Chapter 4 – Force and Motion I

I. Newton's first law.

II. Newton's second law.

III. Particular forces:

-Gravitational
- Weight
- Normal
- Friction
- Tension

IV. Newton's third law.

Newton mechanics laws cannot be applied when:

1) The speed of the interacting bodies are a fraction of the speed of light → Einstein's special theory of relativity.

2) The interacting bodies are on the scale of the atomic structure → Quantum mechanics

I. Newton's first law: If no *net force* acts on a body, then the body's velocity cannot change; the body cannot accelerate → $\vec{v}$ = constant in magnitude and direction.

- Principle of superposition: when two or more forces act on a body, the net force can be obtained by adding the individual forces vectorially.

- Inertial reference frame: where Newton's laws hold.

II. Newton's second law: The net force on a body is equal to the product of the body's mass and its acceleration.

$$\vec{F}_{net} = m\vec{a} \qquad (5.1)$$

$$F_{net,x} = ma_x, \quad F_{net,y} = ma_y, \quad F_{net,z} = ma_z \qquad (5.2)$$

- The acceleration component along a given axis is caused only by the sum of the force components along the same axis, and not by force components along any other axis.

- System: collection of bodies.

- External force: any force on the bodies inside the system.

III. Particular forces:

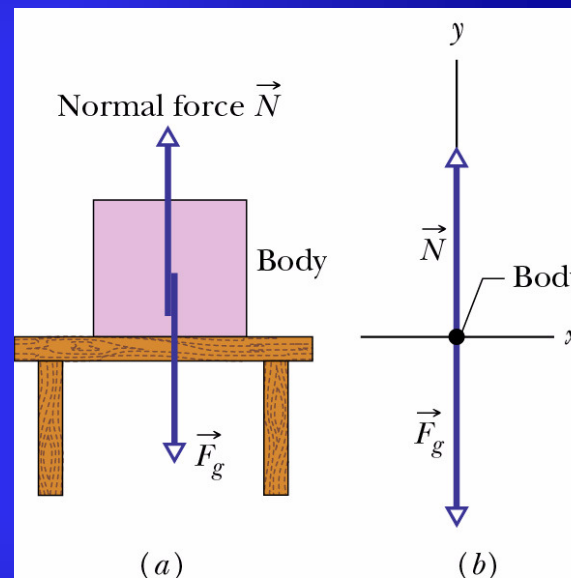
-Gravitational: pull directed towards a second body, normally the Earth →

$$\vec{F}_g = m\vec{g} \qquad (5.3)$$

- Weight: magnitude of the upward force needed to balance the gravitational force on the body due to an astronomical body →

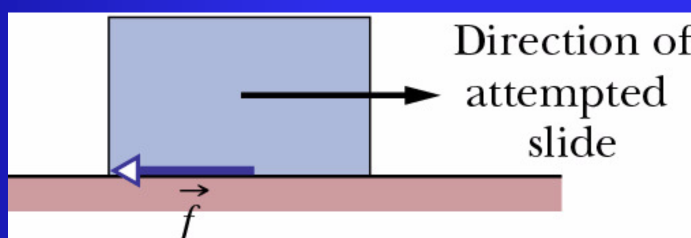
$$W = mg \qquad (5.4)$$

- Normal force: perpendicular force on a body from a surface against which the body presses.

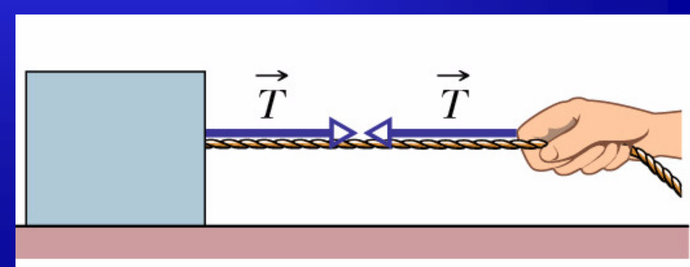


$$N = mg \qquad (5.5)$$

- Frictional force: force on a body when the body attempts to slide along a surface. It is parallel to the surface and opposite to the motion.

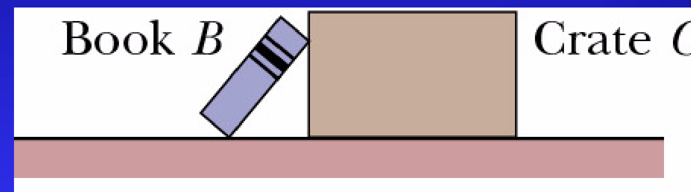


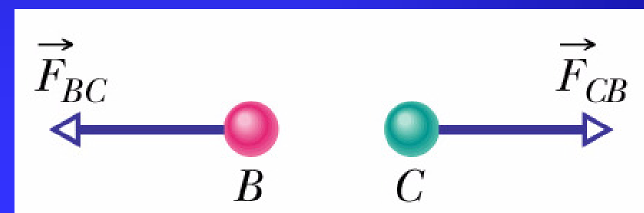
-Tension: pull on a body directed away from the body along a massless cord.



IV. Newton's third law: When two bodies interact, the forces on the bodies from each other are always equal in magnitude and opposite in direction.

$$\vec{F}_{BC} = -\vec{F}_{CB} \qquad (5.6)$$





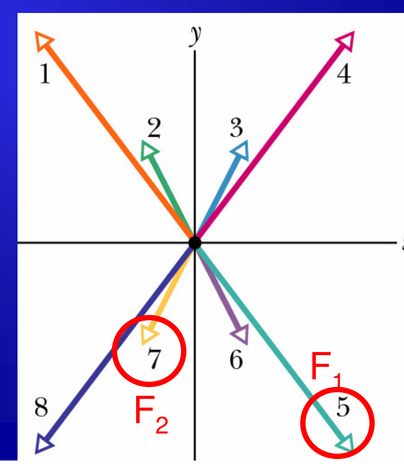
QUESTIONS

Q2. Two horizontal forces $\vec{F}_1$, $\vec{F}_2$ pull a banana split across a frictionless counter. Without using a calculator, determine which of the vectors in the free body diagram below best represent: a) $\vec{F}_1$, b) $\vec{F}_2$. What is the net force component along (c) the x-axis, (d) the y-axis? Into which quadrant do (e) the net-force vector and (f) the split's acceleration vector point?

$$\vec{F}_1 = (3N)\hat{i} - (4N)\hat{j}$$
$$\vec{F}_2 = -(1N)\hat{i} - (2N)\hat{j}$$

$$\vec{F}_{net} = \vec{F}_1 + \vec{F}_2 = (2N)\hat{i} - (6N)\hat{j}$$

Same quadrant, 4



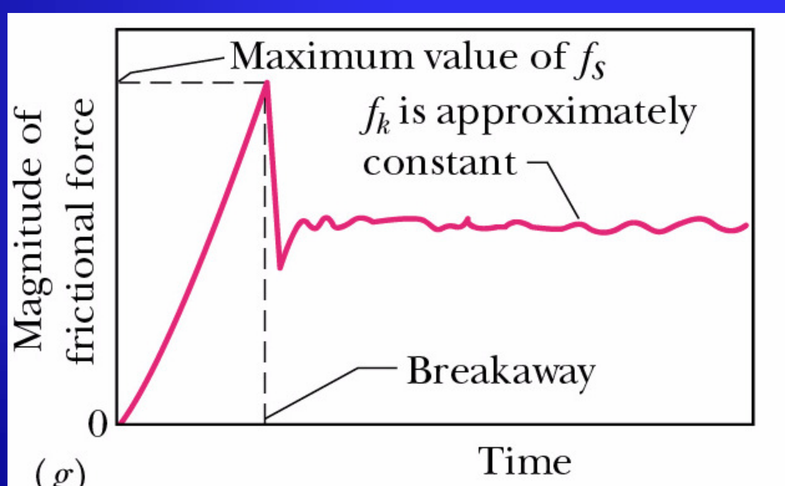
I. Frictional force

Counter force that appears when an external force tends to slide a body along a surface. It is directed parallel to the surface and opposite to the sliding motion.

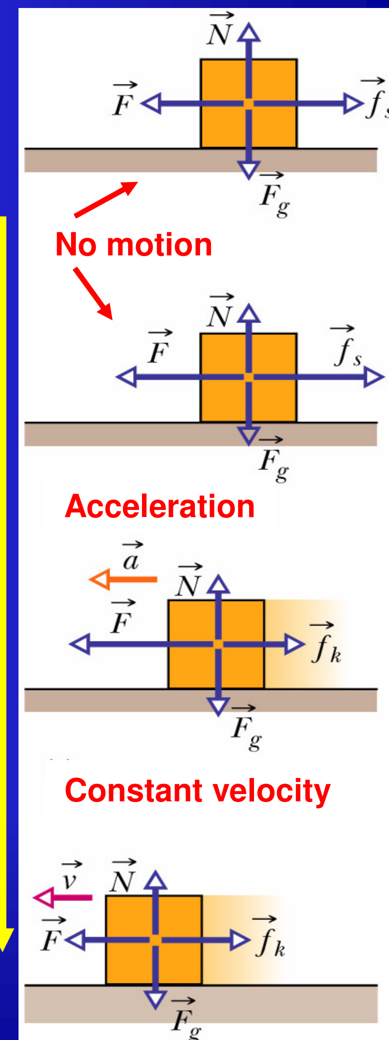
-Static: (f_s) compensates the applied force, the body does not move.

$$\vec{f}_s = -\vec{F}_{//}$$

-Kinetic: (f_k) appears after a large enough external force is applied and the body loses its intimate contact with the surface, sliding along it.



$\vec{F}$ (applied force)



$$f_k < f_{s,\max}$$

$$f_{s,\max} = \mu_s N \qquad (6.1)$$

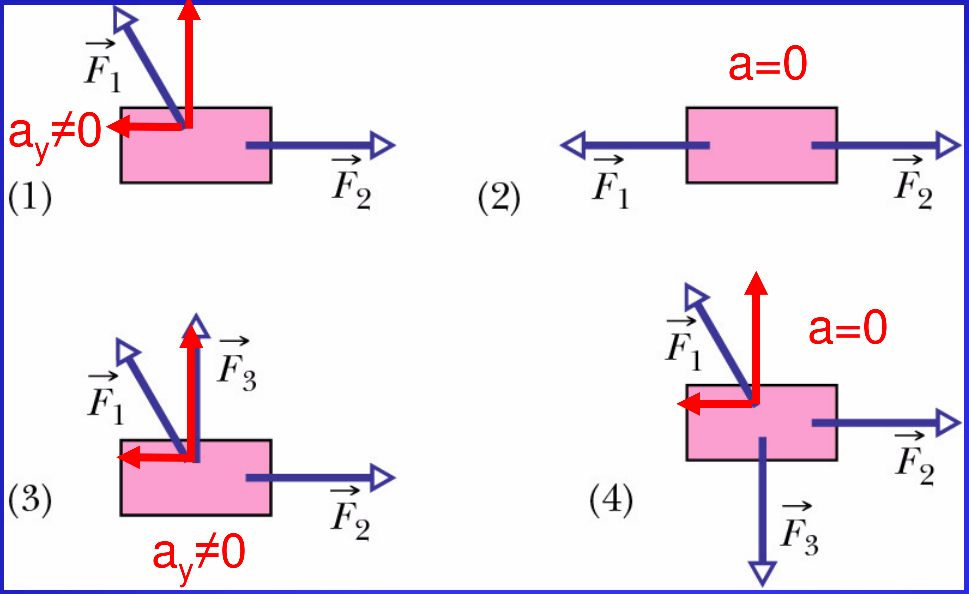
Friction coefficients

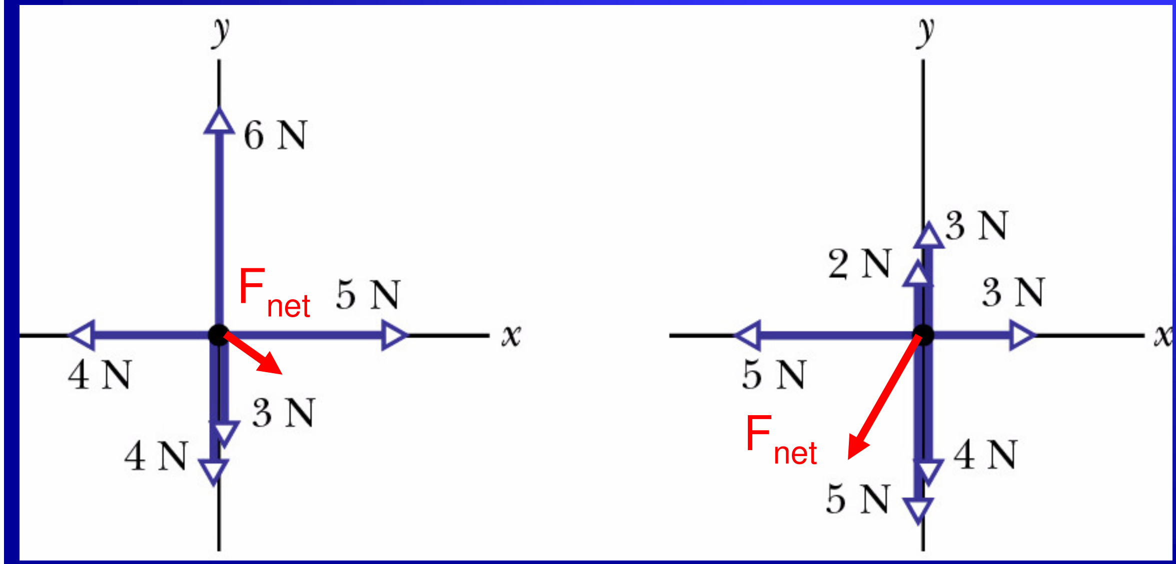
$$If \ F_{//} > f_{s,\max} \rightarrow body \ slides$$

$$f_k = \mu_k N \qquad (6.2)$$

After the body starts sliding, f_k decreases.

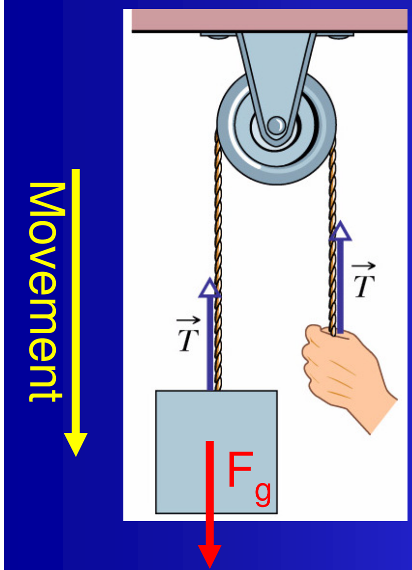
Q1. The figure below shows overhead views of four situations in which forces act on a block that lies on a frictionless floor. If the force magnitudes are chosen properly, in which situation it is possible that the block is (a) stationary and (b) moving with constant velocity?





Q5. In which situations does the object acceleration have (a) an x-component, (b) a y component? (c) give the direction of a.

Q. A body suspended by a rope has a weigh of 75N. Is T equal to, greater than, or less than 75N when the body is moving downward at (a) increasing speed and (b) decreasing speed?

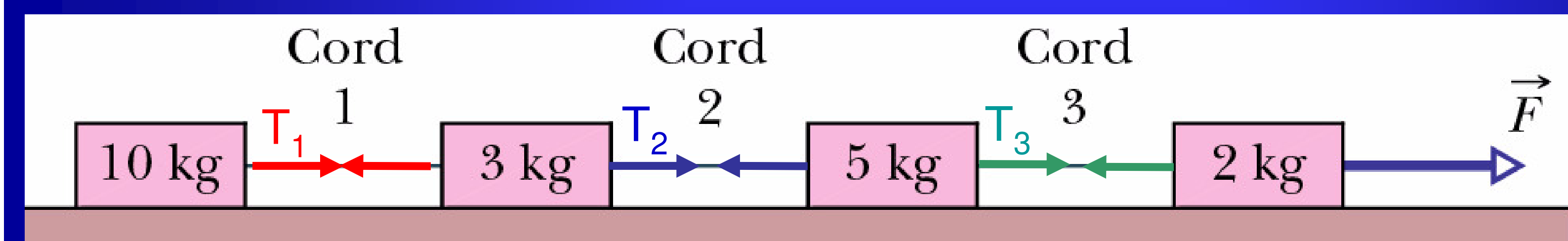


$$\vec{F}_{net} = \vec{F}_g - \vec{T} = m\vec{a} \rightarrow T = m(g-a)$$

(a) Increasing speed: $v_f > v_0 \rightarrow a>0 \rightarrow T< F_g$

(b) Decreasing speed: $v_f < v_0 \rightarrow a<0 \rightarrow T> F_g$

Q8. The figure below shows a train of four blocks being pulled across a frictionless floor by force $\vec{F}$. What total mass is accelerated to the right by (a) F, (b) cord 3 (c) cord 1? (d) Rank the blocks according to their accelerations, greatest first. (e) Rank the cords according to their tension, greatest first.



(a) F pulls m_{total}= (10+3+5+2)kg = 20kg

(b) Cord 3 → T_3 → m=(10+3+5)kg = 18kg

(c) Cord 1 → T_1 → m= 10kg

(d) F=ma → All tie, same acceleration

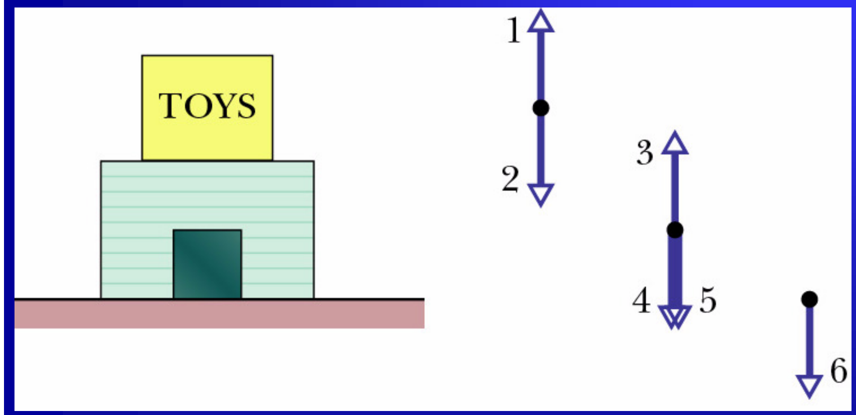
(e) $F-T_3 = 2a$ → $F-T_3 = 2a \rightarrow F = 18a+2a = 20a$

$T_3-T_2 = 5a$ → $T_3 - 13a = 5a \rightarrow T_3 = 18a$

$T_2-T_1 = 3a$ → $T_2 - 10a = 3a \rightarrow T_2 = 13a$

$T_1 = 10a$ → $T_1 = 10a$

Q. A toy box is on top of a heavier dog house, which sits on a wood floor. These objects are represented by dots at the corresponding heights, and six vertical vectors (not to scale) are shown. Which of the vectors best represents (a) the gravitational force on the dog house, (b) on the toy box, (c) the force on the toy box from the dog house, (d) the force on the dog house from the toy box, (e) force on the dog house from the floor, (f) the force on the floor from the dog house? (g) Which of the forces are equal in magnitude? Which are (h) greatest and (i) least in magnitude?



(a) F_g on dog house: 4 or 5

(b) F_g on toy box: 2

(c) F_{toy} from dog house: 1

(d) $F_{dog\text{-}house}$ from toy box: 4 or 5

(e) $F_{dog\text{-}house}$ from floor: 3

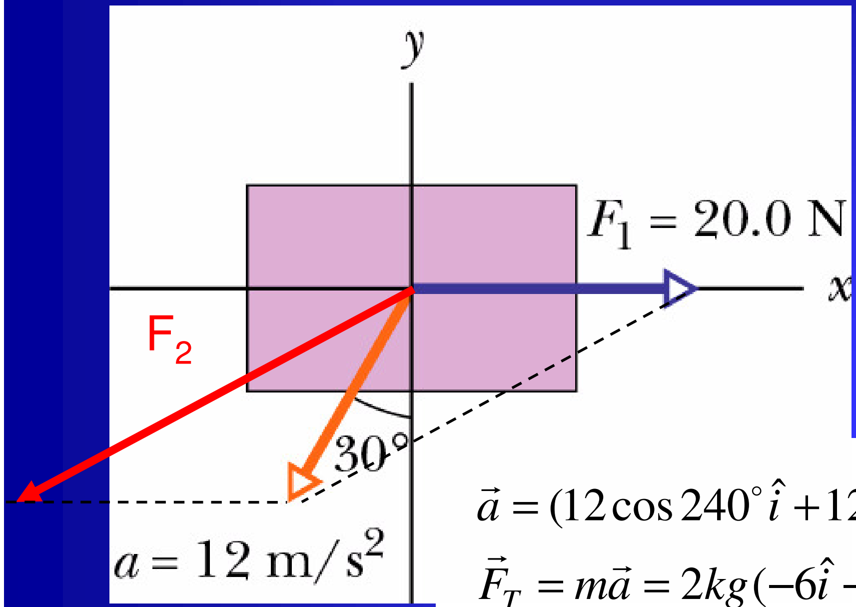
(f) F_{floor} from dog house: 6

(g) Equal: 1=2, 1=5, 3=6

(h) Greatest: 6,3

(i) Smallest: 1,2,5

5. There are two forces on the 2 kg box in the overhead view of the figure below but only one is shown. The figure also shows the acceleration of the box. Find the second force (a) in unit-vector notation and as (b) magnitude and (c) direction.



$$\vec{a} = (12\cos 240^\circ\,\hat{i} + 12\sin 240^\circ\,\hat{j})m/s^2 = (-6\hat{i} - 10.39\hat{j})m/s^2$$

$$\vec{F}_T = m\vec{a} = 2kg(-6\hat{i} - 10.39\hat{j})m/s^2 = (-12\hat{i} - 20.78\hat{j})N$$

$$\vec{F}_T = \vec{F}_1 + \vec{F}_2 = 20\hat{i} + \vec{F}_2$$

$$F_{Tx} = -12N = F_{2x} + 20N \rightarrow F_{2x} = -32N$$

$$F_{Ty} = -20.78N = F_{2y}$$

$$F_2 = (-32\hat{i} - 20.78\hat{j})N$$

$$F_2 = \sqrt{32^2 + 21^2} = 38.27N \qquad \tan\theta = \frac{-20.78}{-32} = 33^\circ \;\; or\; 180^\circ + 33^\circ = 213^\circ$$

Rules to solve Dynamic problems

- Select a reference system.

- Make a drawing of the particle system.

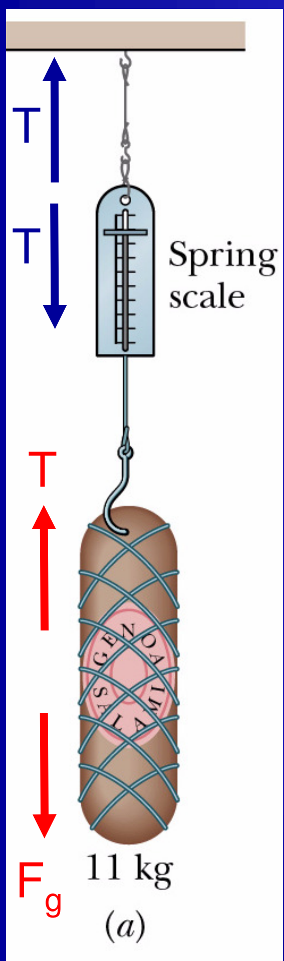
- Isolate the particles within the system.

- Draw the forces that act on each of the isolated bodies.

- Find the components of the forces present.

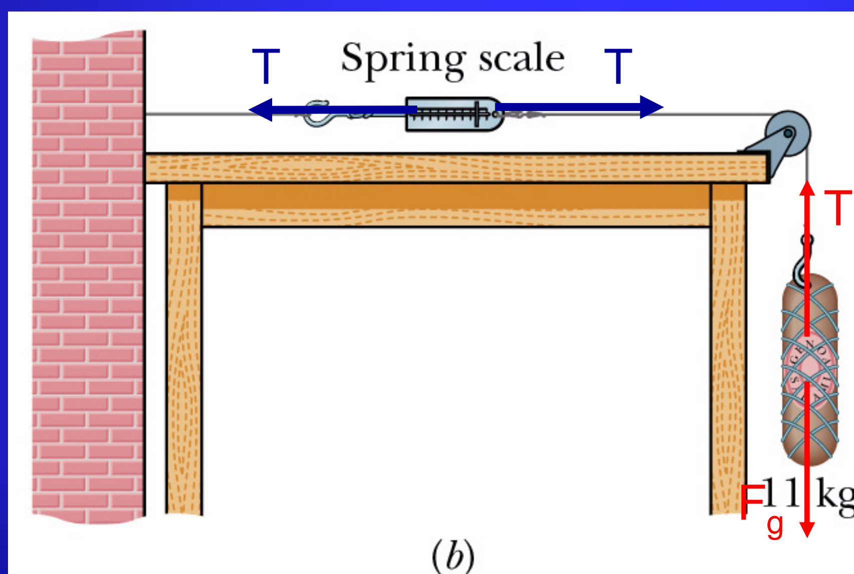
- Apply Newton's second law (F=ma) to each isolated particle.

9. (a) A 11kg salami is supported by a cord that runs to a spring scale, which is supported by another cord from the ceiling. What is the reading on the scale, which is marked in weigh units? (b) Here the salami is supported by a cord that runs around a pulley and to a scale. The opposite end of the scale is attached by a cord to a wall. What is the reading on the scale? (c) The wall has been replaced by a second salami on the left, and the assembly is stationary. What is the reading on the scale now?

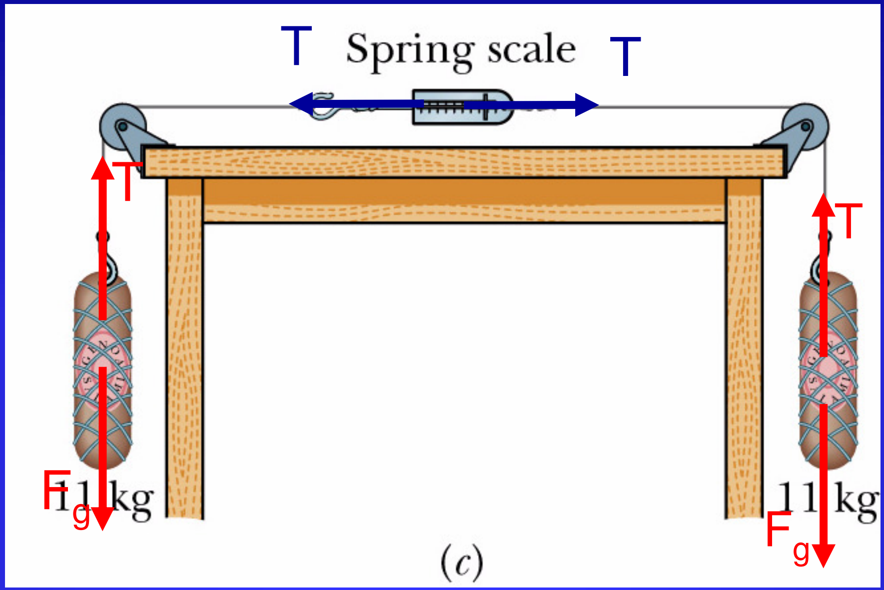


$$W = |F_g| = mg = (11kg)(9.8m/s^2) = 107.8N$$

$$(a)\ a = 0 \rightarrow T = F_g = 107.8N$$



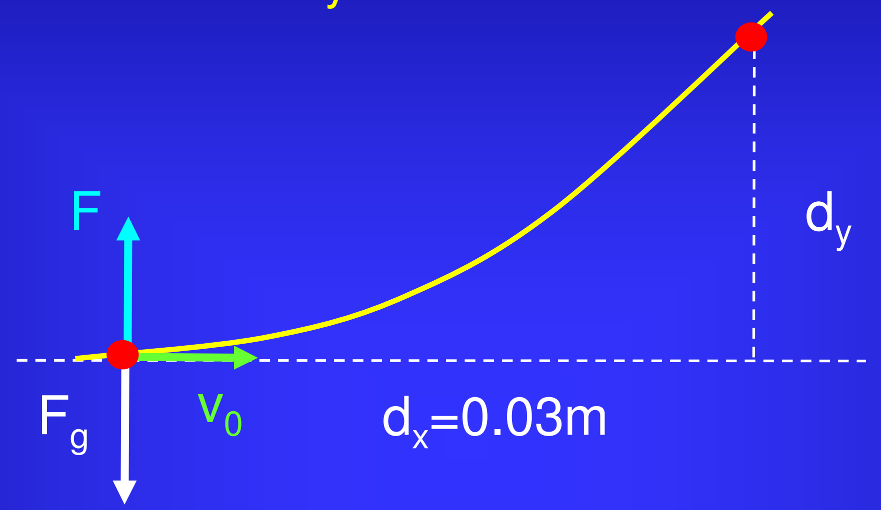
$$(b)\ a = 0 \rightarrow T = F_g = 107.8N$$



$$(c)\ \ a = 0 \rightarrow T = F_g = 107.8N$$

In all three cases the scale is not accelerating, which means that the two cords exert forces of equal magnitude on it. The scale reads the magnitude of either of these forces. In each case the tension force of the cord attached to the salami must be the same in magnitude as the weigh of the salami because the salami is not accelerating.

23. An electron with a speed of 1.2×10^7 m/s moves horizontally into a region where a constant vertical force of 4.5×10^{-16} N acts on it. The mass of the electron is $m = 9.11 \times 10^{-31}$ kg. Determine the vertical distance the electron is deflected during the time it has moved 30 mm horizontally.



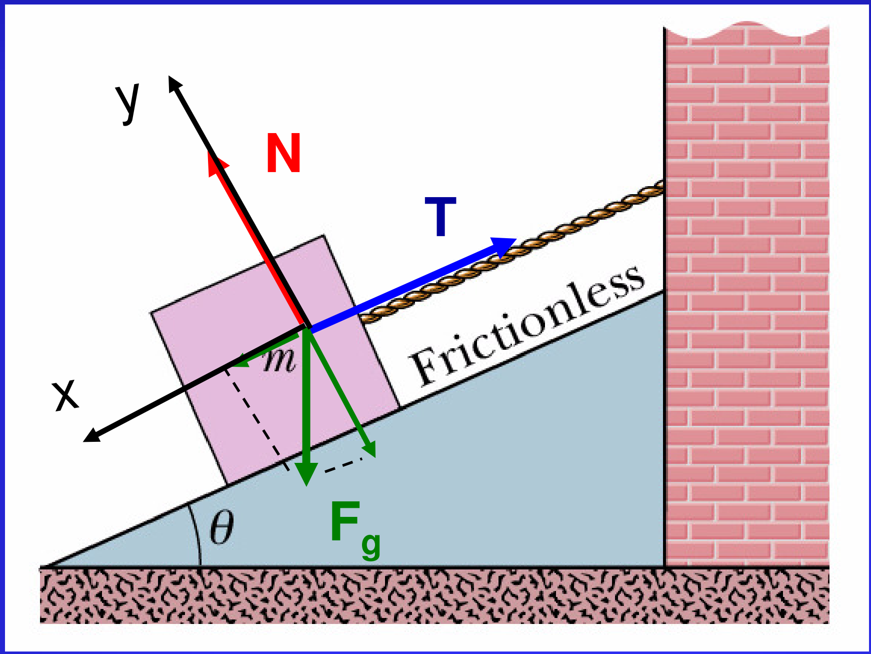
$$d_x = v_x t = 0.03m = (1.2 \cdot 10^7\, m/s)t \rightarrow t = 2.4ns$$

$$F_{net} = ma_y = F - F_g = 4.5 \cdot 10^{-16} N - (9.11 \cdot 10^{-31} kg)(9.8 m/s^2)$$

$$F_{net} = (9.11 \cdot 10^{-31} kg) a_y \rightarrow a_y = 4.94 \cdot 10^{14} m/s^2$$

$$d_y = v_{oy} t + 0.5 a_y t^2 = 0.5 \cdot (4.94 \cdot 10^{14} m/s^2) \cdot (2.5 \cdot 10^{-9} s)^2 = 0.0015m$$

13. In the figure below, m_{block}=8.5kg and θ=30º. Find (a) Tension in the cord. (b) Normal force acting on the block. (c) If the cord is cut, find the magnitude of the block's acceleration.



$$(a) \quad a = 0 \rightarrow a_x = 0 \rightarrow T - F_{gx} = 0 \rightarrow$$

$$T = F_{gx} = mg\sin 30^\circ = (8.5kg)(9.8m/s^2)0.5 = 41.65N$$

$$(b) \quad a_y = 0 \rightarrow N - F_{gy} = 0 \rightarrow N = F_{gy} = mg\cos 30^\circ = 72.14N$$

$$(c) \quad T = 0 \rightarrow F_{gx} = ma = 41.65N = 8.5a \rightarrow a = 4.9m/s^2$$

55. The figure below gives as a function of time t, the force component F_x that acts on a 3kg ice block, which can move only along the x axis. At t=0, the block is moving in the positive direction of the axis, with a speed of 3m/s. What are (a) its speed and (b) direction of travel at t=11s?

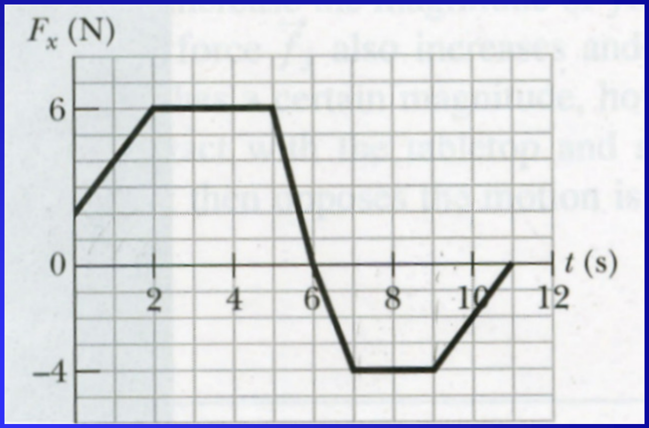
$$t = 0 \rightarrow v_0 = 3m/s$$

$$t = 11s \rightarrow v_f = ?$$

$$a_x = \frac{F_x}{m} = \frac{dv_x}{dt} \rightarrow \int \frac{dv_x}{dt} dt = v_f - v_0 = \int_0^{11s} \frac{F_x}{m} dt$$

$$Total\ \ graph\ area = 15Ns = \int_0^{11s} F_x dt = (v_f - v_0)m = (v_f - 3m/s)3kg$$

$$\rightarrow v_f = \frac{15kgm/s}{3kg} + 3m/s = 8m/s$$



Midterm1_extra_Spring04. Two bodies, m1= 1kg and m2=2kg are connected over a massless pulley. The coefficient of kinetic friction between m2 and the incline is 0.1. The angle θ of the incline is 20º. Calculate:

(a) Acceleration of the blocks. (b) Tension of the cord.

$$F_{2g,x} = m_2 g \sin 20^\circ = 6.7N$$

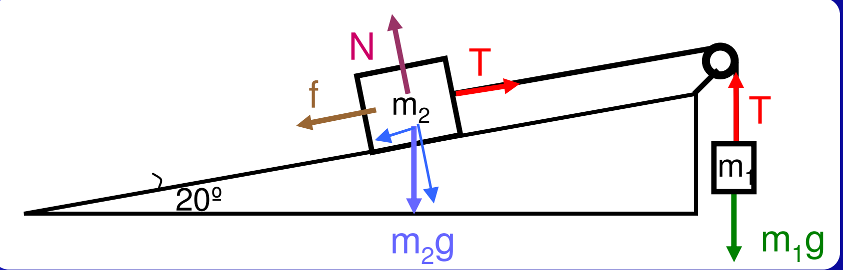
$$N_2 = F_{2g,y} = m_2 g \cos 20^\circ = 18.42N$$

$$f = \mu_k N_2 = \mu_k m_2 g \cos 20^\circ = 1.84N$$

$$Block\ 1:\ m_1 g - T = m_1 a \qquad \rightarrow 9.8 - T = a$$

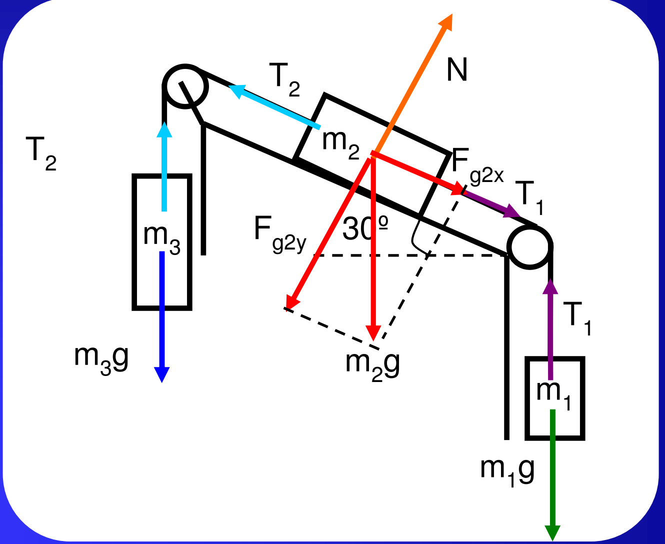
$$Block\ 2:\ T - f - F_{2g,x} = m_2 a \qquad \rightarrow T - 1.84 - 6.7 = 2a$$

$$Adding\ \ 3a = 1.26 \rightarrow a = 0.42m/s^2,\ T = 9.38N$$



Midterm1_Spring04. The three blocks in the figure below are connected by massless cords and pulleys. Data: m_1=5kg, m_2=3kg, m_3=2kg. Assume that the incline plane is frictionless.

(i) Show all the forces that act on each block.
(ii) Calculate the acceleration of m_1, m_2, m_3.
(iii) Calculate the tensions on the cords.
(iv) Calculate the normal force acting on m_2



$Fg_{2y}=m_2 g\cos 30º$
$Fg_{2x}=m_2 g\sin 30º$

Block 1: $m_1 g - T_1 = m_1 a$
Block 2: $m_2 g(\sin 30º) + T_1 - T_2 = m_2 a$
Block 3: $T_2 - m_3 g = m_3 a$

(i) Adding (1)+(2)+(3) → $g(m_1+0.5m_2-m_3)=a(m_1+m_2+m_3)$ → $a= 4.41 m/s^2$

(ii) $T_1=m_1(g-a)= 5kg(9.8\ m/s^2-4.41\ m/s^2) = 26.95N$

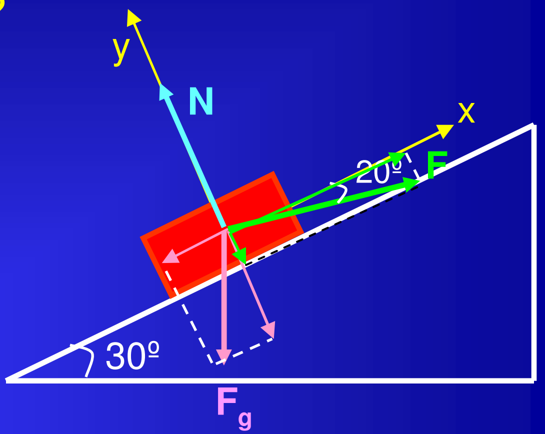
(iii) $T_2=m_3(g+a)= 2kg(9.8\ m/s^2+4.41\ m/s^2)= 28.42N$

(iv) $N_2= Fg_{2y}= m_2 g\cos 30° = 25.46N$

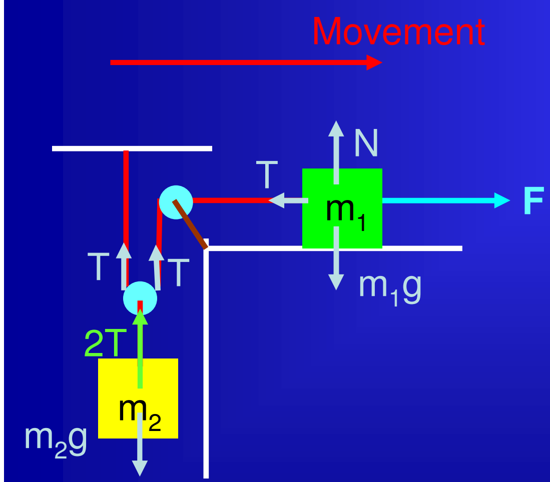
1B. (a) What should be the magnitude of F in the figure below if the body of mass m=10kg is to slide up along a frictionless incline plane with constant acceleration a=1.98 m/s²? (b) What is the magnitude of the Normal force?

$$F\cos 20^\circ - mg\sin 30^\circ = ma \rightarrow F = \frac{m(a+0.5g)}{\cos 20^\circ} = 73.21N$$

$$N - mg\cos 30^\circ - F\sin 20^\circ = 0 \rightarrow N = 109.9N$$



2B. Given the system plotted below, where m_1=2kg and m_2=6kg, calculate the force F necessary to lift up m_2 with a constant acceleration of 0.2m/s². The pulleys and cords are massless, and the table surface is frictionless.



$$d_1 = \frac{1}{2}a_1t^2$$

$$d_2 = \frac{d_1}{2} = \frac{1}{2}a_2t^2 \rightarrow 0.5a_1t^2 = a_2t^2 \rightarrow a_2 = 0.5a_1 = 0.2m/s^2 \rightarrow a_1 = 0.4m/s^2$$

$$2T - m_2g = m_2a_2 \rightarrow T = 0.5m_2(a_2+g) = 0.5(6kg)(0.2+9.8)m/s^2 = 30N$$

$$F - T = m_1a_1 \quad \rightarrow F = T + m_1a_1 = 30N + (2kg)(0.4m/s^2) = 30.8N$$