University of KwaZulu-Natal
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School of Physics

Physics 131: tutorial week 3 - Motion & Newton's laws

Unless otherwise stated in the question, take the acceleration due to gravity, $g = 9,8\ \text{ms}^{-2}$.

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1. If sound travels at a constant speed of $343\ \text{ms}^{-1}$ in air, how much time (in seconds) does it take for the sound of thunder to travel 1609 m? (4,69 s)

   The speed is constant, so we can use $v = \dfrac{s}{t}$ with $v = 343\,\text{ms}^{-1}$ and $s = 1609\,\text{m}$

   $\therefore \quad t = \dfrac{1609}{343} = 4,69\,\text{s}$

2. Before leaving the ground, an aircraft moves with constant acceleration and travels 720 m in 12 s from rest. It then leaves the ground. Determine (i) the acceleration, (ii) the speed with which it leaves the ground, (iii) the distance covered during the first second and during the twelfth second. ($10\ \text{ms}^{-2}$; $120\ \text{ms}^{-1}$; 5 m; 115 m)

   (i) The acceleration is uniform and from rest, hence we can use $s = ut + \frac{1}{2}at^2$ with $u = 0$:
   $a = \dfrac{2s}{t^2} = \dfrac{2 \times 720}{12^2} = 10\,\text{ms}^{-2}$.

   (ii) Using the value for a obtained in (i), $u = 0\,\text{ms}^{-1}$ and $t = 12\,\text{s}$ in $v = u + at$,
   $v = 0 + 10 \times 12 = 120\,\text{ms}^{-1}$.

   (iii) During the first second: $t = 1\,\text{s}$, $u = 0\,\text{ms}^{-1}$ and $a = 10\ \text{ms}^{-2}$
   $s = ut + \frac{1}{2}at^2 = 0 + \frac{1}{2}10 \times 1 = 5\,\text{m}$.

   For the twelfth second, find s during the first 11 s and subtract from the total distance.
   $s\ (\text{in first 11 seconds}) = ut + \frac{1}{2}at^2 = 0 + \frac{1}{2}10 \times 121 = 605\,\text{m}$,
   hence $s = 720 - 605 = 115\,\text{m}$.

3. A moving car passes three points A, B, and C which are 150 m apart. The time taken to move from A to B was 10 s, and the time taken to move from B to C was 5 s. If the motion of the car was uniformly accelerated, how fast was the car moving as it passed C?

   ($35\ \text{ms}^{-1}$)

   Let the velocity of the car be u at A, v at B and w at C. Using $s = \frac{1}{2}(u+v)t$ for the intervals AB, BC and AC, we find:

$$
\begin{array}{lrcll}
 & 150 & = & \frac{1}{2}(u+v)\cdot 10 & (1) \\
 & 150 & = & \frac{1}{2}(v+w)\cdot 5 & (2) \\
 & 300 & = & \frac{1}{2}(u+w)\cdot 15 & (3) \\
2\times(2) - (1): & 150 & = & \frac{1}{2}(w-u)\cdot 10 & (4) \\
2\times(3) + 3\times(4): & 1050 & = & \frac{1}{2}(2w)\cdot 30 &
\end{array}
$$

   Hence the velocity at C, $w = 35\,\text{ms}^{-1}$.

4. A jetliner is landing with a speed of $69\,\text{ms}^{-1}$. Once the jet touches down, it has $750\,\text{m}$ of runway in which to reduce its speed to $6{,}1\,\text{ms}^{-1}$. Determine the acceleration of the plane during landing. $(-3,1\,\text{ms}^{-2})$

Use $v^2 = u^2 + 2as$ with $u = 69\,\text{ms}^{-1}$, $v = 6,1\,\text{ms}^{-1}$ and $s = 750\,\text{m}$, then

$$a = \frac{v^2 - u^2}{2s} = \frac{6,1^2 - 69^2}{2 \times 750} = -3,1\,\text{ms}^{-2}.$$

5. A car driver travelling at 72 km/hr suddenly sees a fallen tree on the road 40 m ahead. He puts on the brakes to stop before he hits the tree. To put on the brakes requires 0,75 s (the reaction time of the driver), after which the retardation is $8\,\text{ms}^{-2}$. What is the total stopping time? How far does he travel before the brakes are applied? What is his total stopping distance? If he subsequently travels at twice the speed, how far ahead should he be able to see clearly for safety?

(3,25 s ; 15 m ; 40 m ; 130 m)

To find the total time taken to stop, we add the reaction time (t_r) to the time taken to slow down from $u = 72$ km/hr ($= 20\,\text{ms}^{-1}$) to $0\,\text{ms}^{-1}$ at constant acceleration $a = -8\,\text{ms}^{-2}$. Using $v = u + at$:

$$t = \frac{v-u}{a} = \frac{-20}{-8} = 2,5\,\text{s}.$$

$$\therefore \quad \text{total stopping time} = t + t_r = 2,5 + 0,75 = 3,25\,\text{s}.$$

Before the brakes are applied, the driver drives at constant velocity $v = u = 20\,\text{ms}^{-1}$. The distance travelled in time $t_r = 0,75$ s is

$$s = vt_r = 20 \times 0,75 = 15\,\text{m}.$$

The total stopping distance is the distance to the fallen tree, $s = 40\,\text{m}$.

We require the total stopping distance when the initial speed is twice $20\,\text{ms}^{-1}$ ($= 40\,\text{ms}^{-1}$). The reaction time remains the same ($t_r = 0,75$s) as does the deceleration ($a = -8\,\text{ms}^{-2}$).

Distance travelled while reacting $= 40 \times 0,75 = 30\,\text{m}$.

Distance travelled while decelerating (use $v^2 = u^2 + 2as$)

$$s = \frac{v^2 - u^2}{2a} = \frac{0 - 40^2}{-2 \times 8} = 100\,\text{m}.$$

Hence the total stopping distance $= 30\,\text{m} + 100\,\text{m} = 130\,\text{m}$

6. A train moving between two stations 1100 m apart accelerates uniformly for 40 s, and then moves at constant speed until the brakes are applied. If it comes to rest after 30 s and the whole journey takes 90 s, find the maximum speed, the acceleration, and the retardation.

(20 ms^{-2} ; 0,5 ms^{-2} ; 0,67 ms^{-2})

The total distance travelled by the train is equal to the area under the speed versus time graph. If the maximum speed attained is v (see graph), then:

$$s = \frac{1}{2}v \times 40 + v \times (90-30-40) + \frac{1}{2}v \times 30 = 1100\,\text{m}$$

Hence $v = 20\,\text{ms}^{-1}$.

Using $v = u + at$, the initial acceleration

$$a = \frac{v-u}{t} = \frac{20-0}{40} = 0,5\,\text{ms}^{-2}$$

and the acceleration produced by the brakes,

$$a = \frac{v-u}{t} = \frac{0-20}{30} = -0,67\,\text{ms}^{-2},$$

Hence the retardation is 0,67 ms^{-2} .

7. Suppose you are visiting a planet in a distant part of the galaxy. To determine the acceleration due to gravity on this planet, you drop a rock from a height of 55 m. The rock strikes the ground 1,9 s later. How many times greater is the acceleration due to gravity on this planet than that on earth? (3,1 times)

Use $s = ut + \frac{1}{2}at^2$ with $u = 0\,\text{ms}^{-1}$ (since the rock is dropped not thrown). Hence

$$a = \frac{2s}{t^2} = \frac{2 \times 55}{1,9^2}\,\text{ms}^{-2}$$

Taking $g = 9,8\,\text{ms}^{-2}$:

$$\frac{a}{g} = \frac{110}{3,61 \times 9,8} = 3,1$$

8. A stone is dropped from a tower, which is 44,1 m high, and strikes the ground after 3 s. Calculate the acceleration due to gravity and find the speed with which the stone hits the ground. (9,8 ms^{-2}; 29,4 ms^{-1})

Use $s = ut + \frac{1}{2}at^2$ with $u = 0\,\text{ms}^{-1}$.

$$a = \frac{2s}{t^2} = \frac{2 \times 44,1}{3^2} = 9,8\,\text{ms}^{-2}.$$

The velocity with which the stone hits the ground may now be determined from $v = u + at$

$$v = 0 + 9,8 \times 3 = 29,4\,\text{ms}^{-1}.$$

9. A ball is thrown upward with an initial speed of 35 ms^{-1}. What is its speed at $t = 2,00$ s?

(15,4 ms^{-1})

Taking motion in the upward direction as positive, use of $v = u + at$ yields

$$v = 35,0 - 9,8 \times 2,00 = 15,4\,\text{ms}^{-1}$$

10. A stone is projected vertically upward with a speed of $14\,\text{ms}^{-1}$ from a tower 100 m high. Find the maximum height attained and the speed with which it strikes the ground.

(110 m ; 46,4 ms^{-1})

Take motion upwards as positive. For the trajectory of the stone from the top of the tower to maximum height $u = 14\,\text{ms}^{-1}$, $v = 0\,\text{ms}^{-1}$ and $a = -g = -9,8\,\text{ms}^{-2}$.
Using $v^2 = u^2 + 2as$

$$s = \frac{-u^2}{2a} = \frac{-196}{2\times(-9,8)} = 10\,\text{m}.$$

The maximum height attained is therefore $100 + 10 = 110\,\text{m}$.
Again using $v^2 = u^2 + 2as$, now with $s = -110\,\text{m}$ and $u = 0\,\text{ms}^{-1}$ we find

$$v^2 = 2as = 2\times(-9,8)\times(-110),$$

which gives $v = 46,4\,\text{ms}^{-1}$ (downwards).

11. A stone is dropped and then 1,0 s later, from a point 5,0 m lower, a second stone is dropped. When will the two stones be 15 m apart? (2,54 s after the first stone is dropped.)

Suppose the second stone drops x m. Then the first stone drops $5 + x + 15 = x + 20\,\text{m}$.
Let the time taken for the first stone to drop be t s, then the time taken for the second stone is $(t-1)$ s.
The stones are dropped from rest so $u = 0\,\text{ms}^{-1}$ for both.
Considering motion downwards to be positive so that $a = g = 9,8\,\text{ms}^{-2}$ and using $s = ut + \frac{1}{2}at^2$:

For stone 1 : $x + 20 = \frac{1}{2}\times 9,8t^2$
For stone 2 : $x = \frac{1}{2}\times 9,8(t-1)^2$

Elliminating x in the above equations, we find

$$20 + \tfrac{1}{2}9,8(t-1)^2 = \tfrac{1}{2}9,8t^2.$$

Solving for t yields $t = 2,54\,\text{s}$.

12. Four–tenths of a second after bouncing on a trampoline, a gymnast is moving upward with a speed of $6,0\,\text{ms}^{-1}$. To what height above the trampoline does the gymnast rise before falling back down? (5,0 m)

Combining $s = ut + \frac{1}{2}at^2$ and $v = u + at$, we obtain

$$s = vt - \tfrac{1}{2}at^2$$

The displacement from the moment the gymnast leaves the trampoline to $t = 0,4\,\text{s}$ is therefore

$$s = 6,0\times 0,4 - \tfrac{1}{2}\times(-9,8)\times 0,4^2 = 3,2\,\text{m}$$

The displacement from $t = 0,4\,\text{s}$ to the maximum height can be found from $v^2 = u^2 + 2as$ with $u = 6\,\text{ms}^{-1}$ and $a = -9,8\,\text{ms}^{-2}$:

$$s = \frac{v^2 - u^2}{2a} = \frac{0 - 6,0^2}{2(-9,8)} = 1,8\,\text{m}$$

The maximum height reached is therefore $3,2 + 1,8 = 5,0\,\text{m}$.

13. What constant force is required to give a 0,49 kg mass an acceleration of 1,50 ms^{-2}?

(0,74 N)

$$F = ma = 0,49\times 1,50 = 0,74\,\text{N}$$

14. A car is towing a trailer. The driver starts from rest and accelerates to a speed of $11\,\text{ms}^{-1}$ in a time of 28 s. The mass of the trailer is 410 kg. What is the tension in the hitch that connects the trailer to the car? (161 N)

From $v = u + at$ we obtain the acceleration of the whole system (car and trailer).

$$a = \frac{v-u}{t} = \frac{11-0}{28}\ \text{ms}^{-2}$$

The only unbalanced force on the trailer is the force due to the car pulling it. This is the tension in the hitch and equals *ma*, where *m* is the mass of the trailer and *a* the acceleration. Thus

$$T = 410 \times \frac{11}{28} = 161\,\text{N}.$$

15. A car of mass 1380 kg is moving due east with an initial speed of $27{,}0\,\text{ms}^{-1}$. After 8,00 s the car has slowed down to $17{,}0\,\text{ms}^{-1}$. Find the magnitude and direction of the net force that produces the deceleration. (1730 N due west)

From $v = u + at$ with $u = 27{,}0\,\text{ms}^{-1}$, $v = 17\,\text{ms}^{-1}$ and $t = 8{,}0$ s, the acceleration

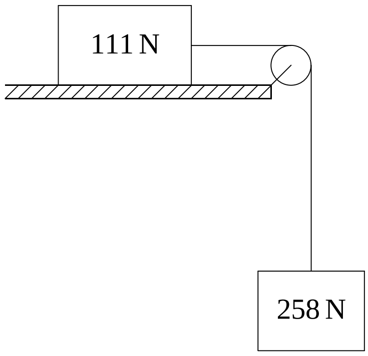
$$a = \frac{v-u}{t} = \frac{17{,}0-27{,}0}{8} = -1{,}25\,\text{ms}^{-2}.$$

(The direction of motion is taken as positive.) The force producing the acceleration,

$$F = ma = 1380 \times (-1{,}25) = -1{,}73\,\text{kN}$$

Here the negative sign indicates the force opposes the motion and is therefore in a westerly direction.

16. In the drawing, the weight of the block on the table is 111 N and that of the hanging block is 258 N. Ignoring all frictional effects and assuming the pulley to be massless, find (i) the acceleration of the two blocks and (ii) the tension in the cord. (6,9 ms^{-2} ; 77 N)



The acceleration of the whole system is due to the 258 N block, hence

$$a = \frac{F}{m} = \frac{258 \times 9{,}8}{111+258} = 6{,}9\,\text{ms}{-2}$$

Applying Newton's second law to the 111 N block (and the tension in the cord), we have:

$$F = T = \frac{111}{9{,}8} \times 6{,}9 = 78\,\text{N}.$$

17. Two frictionless bodies A and B are connected by a cord passing over a frictionless pulley. If 0,40 kg is shifted from B to A, (i) what acceleration results and (ii) what is the tension in the cord? (0,49 ms^{-2} ; 78 N)

The net weight free to produce acceleration is $(8,40-7,60)g = 7,84\,\text{N}$.

$$a = \frac{F}{m} = \frac{7,84}{16} = 0,49\,\text{ms}^{-2}.$$

Applying Newton's second law to A, we have

$$\begin{aligned} W+T &= ma \\ \therefore\quad -8,4\times 9,8+T &= 8,4\times(-0,49) \\ \therefore\quad T &= 8,4\times(9,8-0,49) = 78\,\text{N}. \end{aligned}$$

18. A man of mass 100 kg stands in a lift. What force does the floor exert on him (i) when the lift rises at constant speed, (ii) when it accelerates upwards at 2 ms^{-2} and (iii) when it falls freely? (980 N; 1280 N; 0 N)

(i) When the lift ascends at constant velocity, there is no unbalanced force so the lift exerts a reaction force equal to the man's weight = 980 N.

(ii) $F = ma = 100\times 3 = 300\,\text{N}$.
$\therefore$ Reaction force $= F + W = 980 + 300 = 1280\,\text{N}$

(iii) The person in the lift falls with the same acceleration as the lift and experiences no force. $F = 0$.

19. A rescue helicopter is lifting a man ($W = 822$ N) from a capsized boat by means of a cable and harness. (i) What is the man's mass? (ii) What is the tension in the cable when the man is given an initial upward acceleration of 1,0 ms^{-2} ? (iii) What is the tension during the remainder of the rescue when he is pulled upward at a constant velocity?

(84 kg ; 914 N ; 822 N)

(i) $m = \dfrac{W}{g} = \dfrac{822}{9,8} = 84\,\text{kg}$

(ii) Force due to the upward acceleration $F = ma = 84\times 1,10 = 92\,\text{N}$
$\therefore\ T = 822+92 = 914\,\text{N}$

(iii) The tension equals the weight of the person, $T = W = 822\,\text{N}$.

20. A student is skateboarding down a ramp that is 6,0 m long and inclined at 18° with respect to the horizontal. The initial speed of the skateboarder at the top of the ramp is 2,6 ms^{-1}. Neglect friction and find (i) the acceleration and (ii) the speed at the bottom of the ramp.

(3,0 ms^{-2}; 6,6 ms^{-1})

(i) The acceleration of the skateboarder is down the ramp. The force producing this acceleration is the component of the skateboarders weight parallel to the slope. Since $F \propto a$,
$$a_{\parallel} = 9,8\sin 18^\circ = 3,03\,\text{ms}^{-2}.$$

(ii) The speed at the bottom of the ramp can now be determined from $v^2 = u^2 + 2as$,
$$\begin{aligned} v^2 &= 2,6^2 + 2\times 3,03\times 6,0\,\text{m}^2\text{s}^{-2} \\ \therefore\quad v &= 6,6\,\text{ms}^{-1} \end{aligned}$$

21. A lunar landing craft (mass $m = 11\,400$ kg) is about to touch down on the surface of the moon, where the acceleration due to gravity is 1,6 ms^{-2}. At an altitude of 165 m the craft's downward velocity is 18,0 ms^{-1}. To slow down the craft, a retrorocket is fired to provide an upward thrust. Assuming the descent is vertical, find the magnitude of the thrust needed to reduce the velocity to zero at the instant when the craft touches the lunar surface. (2,94 $\times 10^4$ N)

Take downward motion as negative. We are given:

$g = -1,6\,\text{ms}^{-2}, \quad m = 11,4\times10^3\,\text{kg} \quad \text{and} \quad u = -18,0\,\text{ms}^{-1} \quad \text{at} \quad s = -165\,\text{m}.$

The thrust required is such that the final velocity at touchdown $u = 0\,\text{ms}^{-1}$. The acceleration required to achieve this can be calculated from $v^2 = u^2 + 2as$:

$$a = \frac{v^2 - u^2}{2s} = \frac{0 - 18^2}{2\times(-165)} = 0,982\,\text{ms}^{-2}.$$

Using Newton's second law,

$$\begin{aligned} \text{Weight} + \text{Thrust} &= ma \\ \therefore \quad \text{Thrust} &= 11,4\times10^3\times\frac{18^2}{330} - 11,4\times10^3\times(-1,6) \\ &= 2,94\times10^4\,\text{N}. \end{aligned}$$

True or false questions

	TRUE	FALSE
1. If a man runs the Comrades marathon from PMB to Durban at 10 km/hr, and then back at 5 km/hr, the average speed for the round trip is 7,5 km/hr	X	
2. At the moment when a car starts to move (as the traffic light goes green) its velocity is zero but its acceleration is not zero.	X	
3. At a certain moment, a car and a truck are travelling side by side on the freeway. If the car at that moment has a greater velocity than the truck it *must* have the greater acceleration.		X
4. A ball thrown into the air reaches a maximum height and then drops back to the ground. During the entire motion the acceleration (due to gravity) is always downwards.	X	
5. If no unbalanced force acts on a body it must be at rest.		X
6. A father and his seven–year–old daughter are facing each other on ice–skates. They push each other apart. The same magnitude of force acts on each of them but the daughter will accelerate away faster.	X	
7. When a body is moved from sea–level to the top of a mountain, its weight and therefore its mass changes.		X