.8) + 10 = 255\text{N}$$

$$\mathbf{F_t = F_h + F_v}$$

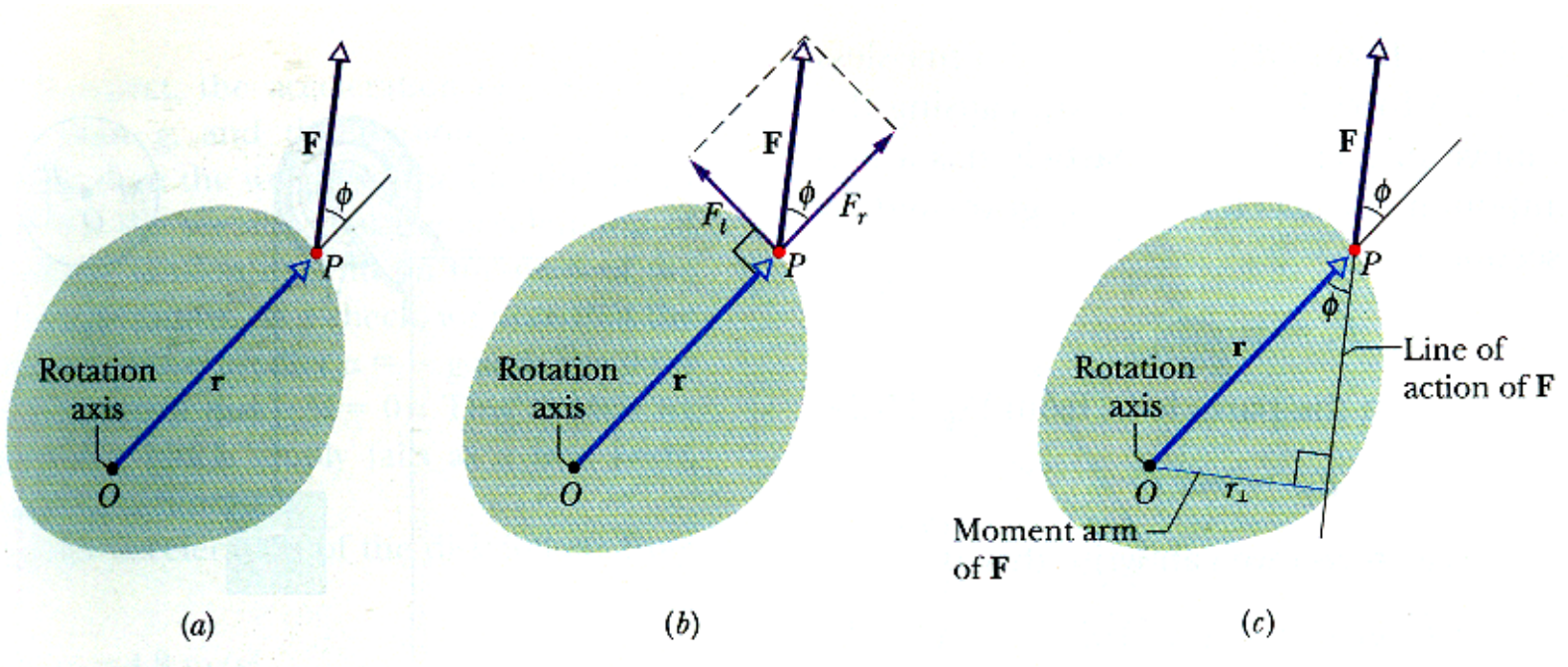
$$\mathbf{F_v + N + mg = 0}$$

Torque and Rotation



Torque

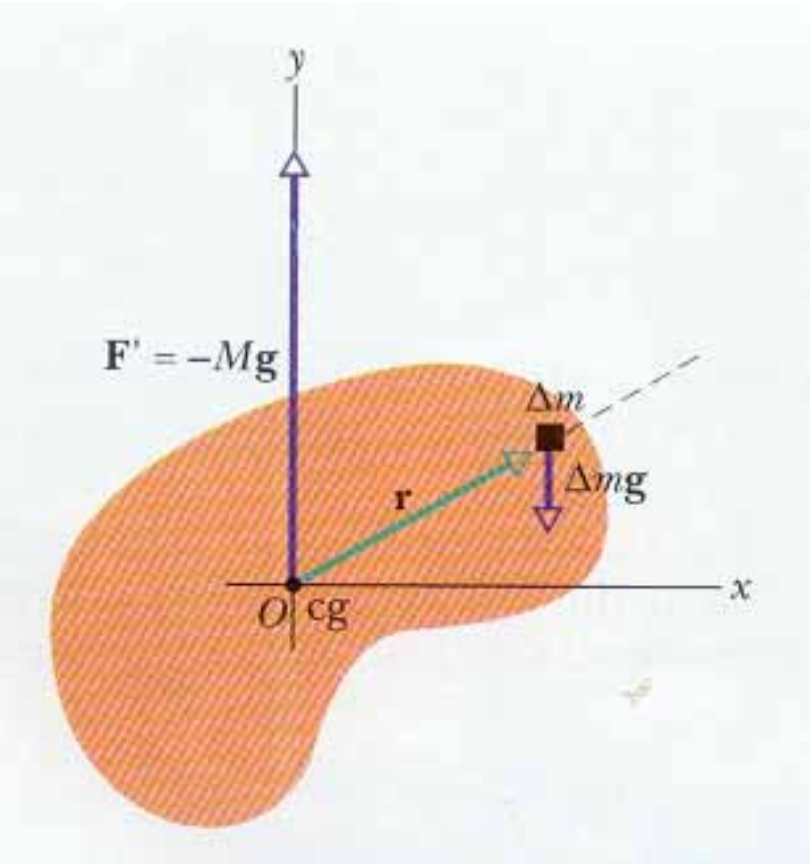
The effectiveness of a force in producing a rotation is called torque

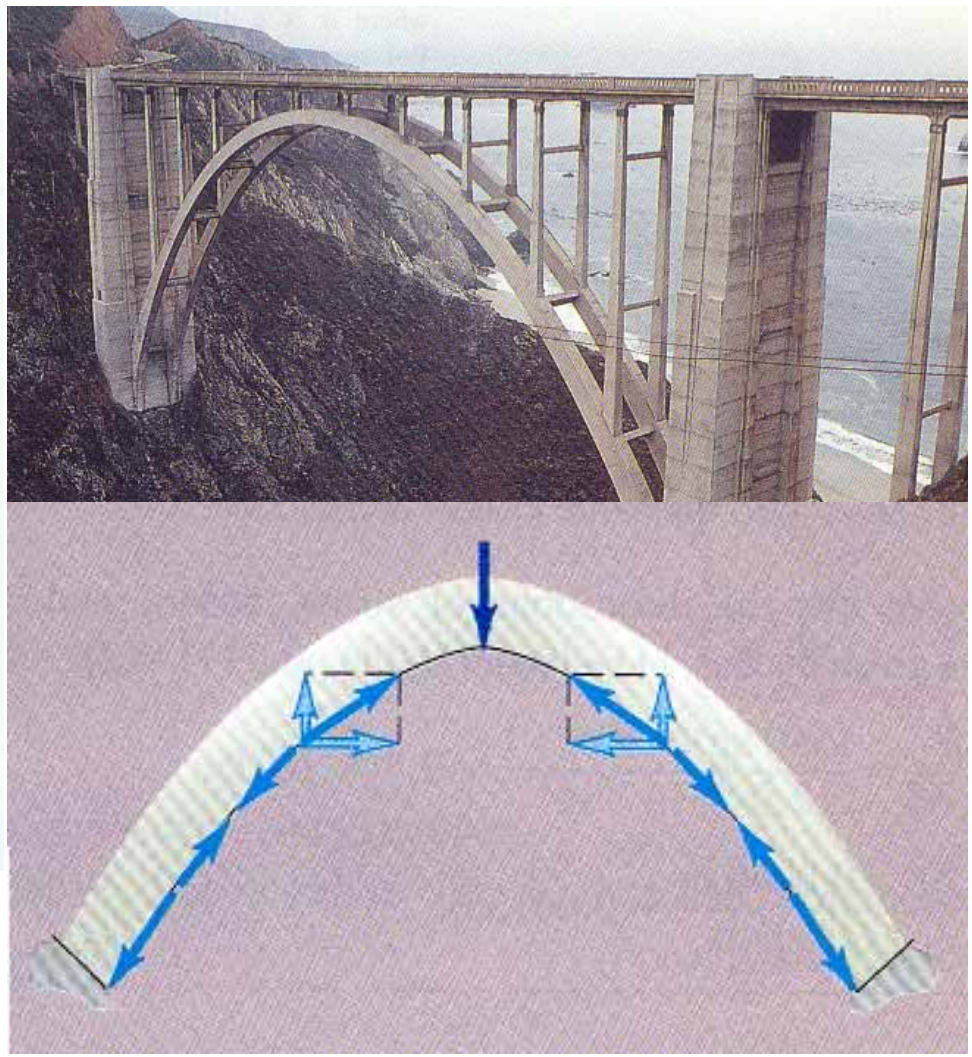


$$\tau = rF_t = rF\sin\phi = r_\perp F$$

$$\boldsymbol{\tau} = \mathbf{r}\times\mathbf{F}, \quad \hat{\tau} \,//\, \hat{\omega}$$

Equilibrium Condition



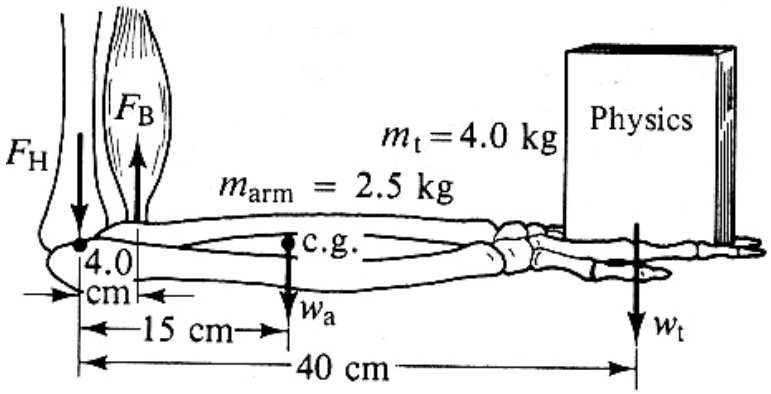


$$\sum \mathbf{F} = 0, \quad \sum \tau = 0$$

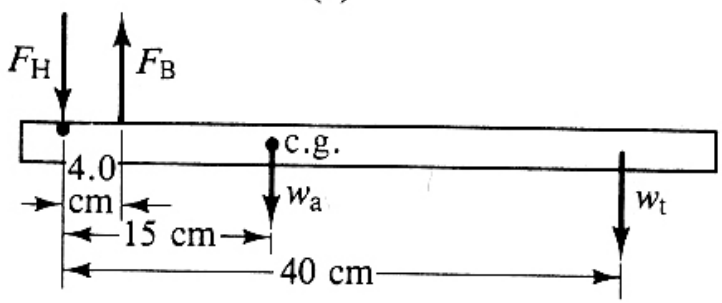
Example 3.9

(a) Calculate the force that the biceps muscle exerts to hold the book

(b) Compare the force exerted by the biceps muscle with the weight of the forearm and book.



(a)



(b)

(clockwise) (counterclockwise)

$$\tau_{cw,\,net} = \tau_{ccw,\,net}$$

$$(15\,\text{cm})(w_a) + (40\,\text{cm})(w_t) = (4.0\,\text{cm})F_B$$

$$F_B = \frac{(15\text{cm})(m_a)(g) + (40\text{cm})(m_t)(g)}{4.0\text{cm}}$$

$$= \frac{(15)(2.5\text{kg})(9.8\text{m/s}^2) + (40)(4.0\text{kg})(9.8\text{m/s}^2)}{4.0}$$

$$= \frac{367.5\text{N} + 1568\text{N}}{4.0} = 484\,\text{N}$$

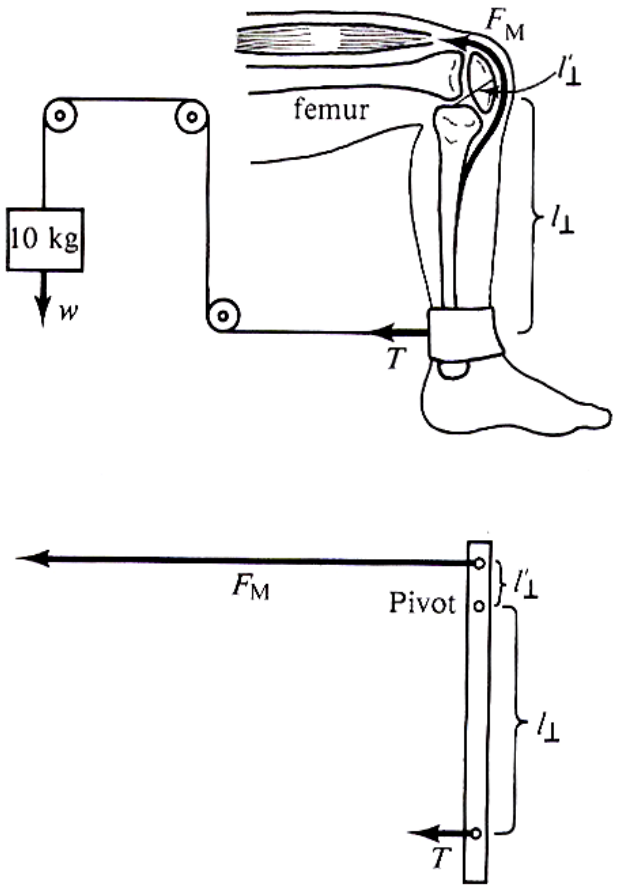
$$w = w_a + w_t = m_a g + m_t g$$

$$w = 63.7\,\text{N}$$

$$484\,\text{N} \rangle\rangle\ 63.7\,\text{N}$$

Example 3.10

Calculate the force exerted by the extensor muscle in the upper leg when lifting a weight as shown below



Note: $l_\perp = 35\text{cm}$

$l'_\perp = 2.0\text{cm}$

$$\tau_{w,net} = \tau_{ccw,net}$$

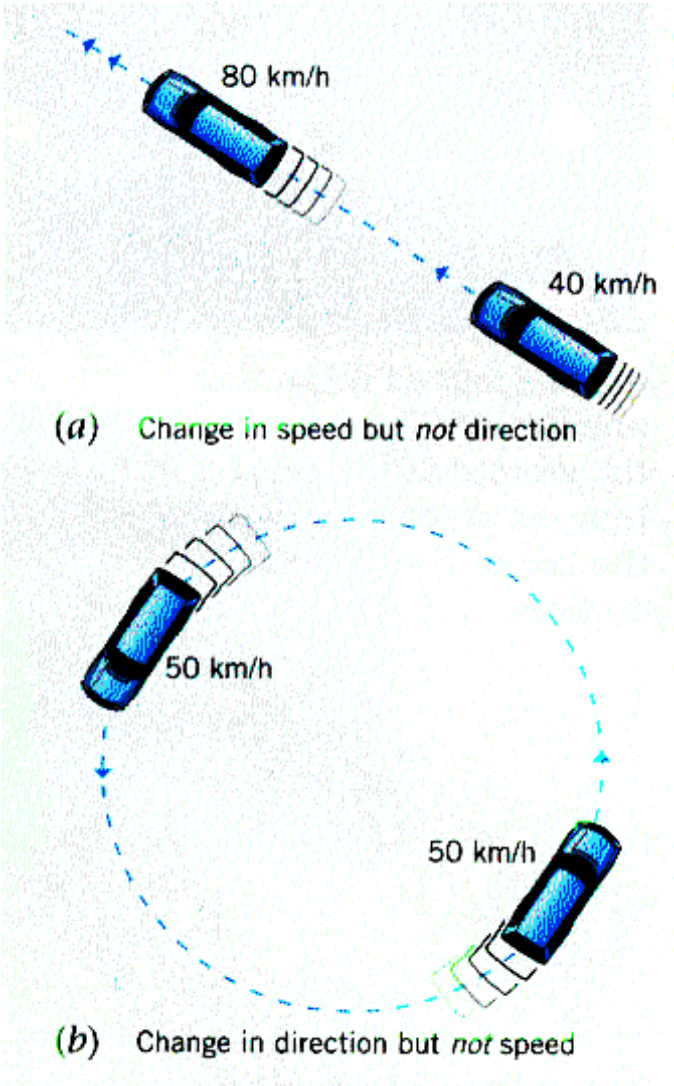
$$l_\perp T = l'_\perp F_M \Rightarrow F_M = (l_\perp / l'_\perp)T$$

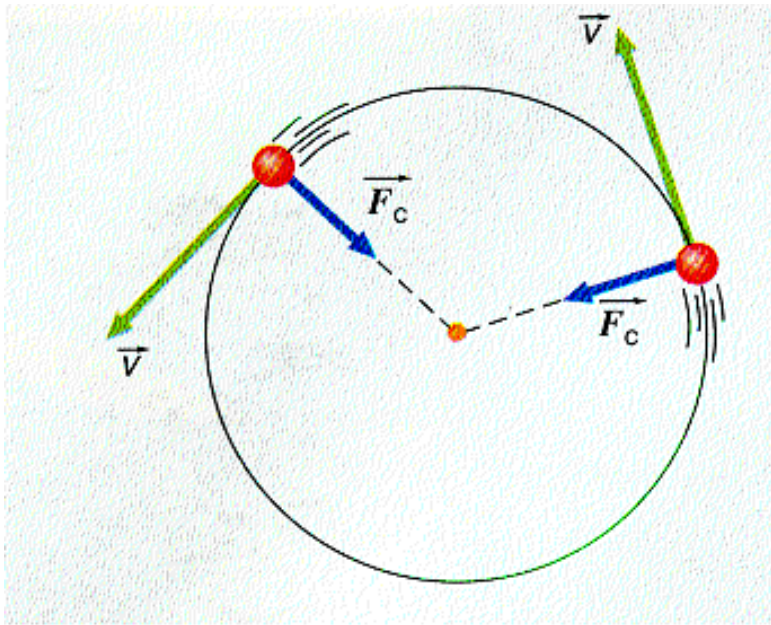
$$F_M = (l_\perp / l'_\perp)mg$$

$$= (35\text{cm}/2.0\text{cm})(98\,\text{N})$$

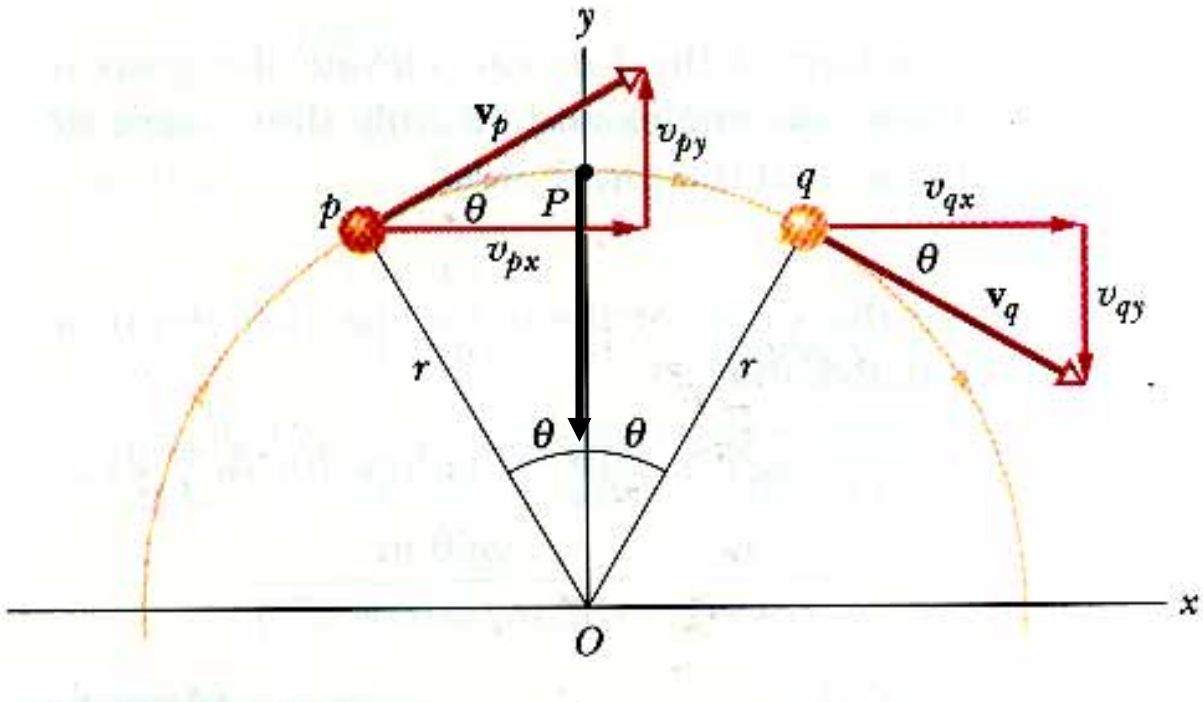
$$= 1715\,\text{N}$$

Rotational Motion and Centripetal Force





$$F_c = ma_r = m\frac{v^2}{r}$$



$$\mathbf{v}_p = v_{px}\mathbf{i} + v_{py}\mathbf{j}$$
$$= v\cos\theta\,\mathbf{i} + v\sin\theta\,\mathbf{j}$$

$$\mathbf{v}_q = v_{qx}\mathbf{i} + v_{qy}\mathbf{j}$$
$$= v\cos\theta\,\mathbf{i} - v\sin\theta\,\mathbf{j}$$

$$\Delta t = \frac{\overline{pq}}{v} \approx \frac{r(2\theta)}{v}$$

$$\overline{a}_x = \frac{v_{qx} - v_{px}}{\Delta t} = \frac{v_q\cos\theta - v_p\cos\theta}{\Delta t} = 0$$

$$\overline{a}_y = \frac{v_{qy} - v_{py}}{\Delta t} = \frac{-v_q\sin\theta - v_p\sin\theta}{(2r\theta)/v} = -\frac{v^2}{r}\left(\frac{\sin\theta}{\theta}\right)$$

$$\mathbf{a} = -a_y\mathbf{j}$$

$$a_y = \lim_{\theta\to 0}\overline{a}_y = \left(\frac{v^2}{r}\right)\lim_{\theta\to 0}\frac{\sin\theta}{\theta} = \frac{v^2}{r}$$

Example 3.11

An ultracentrifuge spins at 50,000 revolutions per minute and the material being centrifuged is 5.0 cm from the pivot point. Calculate the centripetal acceleration and express it as a multiple of the acceleration of gravity (in g's)

$$v = \frac{s}{t} = \frac{50000 \times 2\pi (0.05\,\mathrm{m})}{60\,\mathrm{s}} = 2.62 \times 10^2\ \mathrm{m/s}$$

$$a_c = \frac{v^2}{r} = \frac{(2.62 \times 10^2\,\mathrm{m/s})^2}{0.05\mathrm{m}} = 1.37 \times 10^6\ \mathrm{m/s^2}$$

$$\frac{a_c}{g} = \frac{1.37 \times 10^6\ \mathrm{m/s^2}}{9.8\,\mathrm{m/s^2}} = 1.40 \times 10^5$$

$$a_c = (1.40 \times 10^5) g$$