Oxford IB Physics Course Companion

Unofficial student made suggested solutions

By **Noël M. Nimstad** and **Mzhahid Sibai**

Contents

1 Topic A – Space, time and motion

1.1 Subtopic A.1 – Kinematics

A1:P11 Question 1

a) The total distance is given as the sum of distance traveled during each translation, $2.5 + 3.8 = 6.3\,[\mathrm{km}]$

b) Displacement is a vector quantity, thus taking the magnitude of the sum of the two vector displacements caused by the movement:

$$\begin{aligned}\left\|\begin{pmatrix}2.5\\0\end{pmatrix}+\begin{pmatrix}0\\3.8\end{pmatrix}\right\| &= \left\|\begin{pmatrix}2.5\\3.8\end{pmatrix}\right\|\\ &= \sqrt{2.5^2+3.8^2} \approx \boxed{4.55\,[\mathrm{km}]}\end{aligned}$$

c) Since this can be scenario can be set up as a right angle triangle, with the boat as the hypothesis' outer vertex, using trigenometry the angle can is determined as:

$$\tan\theta = \frac{o}{a} \rightsquigarrow \theta = \tan^{-1}\frac{2.5}{3.8} \approx 33.3°$$

A1:P11 Question 2

a) 15 minutes corresponds to a 90 degree ($\frac{\pi}{2}\,[\mathrm{rad}]$) rotation on a clock, or one quarter of its perimeter. Therefore the distance travelled by the tip of the pointer must be:

$$s = \frac{2\pi r}{4} = \frac{15\pi}{2} \approx 23.6\,[\mathrm{cm}]$$

The displacement however is the distance between the points $\langle 0\,,15\rangle$ and $\langle 15\,,0\rangle$, thus using Pythagoras' theorem[a]:

$$s = \sqrt{15^2+15^2} = \sqrt{450} = 21.2\,[\mathrm{cm}]$$

b) Analagously to part **a)** but for the 180 degrees ($\pi\,[\mathrm{rad}]$) rotation resulting from 30 elapsed minutes:

$$\begin{aligned}s_{\text{distance}} &= \frac{2\pi r}{2} = 15\pi \approx 47.1\,[\mathrm{cm}]\\ s_{\text{displacement}} &= \sqrt{0^2+30^2} = 30\,[\mathrm{cm}]\end{aligned}$$

A1:P12 Question 3

Since they are headed in completley oposite directions, $s_{\text{Ada}} + s_{\text{Matt}} = 580\,[\mathrm{m}]$. Ada's speed of $20\,[\mathrm{km\,h^{-1}}]$

is approximately $5.56\,[\mathrm{m\,s^{-1}}]$, as found by dividing through by 3.6. Since $s = \displaystyle\int v\,\mathrm{d}t$:

$$v_{\text{Ada}}t + v_{\text{Matt}}t = 580$$

$$5.56 \times 60 + v_{\text{Matt}} \times 60 = 580$$

$$\therefore v_{\text{Matt}} \approx 4.11\,[\mathrm{m\,s^{-1}}] \equiv \boxed{14.8\,[\mathrm{km\,h^{-1}}]}$$

A1:P12 Question 4

First multiply the speed of light by the length of a light-year in seconds to obtain $1\,[\mathrm{ly}]$.

$$\begin{aligned} 1\,[\mathrm{ly}] &= 3 \times 10^8\,[\mathrm{m\,s^{-1}}] \times (60 \times 60 \times 24 \times 365)\,[\mathrm{s}] \\ &\approx 9.46 \times 10^{15} \end{aligned}$$

Then, find the conversion between $1\,[\mathrm{au}]$ and one light-year.

$$1\,[\mathrm{au}] \approx \frac{1.5 \times 10^{11}}{9.46 \times 10^{15}} = 1.59 \times 10^{-5}\,[\mathrm{ly}]$$

Therefore,

$$5.5 \times 10^5\,[\mathrm{au}] \approx \boxed{8.72\,[\mathrm{ly}]}$$

A1:P14 Question 5

a) Calculating the speed between stations A and B:

$$v = \frac{1000}{80} = 12.5\,[\mathrm{m\,s^{-1}}]$$

Multiplying by 3.6 to obtain the speed in $[\mathrm{km\,h^{-1}}]$:

$$v = 12.5 \times 3.6 = \boxed{45\,[\mathrm{km\,h^{-1}}]}$$

b) $\Delta y = 1800 - 1000 = 800\,[\mathrm{m}]$

c) The train travels $800\,[\mathrm{m}]$ in 60 seconds, therefore, analagously to part **a)**:

$$v = \frac{800}{60} \approx 13.3\,[\mathrm{m\,s^{-1}}] = \boxed{47.9\,[\mathrm{km\,h^{-1}}]}$$

A1:P14 Question 6

a) i)

$$\frac{4\,[\mathrm{m}]}{10\,[\mathrm{m\,s^{-1}}]} = \boxed{0.4\,[\mathrm{s}]}$$

ii) The ball traveled for a total of $0.9\,[\mathrm{s}]$. If then, it took $0.4\,[\mathrm{s}]$ to the wall, then it took $0.9 - 0.4 = 0.5\,[\mathrm{s}]$.

The speed needed to travel $4\,[\mathrm{m}]$ in $0.5\,[\mathrm{s}]$ is:

$$\frac{4\,[\mathrm{m}]}{0.5\,[\mathrm{s}]} = \boxed{8\,[\mathrm{m\,s^{-1}}]}$$

b)

Note that graph question solutions are not yet done due to lack of time.

A1:P16 Question 7

a) i) Imagining a straight line tangent to the curve (since $v = \frac{\mathrm{d}s}{\mathrm{d}t}$), it goes roughly $6\,[\mathrm{m}]$ in $1\,[\mathrm{s}]$, therefore the velocity is $\boxed{6\,[\mathrm{m\,s^{-1}}]}$

ii) The tangent line at $t = 5\,[\mathrm{s}]$ goes approximately from $\langle 2.5\,, 12.5\rangle$ to $\langle 10\,, 28\rangle$, thus

$$\Delta s = 28 - 12.5 = 15.5\,[\mathrm{m}]$$

$$\Delta t = 10 - 2.5 = 7.5\,[\mathrm{s}]$$

Therefore:

$$v = \frac{\Delta s}{\Delta t} = \frac{15.5}{7.5} \approx \boxed{2\,[\mathrm{m\,s^{-1}}]}$$

b)

$$v = \frac{\Delta s}{\Delta t} = \frac{24}{12.5} = \boxed{1.92\,[\mathrm{m\,s^{-1}}]}$$

A1:P16 Question 8

a) The perimeter of the track is $s = \frac{2\pi r}{2} = 25\pi\,[\mathrm{m}]$. Therefore, the average speed is:

$$v = \frac{25\pi}{19} \approx \boxed{4.13\,[\mathrm{m\,s^{-1}}]}$$

b) For the velocity, we need the magnitude of the displacement which is $50\,[\mathrm{m}]$ since he went from one side of the circle to the other, one length of the diameeter $(2r)$. Therefore, the average velocity is:

$$v = \frac{50}{19} \approx \boxed{2.63\,[\mathrm{m\,s^{-1}}]}$$

A1:P21 Question 9

Since $s = \displaystyle\int v\,\mathrm{d}t$, the sum of the squares under the graph is the distance travelled. Estimating using triangles $(A = \frac{bh}{2})$:

$$\begin{aligned} s &= \frac{4\times 1}{2} + \frac{2\times 1}{2} + \frac{2\times 3}{2} + 11 \\ &= 2 + 1 + 3 + 11 = 17\,[\mathrm{m}] \end{aligned}$$

The triangles in this case underestimate the area, so rounding up we get $20\,[\mathrm{m}]$, making the answer $\boxed{\mathrm{B}}$.

A1:P21 Question 10

The tangent line (since $a = \frac{\mathrm{d}v}{\mathrm{d}t}$) goes from roughly $\langle 0\,,4\rangle$ to $\langle 4\,,8\rangle$, thus:

$$\Delta v = 8 - 4 = 4$$

$$\Delta t = 4 - 0 = 4$$

$$a = \frac{\Delta v}{\Delta t} = \frac{4}{4} = 1\,[\mathrm{m\,s^{-1}}]$$

Therefore the answer is $\boxed{\mathrm{A}}$.

A1:P21 Question 11

At $t = 4\,[\mathrm{s}]$, the max speed has been reached. Since the object was accelerated previously, the average speed is below the max line, thus the answer is either A or C. The tangent line (since $a = \frac{\mathrm{d}v}{\mathrm{d}t}$) at this point, however, is flat, meaning $a_{\text{instant}} = 0$. Thus the answer is $\boxed{\mathrm{A}}$.

A1:P21 Question 12

If the velocity magnitude of the velocity is negative then it is moving in one direction, and if it is positive, then it moves in the oposite direction. Therefore, each time the velocity changes sign, the object is changing direction. The velocity changes sign twice, meaning the answer is $\boxed{\mathrm{B}}$.

A1:P22 Question 13

a) Considering the absolute value of the graph, the velocity is first decreasing between $t = 0\,[\mathrm{s}]$ and $1.5\,[\mathrm{s}]$ and then increasing between $t = 1.5\,[\mathrm{s}]$ and $2.5\,[\mathrm{s}]$. What happens however at $t = 1.5\,[\mathrm{s}]$ is that, with the change of sign (vide **A1:21 Question 12**), is that the direction of travel changes.

b) i) The velocity decreases along a straight line, meaning acceleration is constant. Calculating the slope of the line between 2 nice points:

$$a = \frac{\Delta v}{\Delta t} = \frac{-2}{1.5} \approx \boxed{-1.33\,[\mathrm{m\,s^{-2}}]}$$

ii) The positive and negatibe parts between $t = 0.5\,[\mathrm{s}]$ and $2.5\,[\mathrm{s}]$ will cancel out, thus we only need to compute the area under the curve (since $s = \int v\,\mathrm{d}t$) between $t = 0\,[\mathrm{s}]$ and $0.5\,[\mathrm{s}]$. To compute this we need to know the coordinates of the point $\langle 0.5\,,?\rangle$. Since we know $a \approx -1.33\,[\mathrm{m\,s^{-2}}]$, we can compute:

$$\begin{aligned} v_{0.5} &\approx v_0 - 1.33 \times 0.5 \\ &= 1.335\,[\mathrm{m\,s^{-1}}] \end{aligned}$$

Therefore summing the rectangle and triangle below the curve:

$$s = 0.5 \times 1.335 + \frac{(2 - 1.355) \times 0.5}{2} \approx \boxed{0.834\,[\mathrm{m}]}$$

c)

Note that graph question solutions are not yet done due to lack of time.

A1:P25 Question 14

a) Note that if the cart is returning to it's origin, then the distance travelled s is 0. Using $s = ut + \frac{1}{2}at^2$:

$$\begin{aligned} 0 &= ut + \frac{1}{2}at^2 \\ &= 3t - 0.5 \times 1.8t^2 \\ \implies 0.9t^2 &= 3t \end{aligned}$$

Dividing by t discards the solution of $t = 0$ (since division by 0 is not mathematically allowed), however this solution is trivvial (when the cart begins travelling it is at its origin):

$$\begin{aligned} 0.9t &= 3 \\ \therefore t &= \frac{3}{0.9} \approx \boxed{3.33\,[\mathrm{s}]} \end{aligned}$$

b) When the velocity v is 0 the distance is maximum, since after the velocity changes sign (by passing zero), the object starts moving in the oposite direction. Using $v^2 = u^2 + 2as$:

$$\begin{aligned} 0 &= 3^2 - 2 \times 1.8s \\ \implies s &= \frac{9}{3.6} = \boxed{2.5\,[\mathrm{m}]} \end{aligned}$$

A1:P25 Question 15

a) Converting $100\,[\mathrm{km\,h^{-1}}]$ to $[\mathrm{m\,s^{-1}}]$ by dividing by 3.6 means:

$$v = \frac{100}{3.6}$$

Then using $v = u + at$:

$$\begin{aligned} \frac{100}{3.6} &= 0 + 16a \\ \implies a &= \frac{100}{3.6 \times 16} \approx \boxed{1.74\,[\mathrm{m\,s^{-2}}]} \end{aligned}$$

b) Converting $250\,[\mathrm{km\,h^{-1}}]$ to $[\mathrm{m\,s^{-1}}]$ by dividing by 3.6 means:

$$v = \frac{250}{3.6}$$

Using $v^2 = u^2 + 2as$ and the acceleration from **a)** we derive:

$$\begin{aligned} \frac{250^2}{3.6^2} &= 0 + 2 \times \frac{100}{57.6}s \\ \implies s &= \frac{250^2 \times 57.6}{200 \times 3.6^2} \approx \boxed{1400\,[\mathrm{m}]} \end{aligned}$$

A1:P25 Question 16

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

$$\begin{aligned} 12^2 &= u^2 + 2 \times (-4.3) \times 25 \\ \implies u &= \sqrt{12^2 + 8.6 \times 25} \approx \boxed{18.9\,[\mathrm{m\,s^{-1}}]} \end{aligned}$$

A1:P25 Question 17

a) To reach maximum velocity and be able to stop in time, the train must accelerate the first half of the distance and then immediately start de-accelerating. Therefore $s = 360$. Then using $v^2 = u^2 + 2as$:

$$\begin{aligned} v^2 &= 0 + 2 \times 1.3 \times 360 \\ \implies v &= \sqrt{720 \times 1.3} \approx \boxed{30.6\,[\mathrm{m\,s^{-1}}]} \end{aligned}$$

b) The time is minimised if the velocity is maximised. Since the travel is symmetrical, considering the first half ($s = 360$) with maximum acceleration and using $s = ut + \frac{1}{2}at^2$:

$$\begin{aligned} 360 &= 0 + \frac{1}{2} \times 1.3 \times t^2 \\ \implies t &= \sqrt{\frac{720}{1.3}} \end{aligned}$$

Since this was only half the distance, the total minimum travel time is $2t$:

$$2t = 2\sqrt{\frac{720}{1.3}} \approx \boxed{47.1\,[\mathrm{s}]}$$

A1:P25 Question 18

a) Since we know the distance, initial velocity (0), and time, we can derive the acceleration through the SUVAT equaition $s = ut + \frac{1}{2}at^2$:

$$\begin{aligned} 12 &= 0 + 0.5a \times 4^2 \\ \implies a &= \frac{12}{0.5 \times 4^2} = \frac{12}{8} = 1.5\,[\mathrm{m\,s^{-2}}] \end{aligned}$$

Then using $v = u + at$ we find the velocity at $t = 2$ is:

$$v = 0 + 1.5 \times 2 = 3\,[\mathrm{m\,s^{-1}}]$$

The answer matching this is $\boxed{\mathrm{D}}$.

b)

Note that graph question solutions are not yet done due to lack of time.

A1:P34 Question 19

If both projectiles reach the same height, that means that the vertical component of the initial velocity was the same, since:

$$u_{1y}t - \frac{1}{2}gt^2 = \max y = u_{2y}t - \frac{1}{2}gt^2$$
$$\implies u_{1y} = u_{2y}$$

If the vertical component of the initial velocity is the same, then the time taken to reach the ground is the same. This is because both are experiencing the same gravitational pull. Thus the answer is $\boxed{\mathrm{B}}$.

A1:P34 Question 20

The horizontal distance travelled is proportional to the height $s \propto h$ since the time taken to hit the ground is proportional to the height $t_{\text{final}} \propto h$. The time taken to hit the ground $s_y = -h$, with 0 initial vertical velocity, can be computed as:

$$-h = 0 - \frac{1}{2}gt_{\text{final}}^2$$
$$\implies t_{\text{final}} = \sqrt{\frac{2h}{g}}$$

Note that the negative solution was discarded as it is physically impossible. Thus we derive that:

$$t_{\text{final}} \propto \sqrt{h}$$

Then, we compute that horizontal distance travelled (with initial horizontal velocity u, with no or negligible air resistance) as:

$$s = ut + 0$$

Therefore, the final distance travelled is s evaluated at t_{final}, meaning:

$$s \propto \sqrt{h}$$

Thus to reach a distance of $2s$, we need a height of $4h$, since $\sqrt{4h} = 2\sqrt{h}$. This means the answer is $\boxed{\mathrm{D}}$.

A1:P34 Question 21

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

$$\begin{aligned} s &= -4t - \frac{1}{2}gt^2 \\ &= -4 \times 1.9 - \frac{g}{2}(1.9)^2 \approx -25.3\,[\mathrm{m}] \end{aligned}$$

This is the displacement of the object over that time, so the tower's height is $h = -s = 25.3\,[\mathrm{m}]$. The closest answer is therefore $\boxed{\mathrm{D}}$.

A1:P34 Question 22

The time to hit the floor is given by, as derived in **A1:P34 Question 20**:

$$t_{\text{final}} = \sqrt{\frac{2h}{g}}$$

The horizontal displacement is then given through $s = ut + \frac{1}{2}at^2$ (noting air resistance is negligible, providing 0 acceleration):

$$\begin{aligned} s &= vt_{\text{final}} \\ &= v\sqrt{\frac{2h}{g}} \end{aligned}$$

The answer is therefore $\boxed{\mathrm{C}}$.

A1:P34 Question 23

a) The maximum height is reached when the vertical velocity is 0, since the changing of a sign changes the direction of motion, making the height of the ball strictly decrease post that point. Therefore, using $v = u + at$:

$$\begin{aligned} 0 &= u_y - gt_{\text{max}} \\ u_y &= gt_{\text{max}} = 0.9g \approx \boxed{8.84\,[\mathrm{m\,s^{-1}}]} \end{aligned}$$

b) Noting there is no air resistance, the horizontal velocity can be computed using $s = ut + \frac{1}{2}at^2$ as:

$$\begin{aligned} 16 &= 0.9u_x + 0 \\ \implies u_x &= \frac{16}{0.9} \approx 17.8\,[\mathrm{m\,s^{-1}}] \end{aligned}$$

Using Pythagoras theorem, we get that the total initial velocity is:

$$u = \sqrt{u_x^2 + u_y^2} = \sqrt{17.8^2 + 8.84^2} \approx \boxed{19.9\,[\mathrm{m\,s^{-1}}]}$$

c) Solving the equation $u \sin\theta = u_y$ (or $u\cos\theta = u_x$) gives:

$$\sin\theta \approx \frac{8.84}{19.9}$$
$$\implies \theta \approx \sin^{-1}\frac{8.84}{19.9} \approx 0.4603\ldots\ [\text{rad}]$$

Converting to degrees (using $\theta_{\text{deg}} = \frac{180\theta_{\text{rad}}}{\pi}$):

$$\theta \approx \boxed{26.4^\circ}$$

d) Using $s = ut + \frac{1}{2}at^2$:

$$\begin{aligned}\max h &= u_y t_{\text{max}} - \frac{1}{2}gt_{\text{max}}^2 \\ &= 8.84 \times 0.9 - \frac{g}{2}0.9^2 \approx \boxed{3.98\,[\text{m}]}\end{aligned}$$

A1:P34 Question 24

Since there is 0 initial vertical velocity, the time to reach the net is (using $s = ut + \frac{1}{2}at^2$):

$$\begin{aligned}0.9 - 2.7 &= 0 - \frac{1}{2}gt_{\text{final}}^2 \\ \implies t_{\text{final}} &= \sqrt{\frac{2\times 1.8}{g}} \qquad \text{(Negative solution not possible)} \\ &\approx 0.605\,[\text{s}]\end{aligned}$$

Then to derive the initial horizontal velocity (with assumed 0 acceleration), we use $s = ut + \frac{1}{2}at^2$ again:

$$12 = u_x t_{\text{final}} + 0$$
$$\implies u_x \approx \frac{12}{0.605} \approx \boxed{19.8\,[\text{m}\,\text{s}^{-1}]}$$

A1:P34 Question 25

a) The initial vertical velocity $u\sin\theta$ is approximately $0.628\,[\text{m}\,\text{s}^{-1}]$. Then using $s = ut + \frac{1}{2}at^2$ and checking for approximate equality at $t = 0.3\,[\text{s}]$:

$$-0.25 \approx 0.628 \times 0.3 - \frac{1}{2}g(0.3)^2$$
$$-0.25 \approx -0.2535 \quad \checkmark$$

b) i) The initial horizontal velocity $u\cos\theta$ is approximately $8.98\,[\text{m}\,\text{s}^{-1}]$. Using $s = ut + \frac{1}{2}at^2$ with assumed 0 acceleration:

$$s \approx 8.98 \times 0.3 + 0 = \boxed{2.69\,[\text{m}]}$$

ii) Only the vertical velocity is changing (due to the assumed 0 horizontal acceleration). Therefore, using $v = u + at$:

$$v_{\text{final}} \approx 0.628 - 0.3g = -2.32\,[\mathrm{m\,s^{-1}}]$$

Then using Pythagoras theorem to calculate the total final velocity:

$$v = \sqrt{v_x^2 + v_y^2} = \sqrt{8.98^2 + (-2.32)^2} \approx \boxed{9.27\,[\mathrm{m\,s^{-1}}]}$$

c) i)

Note that graph question solutions are not yet done due to lack of time.

ii)

Note that graph question solutions are not yet done due to lack of time.

1.2 Subtopic A.2 – Forces and momentum

[a] $a^2 + b^2 = c^2$

2 Topic B – The particulate nature of matter

2.1 Subtopic B.1 – Thermal energy transfers