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Examiners' report

FURTHER MATHEMATICS A

H235
For first teaching in 2017

Y533/01 Summer 2019 series

Version 1

Contents

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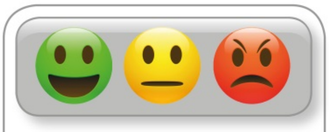

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Introduction

Our examiners' reports are produced to offer constructive feedback on candidates' performance in the examinations. They provide useful guidance for future candidates. The reports will include a general commentary on candidates' performance, identify technical aspects examined in the questions and highlight good performance and where performance could be improved. The reports will also explain aspects which caused difficulty and why the difficulties arose, whether through a lack of knowledge, poor examination technique, or any other identifiable and explainable reason.

Where overall performance on a question/question part was considered good, with no particular areas to highlight, these questions have not been included in the report. A full copy of the question paper can be downloaded from OCR.

Paper Y533 series overview

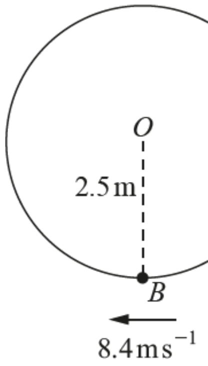
This is one of the optional modules in the new specification for AS Further Maths, alongside the compulsory Pure Core, and the other optional modules in Statistics, Discrete Mathematics and Additional Pure Mathematics. This component complements the Mechanics content of the AS Mathematics course and requires candidates to solve practical problems using a variety of techniques including energy, power, momentum, connected particles, horizontal circles and dimensional analysis. To do well on this paper, candidates needed to be able to work systematically and accurately with the standard principles of Mechanics. They often needed to make sense of more complex situations, for example, correctly combining several forces and/or types of energy in a variety of situations, such as two or more sources of gravitational potential and/or kinetic energy, and have some understanding of the purpose of mathematical modelling.

Candidates who did well on this paper generally did the following:	***Candidates who did less well on this paper generally:***
• Recognised the different sources of energy change relevant in a problem and combined them systematically. • Recognised the different forces that were acting and the correct direction. • Made good use of diagrams to help them understand the problem. • Were able to use Newton's Second Law ($F = ma$) confidently together with the relationship between Force and Power. • Were able to apply their knowledge to complex and unfamiliar problems such as working with an unknown coefficient of restitution. • Were efficient and effective in applying their knowledge, always choosing the simplest possible route to the solution.	• Did not know how to model an unfamiliar situation using familiar techniques, such as Q2 (a) where the particles are effectively combined after the "collision", or 6 (a) where there is an unknown rebound velocity. • Were not always able to use Newton's Second Law in the context of a fixed Power source present. • Did not recognise all the forces and/or energy sources present in a situation, especially in 2 (c) and 5 (d). • Made avoidable errors in calculations. • Used very laborious and inefficient methods, particularly for momentum problems, leading to errors in both method and application.

There was no evidence that any time constraints had led to a candidate underperforming and scripts where there was no response to the final question often had earlier sections of the paper which had not been tackled.

Question 1 (a)

1



A smooth wire is shaped into a circle of radius 2.5 m which is fixed in a vertical plane with its centre at a point O. A small bead B is threaded onto the wire. B is held with OB vertical and is then projected horizontally with an initial speed of 8.4 m s^{-1} (see diagram).

(a) Find the speed of B at the instant when OB makes an angle of 0.8 radians with the downward vertical through O. **[3]**

This question required candidates to relate gain in potential energy to loss of kinetic energy in a pendulum in order to calculate the final velocity.

This question was generally well received. Almost all candidates attempted this question, with most being successful and gaining full marks. Most candidates recognised the need to subtract the potential energy change from the initial kinetic energy to get the final kinetic energy. A small number equated the initial and final energies, which is a little more complicated and led to errors on occasion.

A significant minority of candidates chose not to work in radians, opting to convert to degrees rather than change the angle setting on their calculator. The extra complexity meant that in some cases an incorrect angle was used, often 0.8 × 180 = 144°.

As per the previous year, some thought that the height change was $r\cos\theta$ rather than $r(1 - \cos\theta)$; a very small number mistakenly thought that this was a conical pendulum and were therefore unable to gain any marks. A few tried to equate the gain in GPE with the final KE.

Question 1 (b)

(b) Determine whether B has sufficient energy to reach the point on the wire vertically above O. **[3]**

This question required candidates to determine whether or not the pendulum would be able to make a full vertical circle by considering whether or not the initial KE was as great as the GPE at the top.

This question was attempted very successfully by most candidates who realised that the energy available was insufficient. A variety of other methods were seen, such as finding the final angle and comparing to 2π or 180°, finding the maximum possible height gain and comparing to 5 m, or finding the velocity required to reach the top and comparing to 8.4 m/s. In all cases, the key to getting full marks was to present a correct and convincing argument to determine the result.

Some candidates were not sufficiently careful and made a wrong statement such as: "35.28 m > 49 m", without explaining that since this is false, the top is not reached. Others concluded that $v^2 = -27.44$ and then attempted to square root this. A small number of other mistakes were made such as using the radius rather than the diameter.

Question 2 (a)

2 A particle A of mass 3.6 kg is attached by a light inextensible string to a particle B of mass 2.4 kg.

A and B are initially at rest, with the string slack, on a smooth horizontal surface. A is projected directly away from B with a speed of $7.2\,\mathrm{m\,s^{-1}}$.

(a) Calculate the speed of A after the string becomes taut. **[3]**

This question required candidates to recognise the use of conservation of momentum where the two objects were tethered rather than colliding directly.

Almost all candidates attempted this question and the clear majority were successful. However, some did not realise that tethering meant that the final velocities were the same and therefore a second equation for restitution (or possibly energy) was not required. As a result, most candidates either scored 1 mark or full marks on this question. Some candidates made careless errors such as assigning the initial velocity to object B rather than object A.

In order to get around the difficulty of not having a second equation for restitution, candidates employed a variety of strategies. Some assumed, contrary to the question, that the initial velocities were both zero and that 7.2 was the final velocity of one or other of the objects, using this to calculate the other velocity. Another popular option was to attempt to formulate an equation using kinetic energy, often with both final velocities equal or using an assumed value.

Question 2 (b)

(b) Find the impulse exerted on A at the instant that the string becomes taut. **[2]**

This question required candidates to use the equation $I = mv - mu$ to find the impulse acting on *A*. It was only available to those that had already attempted some kind of momentum equation in part (a) and obtained a definite result from it.

Most candidates who attempted this question scored at least one mark. For full marks, the correct use of the formula and/or recognition of the vector nature of impulse was required, usually seen as a negative value (but dependent on how they framed the initial velocity of *A*) or described as being in the opposite direction to *A* or such like. A significant proportion of candidates did not meet this requirement and therefore lost the accuracy mark at the end.

Question 2 (c)

(c) Find the loss in kinetic energy as a result of the string becoming taut. **[2]**

To be successful at this question, candidates needed to have used a momentum equation in part (a) and to compare the kinetic energy of the system before and after the "collision". This involved finding the kinetic energy of *A* before the change of motion, and the energy of both *A* and *B* afterwards. Having just calculated the change in momentum of *A* in part (b), many candidates went on to calculate the energy change of *A* rather than the energy change of the system and gained 0 marks.

Question 3 (a)

3 A car of mass 1500 kg has an engine with maximum power 60 kW. When the car is travelling at $10\,\text{m s}^{-1}$ along a straight horizontal road using maximum power, its acceleration is $3.3\,\text{m s}^{-2}$.

In an initial model of the motion of the car it is assumed that the resistance to motion is constant.

(a) Using this initial model, find the greatest possible steady speed of the car along the road. **[4]**

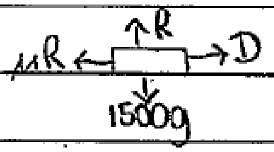
This question required candidates to use the relationship between Power, Force and Velocity in the context of Newton's Second Law in order to find the frictional force on a moving object, and then to find the terminal velocity.

Most candidates were able to solve this problem successfully using standard techniques. Owing to the nature of the numbers, very few arithmetical errors were made and nearly all candidates scored full marks or no marks.

A very small number of candidates managed to find the friction but were unable to reformulate the problem to find the correct terminal velocity.

Of those that attempted the question but did not score any marks, some simply did not know how to formulate the problem, but more commonly, the mass × acceleration (= 4950) was taken to be the (frictional) force and used to find the terminal velocity.

Exemplar 1



$P = Fv \qquad F = ma$

Resultant Driving Force $= 1500 \times 3.3$
$= 4950$ N

$\cancel{\Rightarrow v = \frac{P}{F} = \frac{60\times10^3}{4950}} =$

Total Driving Force $= \frac{60\times10^3}{10} = 6000$ N

$\Rightarrow$ resistance to motion $= 1050$ N

$v = \frac{P}{F} = \frac{60\times10^3}{4950} = 12.1\,\text{ms}^{-1}$ (3sf) = greatest steady speed

Here the candidate has correctly found the resistance of 1050 N. Unfortunately, they have then gone on to use the resultant force of 4950 N instead of the resistance to find the terminal velocity, losing the final 2 marks.

Question 3 (b)

In a refined model the resistance to motion is assumed to be proportional to the speed of the car.

(b) Using this refined model, find the greatest possible steady speed of the car along the road. **[5]**

This question is very similar to part (a) but requires a slightly more complicated equation since the friction is now given by $R = kv$ rather than having a fixed value. Other than that, the principles are the same as for part (a).

Due to the extra complexity, candidates were somewhat less successful at this question overall. Again, most scored full marks or no marks, but the numbers gaining zero marks was much closer to the number gaining full marks.

Question 3 (c)

The greatest possible steady speed of the car on the road is measured and found to be $21.6\,\mathrm{m\,s^{-1}}$.

(c) Explain what this value means about the models used in parts **(a)** and **(b)**. **[2]**

In this question, candidates were required to make two meaningful statements about the models, ideally comparing the terminal velocity predicted by each model with the actual terminal velocity given in the question, and evaluating the appropriateness of each model.

Most candidates were not able to interpret the results effectively, often showing that they did not grasp the nature and purpose of a mechanical model. Candidates should understand that a model is necessarily an approximation to real life, and by its nature is not expected to be completely accurate.

What we are looking for here, is whether or not the model gives a good approximation or a good fit to the friction in real life, by comparing the terminal velocity predicted by each model with the actual terminal velocity. Therefore, comments such as "(a) (or (b)) is not accurate" did not earn any marks, as they do not say anything meaningful. Statements to the effect that one or other model is correct were also not appropriate, since a model is only an approximation and does not take account of every factor.

To gain marks, candidates needed to note that (a) is a very poor model for the friction as the predicted speed was very inaccurate, and that (b) is a good model as the predicted speed is quite close to the actual figure. Other comments, such as those comparing the two models with each other required awareness that the model in (b) is much better than (a), and rather than just "better", ideally with some justification.

Candidates should also be aware that marks are only available for using the information from the question itself and for statements that are directly relevant to the modelling assumptions being made. Therefore, any comments relying on prior knowledge, such as that air resistance tends to increase with speed or is proportional to the square of the speed, or about the efficiency of the engine, etc., do not gain any credit.

Question 4 (a)

4 A student is studying the speed of sound, u, in a gas under different conditions.

He assumes that u depends on the pressure, p, of the gas, the density, ρ, of the gas and the wavelength, λ, of the sound in the relationship $u = kp^{\alpha}\rho^{\beta}\lambda^{\gamma}$, where k is a dimensionless constant. (The wavelength of a sound is the distance between successive peaks in the sound wave.)

(a) Use the fact that density is mass per unit volume to find $[\rho]$. **[1]**

This question required candidates to use the relevant standard dimensional units, i.e. M, L and T, to express the units of density.

The vast majority of candidates gained this mark. A few errors and misconceptions were seen, primarily through the use of non-standard units such as *m*, *kg* and *s* instead of the correct ones. This was only penalised once throughout the question.

Question 4 (b)

(b) Given that the units of p are $\mathrm{N\,m^{-2}}$, determine the values of α, β and γ. **[7]**

This question required candidates to use the method of dimensional analysis to determine the values of the exponents of a formula.

Despite being considerably more challenging than last year's question on the same topic, candidates were much better prepared for this question and about half gained full marks, with most of the rest gaining at least half marks.

The first mark was given for finding an expression for the pressure. Most were able to do this successfully, but a significant minority produced the wrong expression, often because they confused the common units with the standard notation. In particular, there were many instances where Force was correctly quoted as $\mathrm{MLT^{-2}}$ but then the area was mistakenly written as $\mathrm{M^2}$ (from m^2) rather than $\mathrm{L^2}$, giving $(\mathrm{MLT^{-2}})\div(\mathrm{M^2}) = \mathrm{M^{-1}LT^{-2}}$ for the pressure instead of $\mathrm{ML^{-1}T^{-2}}$.

The second mark was for the dimensional equation. Some candidates did not realise that they needed to explicitly substitute their expressions for p, ρ and λ into the given equation $u = kp^{\alpha}\rho^{\beta}\lambda^{\gamma}$, even though the question asks them to determine the values of the exponents.

Similarly, a very small number of candidates did not produce the required equations for each of the dimensions to determine the values of α, β and γ and as a result were not able to gain any credit for their answers.

Question 4 (c)

(c) Comment on what the value of γ means about how fast sounds of different wavelengths travel through the gas. **[1]**

This was another question requiring interpretation of the values found in a previous part of a question, in this case using the candidate's value of γ to determine the effect of wavelength on the speed of the wave.

Most candidates correctly interpreted their values. Some made statements that were incorrect or too vague to gain any credit, e.g. (for $\gamma = 3$): "the wavelength … makes a considerable difference to the speed if it is changed", without saying what kind of difference it would make. Others used inappropriate terms such as distance instead of wavelength, or talked about the value of γ instead of λ, which again did not gain any credit.

Question 4 (d)

The student carries out two experiments, A and B, to measure u. Only the density of the gas varies between the experiments, all other conditions being unchanged. He finds that the value of u in experiment B is double the value in experiment A.

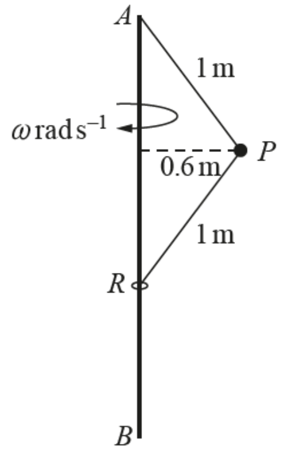
(d) By what factor has the density of the gas in experiment A been multiplied to give the density of the gas in experiment B? **[2]**

In this question, candidates were required to use their value of β to quantify the change in density required to make the wave travel at twice the original speed.

Most candidates attempted this question and some were successful. Whilst most showed some awareness of the formula by substituting their value of β, not all were able to use the mathematical concept of proportionality. In this case, $v \propto \frac{1}{\sqrt{\rho}}$, meaning that $\rho \propto \frac{1}{v^2}$. This gave an answer of ¼, assuming that β was correct.

Question 5 (a)

5



As shown in the diagram, AB is a long thin rod which is fixed vertically with A above B. One end of a light inextensible string of length 1 m is attached to A and the other end is attached to a particle P of mass m_1 kg. One end of another light inextensible string of length 1 m is also attached to P. Its other end is attached to a small smooth ring R, of mass m_2 kg, which is free to move on AB.

Initially, P moves in a horizontal circle of radius 0.6 m with constant angular velocity ω rad s^{-1}. The magnitude of the tension in string AP is denoted by T_1 N while that in string PR is denoted by T_2 N.

(a) By considering forces on R, express T_2 in terms of m_2. **[2]**

In this question, candidates had to use the principles of horizontal circular motion to determine the forces acting on two strings and the rotational speed of *P*, together with the kinetic and potential energy changes as *P* comes to rest.

Like the corresponding question on last year's paper, this question was generally found to be very challenging and few did well after part (b). The key steps in any horizontal circle problem are to establish an equilibrium equation(s) in the vertical direction and an equation for the centripetal acceleration in the horizontal direction, in either order as appropriate to the question.

The first part involves resolving vertically for object *R* to find T_2 by first finding the cosine of the angle *RAP* (or the sine of the angle between *AP* and the horizontal), preferably using Pythagoras' theorem to get the correct exact value.

Most candidates attempted to do this. Some candidates attempted to resolve in the direction *AP* or confused the sine and the cosine. Others used trigonometry to find θ and then cosθ, which was condoned as long as a value of exactly 0.8 was stated later on.

A significant number of candidates did not simplify their answer adequately, leaving it as $\frac{m_2 g}{0{,}8}$ or $\frac{m_2 g}{\sin 53.13}$ for example and therefore did not gain the second mark. Candidates are reminded that final answers should be put in fully simplified form and given to 3 significant figures unless stated otherwise. In this case we allowed the use of *g*, but the coefficient needed to be correct to at least 3 significant figures.

Question 5 (b) (i)

(b) Show that

(i) $T_1 = \frac{49}{4}(m_1 + m_2)$, **[2]**

This question again involved resolving vertically, this time on object *P* to find T_1 in terms of m_1 and T_2, having previously found T_2.

Most candidates found the given answer helpful and were able to find it correctly. Some astutely noticed that they could work with the system as a whole and equate the vertical component of T_1 to the combined weight of objects *P* and *R*, removing the need to resolve T_2.

As with all questions with a given answer, it is essential for candidates to show adequate working to justify the answer. Whilst most did this, a small number did not do so and lost the second mark. Similarly, a few candidates did not maintain sufficient accuracy (e.g. using sin(53.13°)) to justify full marks, whilst some had their vertical components of T_1 and T_2 going in the same direction.

Question 5 (b) (ii)

(ii) $\omega^2 = \dfrac{49(m_1 + 2m_2)}{4m_1}$. **[3]**

In this question candidates needed to resolve T_1 and T_2 horizontally to find an expression for the centripetal acceleration and hence find an expression for ω^2.

This question proved to be significantly more challenging than 5(b)(i), with nearly a quarter of candidates not attempting the question and about the same number gaining no marks. Of those who made significant progress, most scored full marks and a few scored 1 or 2 marks.

Common problems included resolving in the wrong direction, only counting one of the forces (usually T_1), not including adequate working for a given answer, lack of accuracy, and using the wrong formula for centripetal acceleration. As always, there were attempts to work backwards from the given answer, which were not successful unless the candidate determined what was incorrect in the first place.

Exemplar 2

$a = r\omega^2 \qquad F = ma$

$T\sin\theta = mr\omega^2$

$T_1 \sin 0.644 = mr\omega^2$

$\frac{49}{4}(m_1 + 2m_2) \times \sin 0.644 = mr\omega^2$

$\frac{49}{4}(m_1 + 2m_2) \times 0.6 = m_1 \times 0.6 \times \omega^2$

$\frac{49}{4}(m_1 + 2m_2) = m_1 \times \omega^2$

$\therefore \omega^2 = \dfrac{49(m_1 + 2m_2)}{4m_1}$

In this response, the candidate has only resolved T_1 in the horizontal direction, losing the first M mark, and has used a non-exact value for sinθ, which has been recovered later. The second M mark is not accessible since they are unable to substitute for T_2 as required in the mark scheme. Having arrived at their final response and found it to be wrong, they have then squeezed a coefficient of 2 in front of all the instances of m_2 without realising that this extra m_2 must have come from somewhere, namely the missing T_2 in the original equation.

Question 5 (c)

(c) Deduce that, in the case where m_1 is much bigger than m_2, $\omega \approx 3.5$. **[2]**

This question required candidates to use the concept of limits to justify the exclusion of m_2 from the calculation of ω, given that m_1 is much bigger than m_2.

Very few candidates were able to justify this correctly using the fact that the ratio $\frac{m_2}{m_1}$ (or appropriate multiple of this) becomes very small or negligible as m_1 becomes comparatively large. Some argued that $m_1 + 2m_2 \approx m_1$ if $m_1 >> m_2$, which we reluctantly allowed if no wrong statement was made alongside it.

Most simply ignored m_2 or wrongly set it equal to zero, and so scored no marks. Some made statements about m_2 being negligible (by comparison to m_1) or used suitable trial values which gave $\omega = 3.5$ to 1d.p. We allowed SC1 for both of these as partially correct reasoning as long as there was no hint of m_2 being equal to zero in the first case, or m_1 was sufficiently large by comparison with m_2 in the second case.

Despite the above, this was still the least well done of all the questions on the paper. Candidates are encouraged to familiarise themselves with finding limiting values in order to tackle similar problems in the future.

Question 5 (d)

In a different case, where $m_1 = 2.5$ and $m_2 = 2.8$, P slows down. Eventually the system comes to rest with P and R hanging in equilibrium.

(d) Find the total energy lost by P and R as the angular velocity of P changes from the initial value of $\omega\,\mathrm{rad\,s^{-1}}$ to zero. **[5]**

This question required candidates to use the result in part 5(b)(ii) to find ω and hence the kinetic energy in P, together with the change in potential energy of the system as P comes to rest.

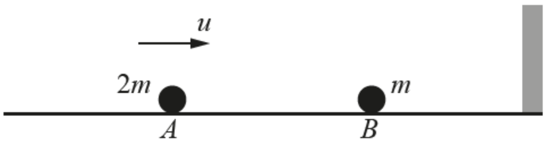
A large number of candidates did not respond to this question. Most candidates who did attempt the question started by trying to find ω and then the kinetic energy, but did not always know how to find the speed and/or the kinetic energy correctly.

Very few candidates realised that the objects would drop in height as the strings moved to a vertical direction, causing a change in potential energy for P and R. This is hinted at in the question since it asks for the total energy lost, not just the kinetic energy. Of those that did, some were able to find the correct vertical distances moved and therefore find the correct change in potential energy.

A small but significant number of candidates substituted $m_1 + m_2$ instead of $m_1 + 2m_2$ into the formula for ω^2. Some also made errors such as using ω instead of v, or giving both P and R the same speed when finding the kinetic energy.

Question 6 (a)

6 Particles A of mass $2m$ and B of mass m are on a smooth horizontal floor. A is moving with speed u directly towards a vertical wall, and B is at rest between A and the wall (see diagram).



A collides directly with B. The coefficient of restitution in this collision is $\frac{1}{2}$.

B then collides with the wall, rebounds, and collides with A for a second time.

(a) Show that the speed of B after its second collision with A is $\frac{1}{2}u$. **[6]**

This question required candidates to solve a three-way collision by considering each collision in turn, with the second collision between object *B* and the wall having an unknown coefficient of restitution.

Almost all candidates were able to access the start of this question and make some progress. The first part was a standard collision with restitution problem and most candidates were able to set up at least one or both of the required equations. In a small number of cases, candidates were not able to set up the correct equations and did not gain any marks.

Some candidates used relatively poor algebraic manipulation which increased the likelihood of making mistakes or not being able to find the speeds after the first collision. In most cases, rearranging the restitution equation and eliminating one variable between this and the momentum equation is the simplest method. Otherwise, substitution for V_A or V_B in the momentum equation will be an efficient technique. Some candidates assumed that the velocities after collision were in different directions, whilst others chose to rearrange the momentum equation for V_1 and then substitute for this in the restitution equation, for example, which could lead to difficulties.

The absence of any given coefficient of restitution between object *B* and the wall confused many candidates who wrongly assumed that it must again be ½, or possibly 1. A small number multiplied V_B (= *u*) by an unknown *e* to give a velocity of -*eu* and a very few candidates simply left it as an unknown, which subsequently cancelled out between the equations to give the required speed of *A*.

For those who used an assumed a value for the speed of *B*, this also led to the correct answer if otherwise worked correctly, and we gave this SC1 as a result, provided the velocity of *B* was feasible.

Question 6 (b)

The first collision between A and B occurs at a distance d from the wall. The second collision between A and B occurs at a distance $\frac{1}{5}d$ from the wall.

(b) Find the coefficient of restitution for the collision between B and the wall. **[5]**

This question required candidates to use information about the motion of *A* and *B* between their first and second collisions to determine the value of the coefficient of restitution between *B* and the wall.

For this, candidates needed to find the speed of *B* (= *u*) and set the rebound speed to *eu*. They then had to equate the times taken by *A* and *B* using the standard relationship between distance, speed and time, from which they could form an equation for *e* in terms of *d* and *u*, both of which cancel out later.

Few candidates were able to solve this problem, but since many had already found V_B = u and some had suggested a rebound speed of *eu* in part (a), we gave these marks if already seen in (a) but not used in part (b). Of those who did set up the problem correctly, almost all then found the correct value of *e*.

Some candidates showed considerable ingenuity in recognising that they could just use the distances travelled by *A* and *B* after the collision with the wall ($= \frac{3d}{5}$ and $\frac{2d}{5}$ respectively) to show that the speed of *B* was $\frac{2}{3}$ of the speed of *A* and thus find the value of *e* relatively easily.

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