Part I

1. When a horse pulls a wagon, the force that causes the horse to move forward is

   (a) the force he exerts on the ground.

   (b) the force he exerts on the wagon.

   (c) the force the ground exerts on him.

   (d) the force the wagon exerts on him.

   Answer (c):This is the only force acting on him in the forward direction.

2. If a woman of mass 40 kg is carried by an elevator with upward acceleration 4 m/s^2, the magnitude of the force which she exerts on the floor of the elevator is:

   (a) 560 N (b) 400 N (c) 240 N (d) 160
   Answer (a): The net force is $F_{\text{net}} = ma = 160$ N. So the applied force must be greater than her weight of 400 N by this amount.

3. A big ship crashes into a small canoe. During the collision the force that the ship exerts on the canoe is

   (a) greater than the force the canoe exerts on the ship.

   (b) equal to the force the canoe exerts on the ship.

   (c) less than the force the canoe exerts on the ship.

   (d) is related to the force on the canoe in a way that depends on the nature of the collision.

   Answer (b): By the Newton'w 3rd law. Note the acceleration will be much larger for the canoe since its mass is smaller

4. A mass of 30kg on a smooth horizontal table is tied to a cord running along the table over a frictionless pulley mounted at the edge of the table. A 10kg mass is attached to the other end of the cord. When the two masses are allowed to move freely the tension in the cord is

   (a) 300 N. (b) 150 N. (c) 100 N. (d) 75 N.
   Answer (d)

5. A stationary block sits on a table. Newton's third law is often stated as "To every *action* there is an equal and opposite *reaction*". The reaction to the weight of the book is the force that the

   (a) earth exerts on the book.

   (b) book exerts on the table.

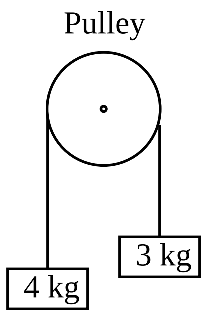
   (c) table exerts on the book.

   (d) book exerts on the earth.

   Answer (d): The weight is the force the earth exerts on the book so the reaction to the weight must be the force the book exerts on the earth.

Part II

1. Atwood's Machine.



The set up illustrated in the diagram on the left consists of two blocks connected by a string which passes over a frictionless (and massless) pulley. (The string, by the way, is massless too – you can get these in the same place you buy the pulley above.)

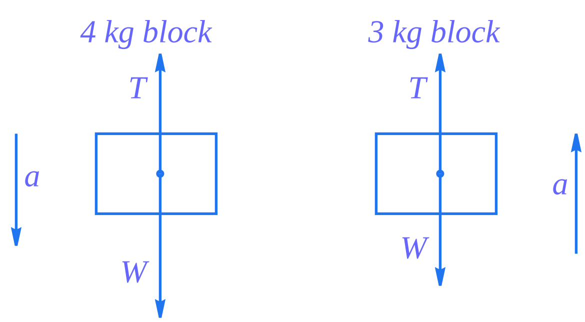
(a) The 3 kg weight is initially held still so that the system is stationary. What is the tension in the string at this time.

If the system is stationary then $F_{\text{net}} = 0$ and so tension is equal to the weight of the 4 kg block. $T = W = mg = 4 \times 9.8 = 39.2$ N.

(b) The weight is then released. Does the tension in the string stay the same, get smaller or get larger?

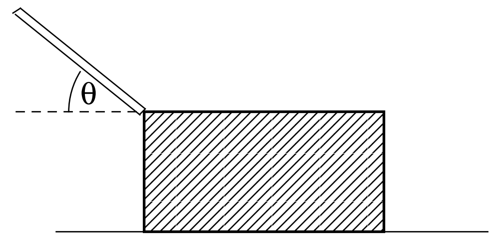
Since the 4 kg block will accelerate downward the force in the downward direction will exceed the upward force of tension. Therefore the tension will get smaller.

(c) To answer the question in part (b) quantitatively, draw free body diagrams for each block separately. Then write down an expression for the net force on each assuming tension is an unknown quantity T. Apply Newton's second law in each case. Hence find the acceleration of the blocks and the tension in the string.

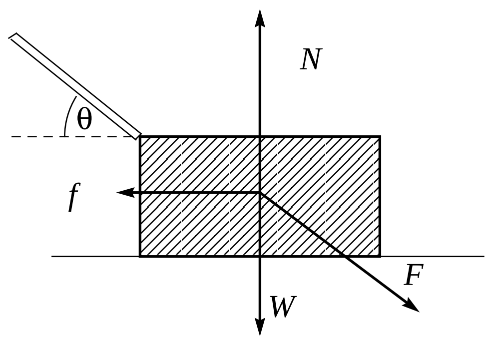


For the 4 kg block acceleration is downward so $F_{\text{net}} = W - T = 39.2 - T$ and Newton's second law states $F_{\text{net}} = ma = 4a$ so we have $39.2 - T = 4a$. Similarly for the 3 kg block the acceleration is up so $F_{\text{net}} = T - W = T - 29.4 = 3a$. It is easiest to solve these simultaneous equations by elimination. Adding the equations together eliminates T and gives $39.2 - T + T - 29.4 = 4a + 3a \;\Rightarrow\; 9.8 = 7a \;\Rightarrow a = 9.8/7 = 1.4$ m/s^2. Now substituting this value of a into either equation gives $T = 33.6$ N. This is less than the weight of the 4 kg block and more than the weight of the 3 kg block.

2. A block of weight $W = 20$ N is pushed with a force $F = 30$ N using a stick which is at an angle of $\theta = 37^o$ above the horizontal as shown. The coefficient of kinetic friction between the table and the block is $\mu = 0.25$.



(a) Draw a free body diagram showing all the forces acting on the block.



(b) Calculate the value of the normal force between the block and the table.

The normal force balances the weight W and the vertical component of the downward force F_y. $N = W + F_y = 20 + 30\sin 37 = 38.1$ N

(c) Find the acceleration of the block.

The acceleration is to the right and $a = F_{\text{net}}/m$ were $m = W/g = 20/9.8 = 2.04$ kg and $F_{\text{net}} = F_x - f$. Now friction is $f = \mu N = 0.25 \times 38.1 = 9.5$ N and $F_x = 30\cos(37) = 24.0$ N so $F_{\text{net}} = 24.0 - 9.5 = 14.5$ N. So $a = 14.5/2.04 = 7.1$ m/s^2

(d) The force F is decreased until the acceleration is zero. Find this value of F.

If acceleration is zero then $F_{\text{net}} = 0$ which means friction exactly balances the horizontal component of F. We treat F as a variable and express normal force N in terms of F. So $N = 20 + F\sin 37$ and hence friction is $f = 0.25(20 + F\sin 37) = 5 + 0.25F\sin 37$. Then $F_x = F\cos 37$ and so for equilibrium $F\cos 37 = 5 + 0.25F\sin 37$ Solving for F we find $F\cos 37 - 0.25F\sin 37 = 5$ so $F = 5/(\cos 37 - 0.25\sin 37) = 7.71N$

(e) There is a critical value of the angle θ for which no force is able to accelerate the block. Find this value of θ.

If we inspect the last equation we see that if the denominator were zero then the expression for F would be undefined. Thus, replacing 37^o with the a variable angle θ and setting the denominator equal to zero we find a critical angle, above which no force could cause the block to accelerate. We must solve the equation $\cos\theta - 0.25\sin\theta = 0$ or $\cos\theta = 0.25\sin\theta$. Now dividing by $\cos\theta$ and noting that $\sin\theta/\cos\theta = \tan\theta$ we have $1 = 0.25\tan\theta \Rightarrow \tan\theta = 1/0.25 = 4 \Rightarrow \theta = \tan^{-1} 4 = 76^o$ So the critical angle is 76^o.