Newton's Laws of Motion

Isaac Newton stated three laws of motion

The first law deals with forces and changes in velocity. Consider the situation where we could apply only one force to an object. That is, you could choose to push the object to the right, or to the left, but not to the left and right at the same time.

Under these conditions the first law states that if an object is not pushed or pulled upon, its velocity will naturally remain constant. This means that if an object is moving along untouched by a force of any kind, it will continue to move along in a perfectly straight line at a constant speed (in *equilibrium*)

> ***Once moving at a steady speed…***
> ***In a straight line…***
> ***It will continue moving…***
> ***At a steady speed...***
> ***In a straight line.***

The first law also means that if an object is standing still and is not contacted by any forces, it will continue to remain motionless. Its velocity is constantly $0ms^{-1}$.

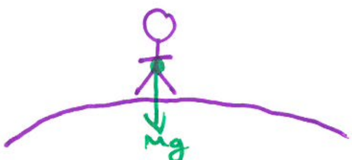
> ***Once standing still…***
> ***It will stay still.***

In order to change the velocity of a body, a non-zero force needs to be applied to the body. When the force is applied, the velocity will change.

At any given instant, and in different situations, any number of forces can be acting on a body at the same time:

The force of gravity.

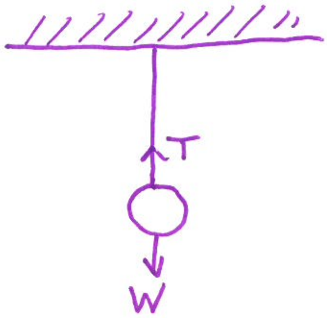
This is the force of attraction between any object and the Earth. Every object on or near the Earth's surface is pulled vertically downwards by the force of gravity. The size or magnitude of the force on an object of mass M kg is Mg Newtons, where g is the acceleration due to gravity ($9.8ms^{-2}$). This is known as the ***weight*** of an object.



Mass 80kg
Weight = 80×9.8 = 784 N

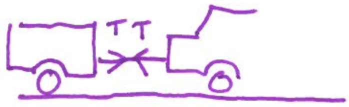
Tension forces

When a light string is pulled, the string will exert a tension force opposite to the pull. The tension force acts along the string, and is the same throughout its length.



Thrust

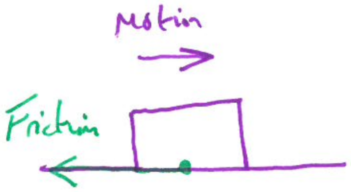
A rod, which is rigid, can exert tension forces in a similar way to a string when it is used to support or pull an object.

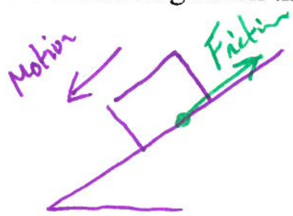


Difference between a tow bar (rigid) & tow rope is that tension can be +ve or negative (Tension & thrust) in a rod.
Rope either in tension or slack (F=0)

Friction

This is a force which opposes the motion between two rough surfaces. It will always act in the direction opposite to the direction of motion. A frictional force never causes motion; it may prevent motion, or it may slow something down that is moving.





When we wish to make frictional forces negligible, way say that the surfaces are smooth.

Air resistance

This force acts in the direction opposite to the motion of an object. The same is true for resistance in a liquid.

Upthrust / buoyancy

When an object is immersed in a fluid it receives an upthrust equal to the weight of the fluid displaced.

Electrical and magnetic forces

Objects may be subjected to forces due to electricity of magnetism. Not an issue for A Level mechanics!

We will see that a group of forces acting on an object add up so that all the forces appear to the object as one force – the ***resultant force***. If this resultant force is non-zero, then according to Newton's first law, the velocity of the object will change – there will be an acceleration.

If the resultant force is zero…
There is no change in velocity…
There is no acceleration.

If the resultant force is non-zero…
There is a change in velocity…
There is an acceleration.

Which leads us to Newtons second law:

Newton's second law of motion explains how an object will change velocity if it is pushed or pulled upon.

Firstly this law states that if you do place a force on an object, it will accelerate in the direction of the force.

> ***It accelerates in the direction…***
> ***That you push it.***

Secondly, this acceleration is directly proportional to the force. For exmple, if you are pushing on an object, causing it to accelerate, and then you push, say three times harder, the acceleration will be three times greater.

> ***If you push twice as hard…***
> ***It accelerates twice as much.***

Thirdly, this acceleration is inversely proportional to the mass of the object. For example if you are pushing equally on two objects and one of the objects has five times more mass than the other, it will accelerate at one fifth of the acceleration of the other.

> ***If it gets twice the mass…***
> ***It accelerates half as much.***

Newton's second law states that if a force F Newtons, acts on a mass m kg, then it produces an acceleration a ms^{-2}, where

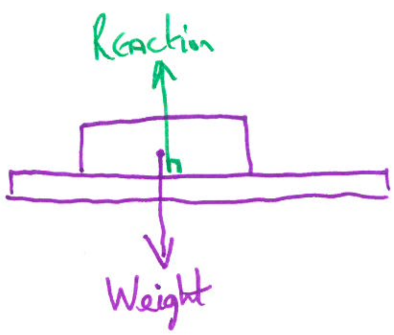
$$\boldsymbol{F = ma}$$

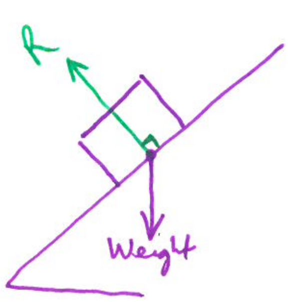
Newton's third law of motion describes the forces of interaction when two objects are in contact. If two objects A and B exert forces on each other then the force exerted on A by B is equal in magnitude and opposite in direction to the force exerted on B by A. For example, if you push on a wall, it will push back on you as hard as you are pushing on it.

> ***If you push on it…***
> ***It pushes on you.***

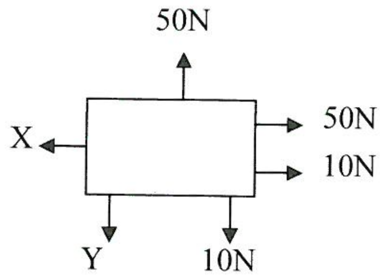
This produces another very important force to consider – the Normal Reaction.

Think about a book on a table. The force of gravity acts downwards on it. As the book is in equilibrium, at rest, the resultant force must be zero – otherwise the book would accelerate. So there must be another force, equal and opposite to the force of gravity, acting on the book in order to maintain equilibrium. This is the normal reaction. It is called normal because its line of action is always normal (perpendicular) to the line of contact between the two surfaces.



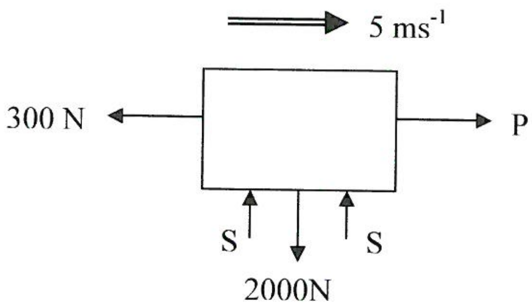


Eg1 A body is at rest when subjected to the forces shown in the diagram.



Find X and Y.

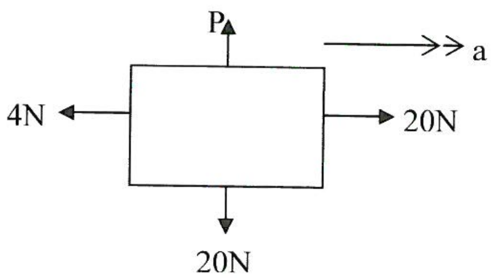
Eg2 A body moves horizontally with a constant speed of 5 ms^{-1} subject to the forces shown. Find P and S.



Eg3 A body of mass 8kg is acted on by a force of 10N. Find the accelerartion.

Eg4 Find the resultant force that would give a body of mass 200g an acceleration of 10 ms^{-2}.

Eg5 A body of mass 2kg, subject to forces as shown in the diagram, accelerated uniformly in the direction indicated. Find the acceleration and the value of P.



Eg6 Find (a) the weight of a box of mass 5kg
(b) the mass of a stone of weight 294N

Exercise 3A Pg 40 1, 3, 6, 7a, 8a, 9a, 10.

Eg1 $\Sigma F_x = 0$ $\quad 50 + 10 - X = 0$

$X = 60\,N$

$\Sigma F_y = 0$ $\quad 50 - Y - 10 = 0$

$Y = 40\,N$

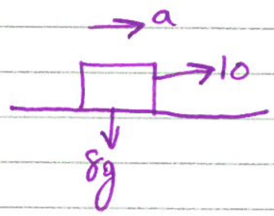
Eg2 $\Sigma F_x = Ma$ $\quad a = 0$ $\quad P - 300 = 0$

$P = 300\,N$

$\Sigma F_y = 0$ $\quad S + S - 2000 = 0$

$S = 1000\,N$

Eg3

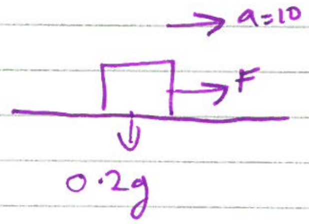


$\Sigma F_x = Ma$

$10 = 8a$

$a = \frac{5}{4}\ ms^{-2}$

Eg4



$\Sigma F_x = Ma$

$F = 0.2 \times 10 = 2N$

Eg5 $\Sigma F_x = Ma$ $\quad 20 - 4 = 2a$

$a = 8\,ms^{-2}$

$\Sigma F_y = 0$ $\quad P - 20 = 0$

$P = 20N$

Eg6 (a) $W = 5 \times 9.8 = 49\,N$

(b) $294 = M \times 9.8$

$M = 30\,kg$

Ex3A

(1) $W = 4 \times 9.8 = 39.2N$

(2) $490 = M \times 9.8 \quad M = 50kg$

(3) Earth $686 = M \times 9.8 \quad M = 70kg$

Moon $W = 70 \times 1.6 = 112N$

(4) $F = 1.2 \times 3.5 = 4.2N$

(5) $120 = 400 \times a \quad a = 0.3ms^{-2}$

(6) $-30 = M \times {}^{-}1.2 \quad M = 25kg$

(7) (a) $P - 2g = 2 \times 3 \quad P = 6 + 2g = 25.6N$

(b) $4g - P + 10 = 4 \times 2 \quad P = 4g + 10 - 8 = 41.2N$

(c) $\rightarrow \quad P - 4 = 5 \times 6 \quad P = 34N$

$\uparrow \quad Q - 5g = 0 \quad Q = 5g = 49N$

(8) (a) $Mg - 10 = 5M$

$M(g-5) = 10$

$M = \frac{10}{g-5} = 2.1kg$

(b) $20 - Mg = 2M$

$M(g+2) = 20$

$M = \frac{20}{g+2} = 1.7kg$

(c) $Mg + 8 - 10 = 0.5M$

$M(g - 0.5) = 2$

$M = \frac{2}{(g-0.5)} = 0.22kg$

(9) (a) $2g - 8 = 2a$

$$a = \frac{2g-8}{2} = 5.8\,ms^{-2}$$

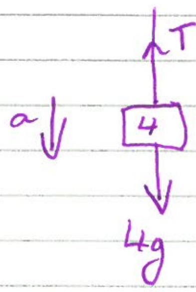
(b) $100 - 8g = 8a$

$$a = \frac{100-8g}{8} = 2.7\,ms^{-2}$$

(c) $30 + 20 - 4g = 4a$

$$a = \frac{50-4g}{4} = 2.7\,ms^{-2}$$

(10)



$4g - T = 4a$

(a) $a = 2 \downarrow$ $\quad 4g - T = 4 \times 2$

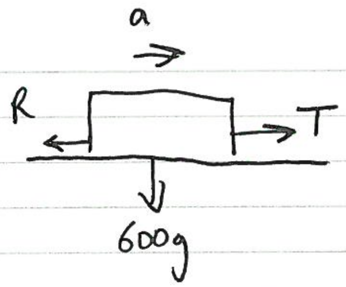
$$T = 4g - 8 = 31.2N$$

(b) $a = 0$ $\quad T = 4g = 39.2\,N$

(c) $a = -0.5$ $\quad 4g - T = 4 \times -0.5$

$$T = 4g + 2 = 41.2N.$$

Eg7



$u=0 \quad v=25 \quad t=12 \quad a=?$

$25=0+12a$

$a=\frac{25}{12}=2.1\,ms^{-2}$

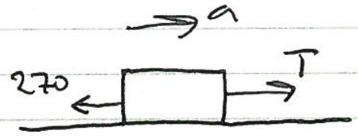
NLL $\quad T-R=600\times 2.1$

$T=1250+R$

(a) $R=0 \qquad T=1250\,N$

(b) $R=350 \qquad T=1600\,N$

Eg8



$u=15 \quad v=20 \quad a=? \quad t=20$

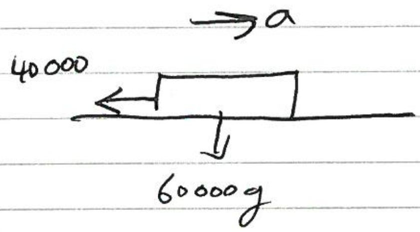
$20=15+20a$

$a=0.25\,ms^{-2}$

$T-270=1000\times 0.25$

$T=520\,N$

Eg9



$-40\,000=60000a$

$a=-\frac{2}{3}$

$u=40 \quad v=0 \quad s=?$

$0^2=40^2+2\times -\frac{2}{3}\times s$

$s=1200\,m$

Situations involving Newton's Laws and Constant Acceleration

Eg7 Find the constant force necessary to accelerate a car of mass 600kg from rest to $25ms^{-1}$ in 12 seconds if the resistance to motion is (a) zero (b) 350N.

Eg8 Find the constant force necessary to accelerate a car of mass 1000kg from $15ms^{-1}$ to $20ms^{-1}$ in 20 seconds against resistances totalling 270N.

Eg9 A train of mass 60 tonnes is travelling at $40ms^{-1}$ when the brakes are applied. If the resultant breaking force is 40 kN, find the distance the train travels before coming to rest.

Exercise 3B Pg44 Q's 5, 6, 8

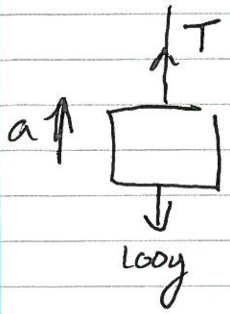
Eg10 A pack of bricks of mass 100kg is hoisted up the side of a house. Find the tension in the lifting rope when the bricks are lifted with an acceleration of $0.25ms^{-2}$.

Eg11 A miners cage of mass 420kg contains three miners of total mass 280kg. For the first 10 seconds the cage accelerates uniformly and descends a distance of 75 metres. Find the tension in the cable during the first 10 seconds.

Eg12 A man of mass 70kg stands on the floor of a lift which is accelerating downwards at $2ms^{-2}$. Calculate the mans *apparent weight.*

Exercise 3B Pg44 Q's 2, 4, 7, 10

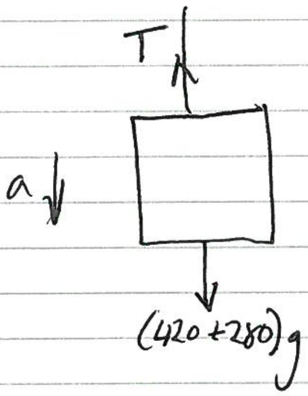
Eg10



$T - 100g = 100 \times \frac{1}{4}$

$T = 1005\ N$

Eg11



$u = 0 \quad t = 10 \quad s = 75 \quad a = ?$

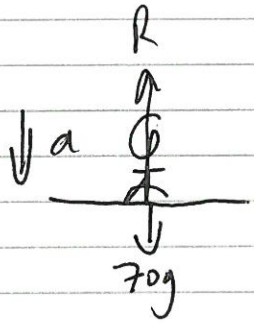
$75 = \frac{1}{2} a\, 10^2$

$a = 1.5\ ms^{-2}$

NLL $\quad 700g - T = 700 \times 1.5$

$T = 5810\ N.$

Eg12.

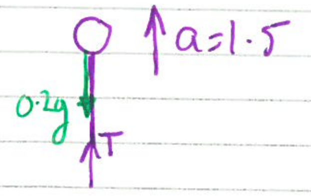


$70g - R = 70 \times 2$

$R = 70g - 140 = 546\ N$

Ex 3B

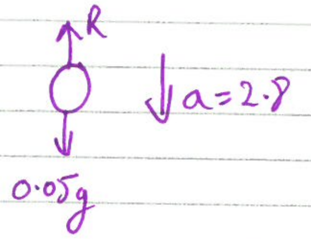
(1)



N2L: $T - 0.2g = 0.2(1.5)$

$T = 0.3 + 0.2g = 2.3N$

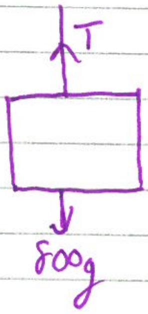
(2)



N2L: $0.05g - R = 0.05 \times 2.8$

$R = 0.35N$

(3)



(a) $u=0 \quad v=3 \quad s=5 \quad a=?$

$v^2 = u^2 + 2as$

$3^2 = 0^2 + 2 \times 5 \times a$

$9 = 10a$

$a = 0.9 \, ms^{-2}$

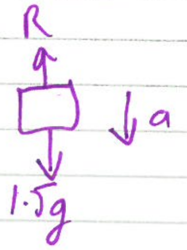
(b) ↓ $800g - T = 800 \times 0.9$

$T = 7120N$

(c) ↑ $T - 800g = 800 \times 0.9$

$T = 8560N$

(4)



$u=0 \quad s=16.6 \quad a=? \quad t=2$

$s = ut + \frac{1}{2}at^2$

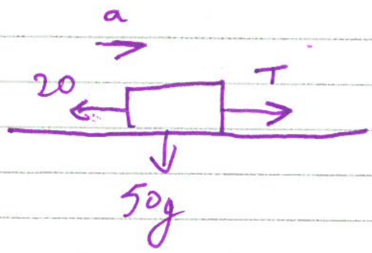
$16.6 = \frac{1}{2} \times a \times 2^2$

$a = 8.3 \, ms^{-2}$

N2L $1.5g - R = 1.5 \times 8.3$

$R = 2.25N$

(5)



$u=0 \quad v=1 \quad t=2 \quad a=?$

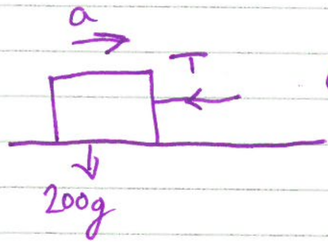
$1 = 0 + 2a$

$a = 0.5 \text{ ms}^{-2}$

N2L $\quad T - 20 = 50 \times 0.5$

$T = 45\text{N}$

(6)



(a) $u=15 \quad v=5 \quad s=25 \quad a=?$

$5^2 = 15^2 + 2 \times 25 \times a$

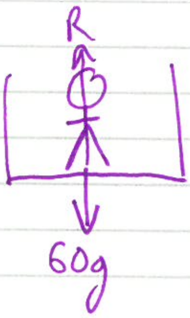
$a = \dfrac{25-225}{50} = -4 \text{ ms}^{-2}$

(b) N2L: $\quad -T = 200 \times {}^{-}4$

$T = 800\text{N}.$

(7)

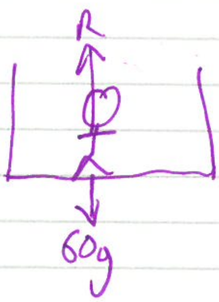
(a)



$\uparrow a = 2$ $\quad$ N2L $\quad R - 60g = 60 \times 2$

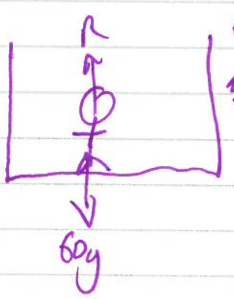
$R = 708\text{N}$

(b)



$\uparrow a = 0$ $\quad$ N2L $\quad R - 60g = 60 \times 0$

$R = 588\text{N}$

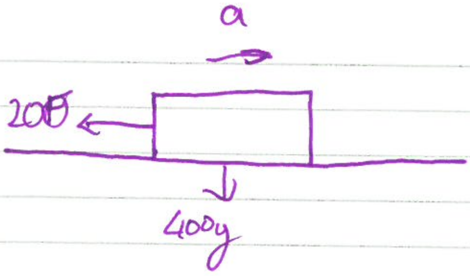


$\uparrow a = {}^{-}1.5$ $\quad$ N2L $\quad R - 60g = 60 \times {}^{-}1.5$

$R = 498\text{N}$

When travelling @ const speed ⇒ actual weight 588N
whilst accel she "feels" 708 N ie heavier
whilst decel she "feels" 498 N ie lighter.

(8)



$u = 16 \quad v = 0$

N2L $\quad -200 = 400a$

$a = -0.5\,ms^{-2}$

$t = ?$

$v = u + at$

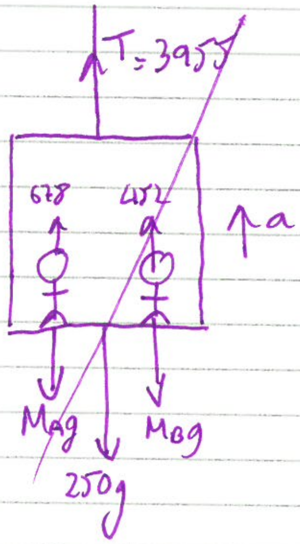
$0 = 16 + -0.5t$

$t = 32$ sec

(b) $S = (16 \times 32) + \frac{1}{2} \times -0.5 \times 32^2 = 512 - 256 = 256$ metres

(c) Air resist is unlikely to be constant.

(9)



① $-\ 3955 - 250g - M_Ag - M_Bg = (250g + M_A + M_B)a$

② $-\ 678 - M_Ag = M_Aa$

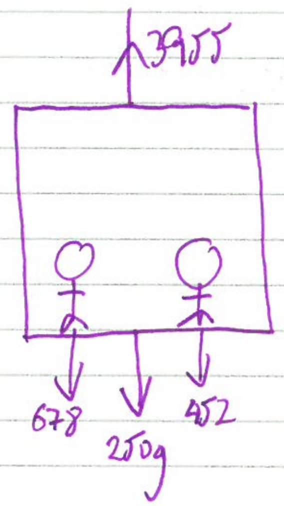
③ $-\ 452 - M_Bg = M_Ba$

From ② $\quad 678 = M_A(g+a) \qquad M_A = \dfrac{678}{g+a}$

From ③ $\quad M_B = \dfrac{452}{g+a}$

In ① $\quad 3955 - 250g - \left(\dfrac{678g}{g+a}\right) - \left(\dfrac{452g}{g+a}\right) = (250 +$

(9)

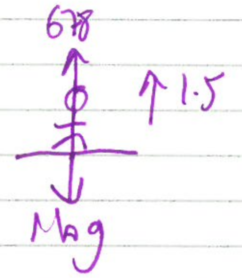


(a) Reaction are equal & opposite to weights.

$3955 - 678 - 452 - 250g = 250a$

$a = \frac{375}{250} = 1.5 \text{ ms}^{-2}$

(b) Albert



$678 - M_A g = 1.5 M_A$

$678 = M_A(1.5 + g)$

$M_A = \frac{678}{(1.5+g)} = 60\text{kg}$

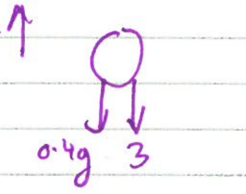
(c) Bella $452 - M_B g = 1.5 M_B$

$M_B = \frac{452}{(1.5+g)} = 40\text{kg}$

(10)

$u = 10\uparrow \quad a = ?\uparrow \quad V = 0 \quad s = ?\uparrow$

(a) a↑



N2L $-3 - 0.4g = 0.4a$

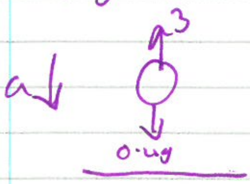
$a = -17.3 \text{ ms}^{-2}\uparrow$

$V^2 = u^2 + 2as$

$0^2 = 10^2 + 2 \times -17.3 \times s$

$s = \frac{100}{34.6} = 2.9\text{m}$

(b) on way back



$0.4g - 3 = 0.4a$

$a = 2.3 \text{ ms}^{-2}\downarrow \quad u = 0 \quad V = ? \quad s = 2.9\downarrow$

$V^2 = 0^2 + 2 \times 2.3 \times 2.9 = 13.34$

$V = 3.7 \text{ ms}^{-1}$

(10) (c) * can't consider whole journey as accel's changed*

time to top $0 = 10 + -17.3 \times t$

$$t = \frac{10}{17.3}$$

time back $3.7 = 0 + 2.3t$

$$t = \frac{3.7}{2.3}$$

total time $= \frac{10}{17.3} + \frac{3.7}{2.3} = 2.17$ sec.