Data-Based Questions

In Support of Practices of Science

Science is more than just acquiring knowledge. It includes understanding the nature of Science, and how it is generated, established, and communicated. DBQs typically show varied types of data presentation and is an opportunity for students to demonstrate their ability to digest data, to apply knowledge in the real-world context, and to recognise technological limitations/trade-offs in each situation.

Assessment Style

DBQs will appear at the end of Paper 2. The context is likely novel and may involve concepts from beyond the syllabus. There will be sufficient contextual information provided. The DBQ(s) will constitute 20 – 25 marks (out of the total 80 marks in Paper 2). Therefore, we should reserve the last 30 minutes for tackling DBQs.

<table>
<tr><th>Paper</th><th>Type of Paper</th><th>Duration</th><th colspan="2">Weighting (%)</th><th colspan="2">Marks</th></tr>
<tr><td>1</td><td>Multiple Choice</td><td>1 h</td><td colspan="2">15</td><td></td><td>30</td></tr>
<tr><td rowspan="2">2</td><td rowspan="2">Structured Questions
- Data-Based Question(s)</td><td>1 h 30 min</td><td>23</td><td rowspan="2">30</td><td>60</td><td rowspan="2">80</td></tr>
<tr><td>30 min</td><td>7</td><td>20</td></tr>
<tr><td>3</td><td>Longer Structured Questions</td><td>2h</td><td colspan="2">35</td><td></td><td>80</td></tr>
<tr><td rowspan="2">4</td><td rowspan="2">Practical
- Planning Question</td><td>2h</td><td>16</td><td rowspan="2">20</td><td>44</td><td rowspan="2">55</td></tr>
<tr><td>30 min</td><td>4</td><td>11</td></tr>
</table>

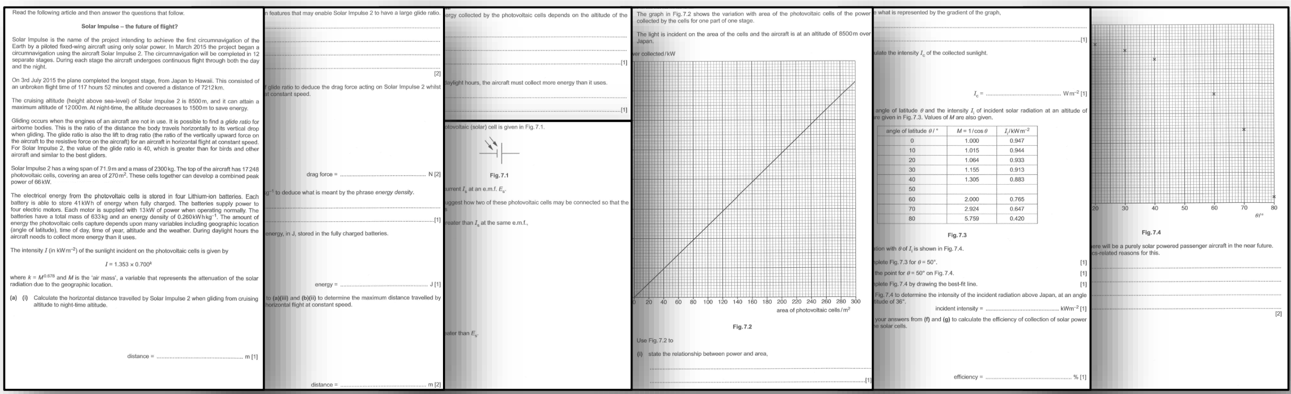
What to expect for a DBQ

We should expect the unexpected. Cliches aside, note that the following is non-exhaustive:

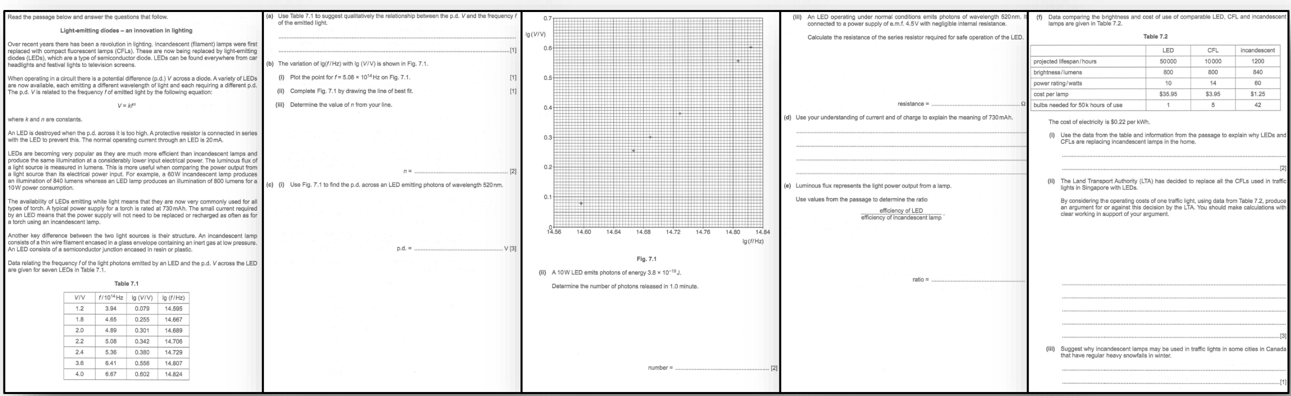
Possible Types of Data	Skillset Needed
• Knowledge from within syllabus • Paragraphs and prose • Novel equations • Tables • Graphs • Statistics	• Linearisation of equations • Selection and/or justifying choice of graph axes • Calculation of constants • Verification of validity for proposed relationships • Graph-drawing • Figure / Diagram sketching • Extracting and using relevant info • Interpreting of meaning behind equations and/or quantities in an equation • Weighing pros and cons

Also, expect lengthy questions. We provide a few past-year DBQs to illustrate:

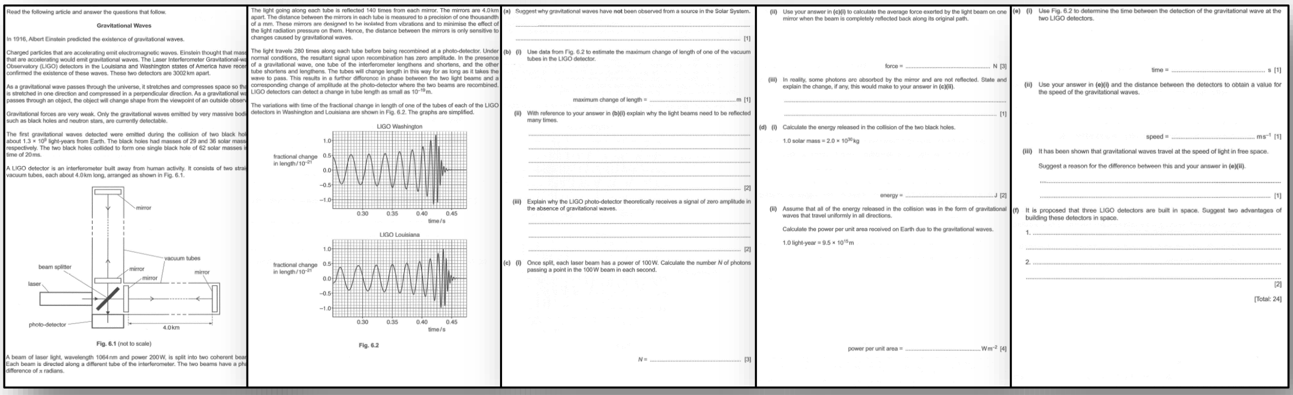
SG 2017: Solar-powered Aircraft (23 marks across 7 pages)



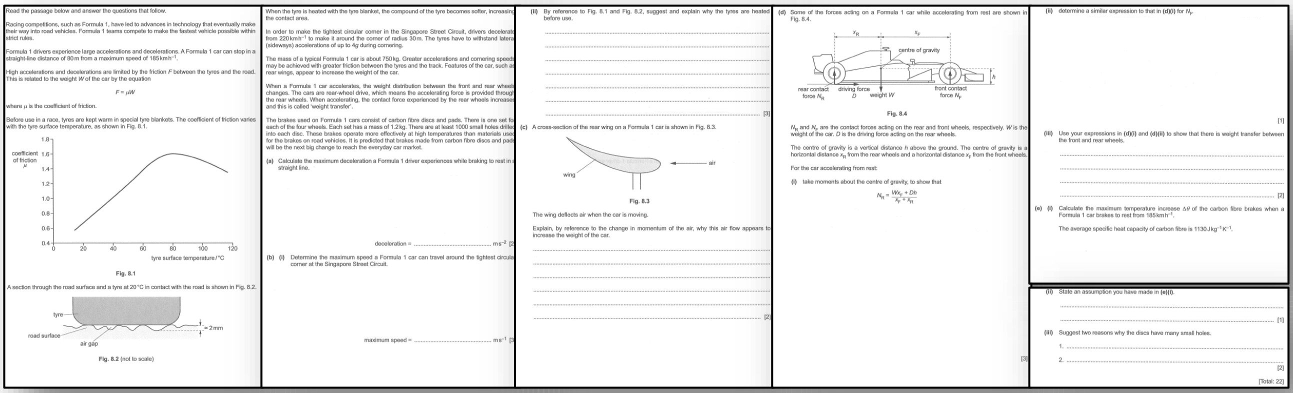
SG 2018: LEDs (22 marks across 5 pages)



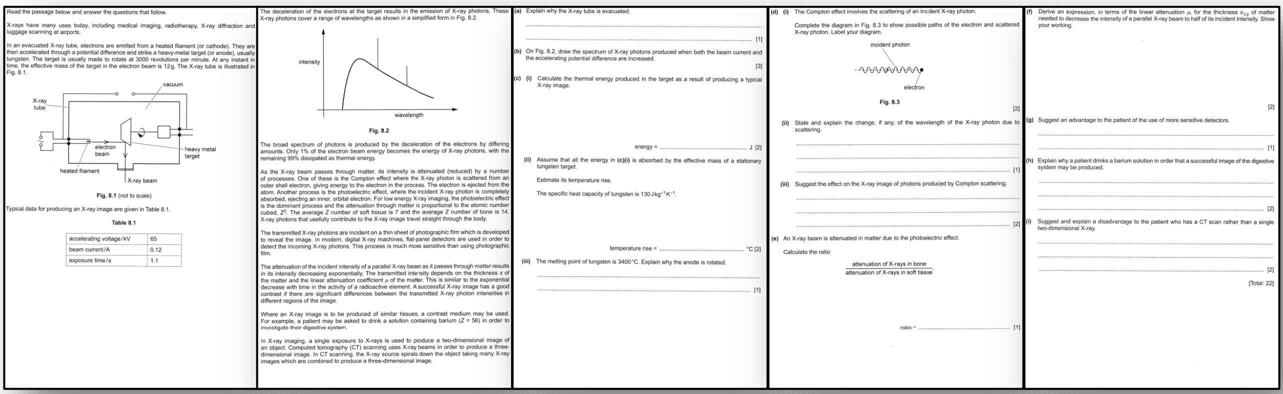
SG 2019: Gravitational Waves (24 marks across 5 pages)



SG 2020: F1 Tyres (24 marks across 6 pages)



SG 2021: X-rays (22 marks across 5 pages)



To get ourselves familiar with DBQs, we will go through a few lecture examples. We will be deliberately explicit in highlighting the type of skills being examined when developing our answers.

We will not be going through the questions in full. Instead we selected a few interesting interesting examples that show varied types of data.

Lecture Example 1: Analysis of braking of a vehicle

Skills

Modern vehicles are provided with different types of brakes. In cars, the foot brake is the most important with respect of control and safety of a vehicle while the hand brake is used as a reserve brake.

Extract info

Brake 1: foot
Brake 2: hand

One of the principal braking parameters of a vehicle is the deceleration *a*. This criterion should satisfy the following condition

$$a \geq [\,0.10 + 0.85\,(\varphi\ -\ 0.20)]\,g$$

constant × *g*

where φ is the coefficient of cohesion and *g* is the acceleration due to gravity.

The values of the deceleration of braking calculated according to the formula depend on the physical features of the wheel and road friction.

factors: wheel (tyres) and road condition

In reference books for experts' examination of traffic accidents as well as in scientific references on dynamics of vehicles, the provided value of coefficient of cohesion of tyres with dry asphalt is φ = 0.80. The value of the coefficient of cohesion equal to 0.80 may be applicable only to old cars and tyres produced about the year 1980. For the present-day cars, the maximum coefficient of cohesion φ is between 1.00 to 1.20, if braking takes place on dry asphalt.

typical values of φ

The anti-lock brake system (ABS) is required to ensure distribution of braking forces between the wheels to prevent the wheels from locking and therefore causing the car to skid. The majority of modern vehicles are equipped with ABS, and their real braking distance is close to the theoretically calculated one based on the maximum values of the coefficient of cohesion. So, the deceleration of such vehicles may be close to $g = 9.81\ \text{m s}^{-2}$. For vehicles without ABS, the deceleration will be smaller.

ABS prevents skidding

deceleration close to *g*

(a) (i) Calculate the minimum deceleration of present-day cars with ABS while braking on dry asphalt. [1]

apply novel equation

$$a_x = [0.1 + 0.85(1.0 - 0.2)]g = 7.65\text{m s}^{-2}$$

(ii) Assuming a car experiences constant deceleration during braking, calculate the maximum braking distance for a present-day car travelling at 50 km/h. [2]

use existing knowledge (kinematics)

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

$$0 = \left(\frac{50 \times 10^3}{3600}\right)^2 + 2(-7.65)s$$

$$s = 12.6\text{ m}$$

(iii) State and explain whether the braking distance of a vehicle will change while braking on wet asphalt. [1]

deduce logically

minimum deceleration decrease as friction reduced between tyre and wet surface
braking distance will increase

(iv) Suggest two disadvantages of modern vehicles that have very large deceleration when braking if travelling on an expressway. [2]

deduce logically

1. driver/passenger may experience discomfort (carsick) travelling in vehicle
2. tailgating (less modern) vehicles may not brake in time and collide
3. tyres wear out sooner

(b) A car has two important braking devices and they function independently. The foot brake is operated by foot and the hand brake is operated by hand.

When a car has a brake test, two sets of measurements are made:

1. maximum braking force on wheels produced by operating the foot brake.
2. maximum braking force produced by operating the hand brake.

Typical data for a car of mass 900 kg are as follows.

description	maximum braking force / N
foot brake	6700
hand brake	2000

In order to determine if the brakes are satisfactory, the data are applied to a chart (called a nomogram) like the one shown in Fig. 1.1. This chart has three vertical lines marked with scales.

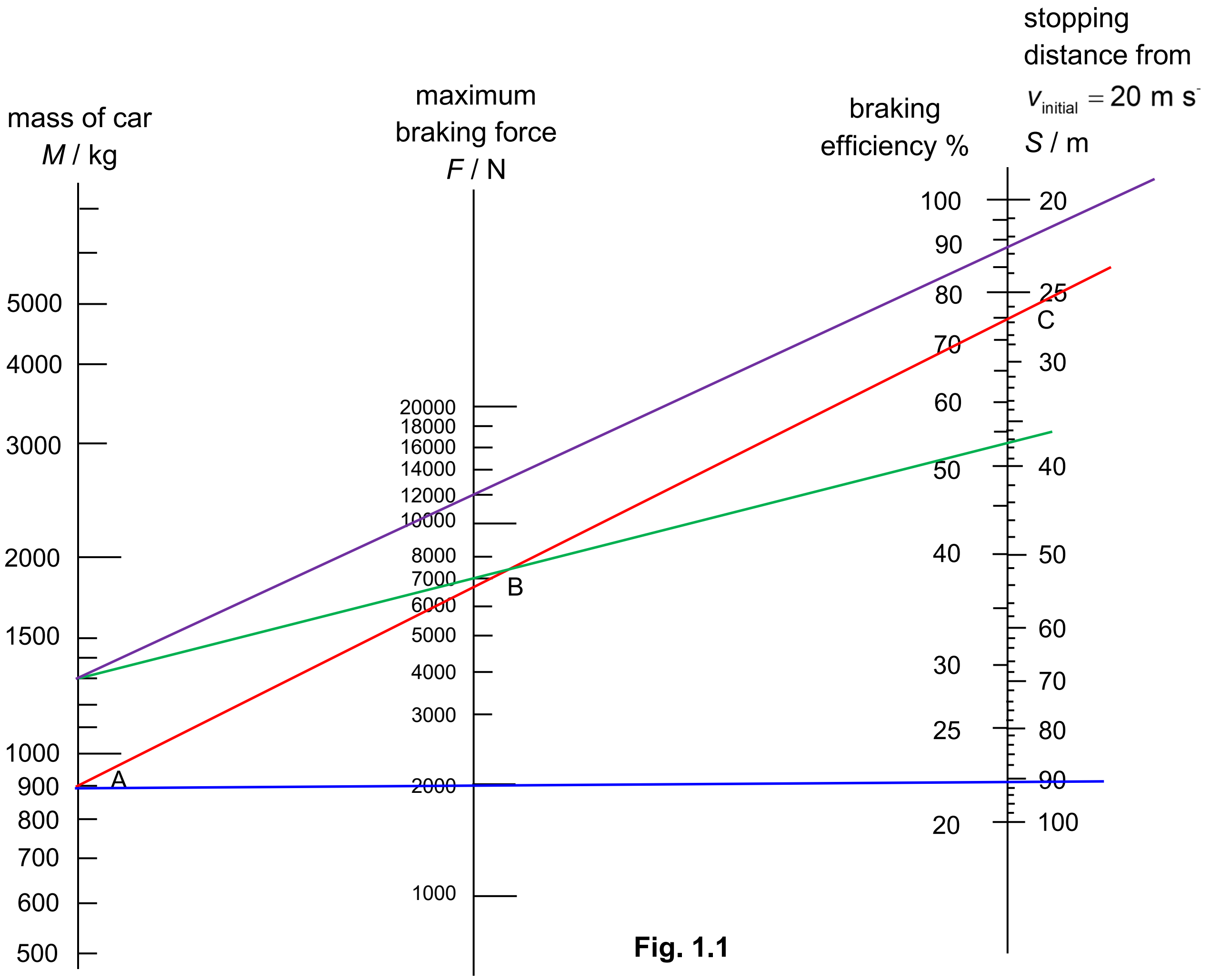


Fig. 1.1

The central vertical line is for the maximum braking force. The left line is for the mass of the car. The right line is for the braking efficiency and the stopping distance from an initial speed of 20 m s^{-1} . The braking efficiency E is defined by the equation

$$E = \frac{\text{deceleration of car}}{\text{acceleration of free fall}} \times 100$$

As an example of the use of this chart for the car of mass 900 kg, the figures in the table show a maximum braking force for the foot brake of 6700 N. The point A corresponding to the mass and the point B corresponding to the braking force are joined to give a straight sloping line. This line is extended to cut the braking efficiency scale at the point C, and shows that in this particular case, the stopping distance S from a speed of 20 m s^{-1} is about 27 m.

deduce that each straight line represents a particular car of a particular mass with a particular braking force

and how the braking performance will turn out as a result

(i) On Fig. 1.1, draw a line to represent results of the hand brake test on the car of mass 900 kg.

(ii) From Fig. 1.1, determine the braking efficiency corresponding to hand brake test. [1]

22.5%

(iii) Calculate the deceleration corresponding to this value of braking efficiency. [1]

do not use $a = \frac{F}{m} = \frac{2000}{900}$ $= 2.22 \text{ m s}^{-2}$ though it gives same answer to 2 s.f. Qns stated to work with efficiency.

$$E = \frac{\text{deceleration of car}}{\text{acceleration of free fall}} \times 100$$

$$22.5 = \frac{\text{deceleration of car}}{9.81} \times 100$$

$$\text{deceleration} = 2.21 \text{ m s}^{-2}$$

(iv) Show that the deceleration is approximately $g = 9.7 \text{ m s}^{-2}$ when both foot brake and hand brake are applied to stop a 900 kg car of speed of 20 m s^{-1}. [1]

use existing knowledge (forces)

$$F_{\text{foot}} + F_{\text{hand}} = ma$$

$$6700 + 2000 = 900a$$

$$a = 9.67 \text{ m s}^{-2}$$

$$\simeq 9.7 \text{ m s}^{-2} \ (2 \text{ s.f.})$$

(v) Suggest why it is not advisable to use the braking technique in (b)(iv). [1]

deduce logically

1. driver should have both hands on steering wheel
   not release hand to use handbrake
2. car may lock up and skid; not designed for using both foot brake and hand brake at the same time / ABS does not apply to hand brake

(c) Now consider a car of mass 1300 kg. The data for maximum braking force and stopping distance from 20 m s^{-1} are given in Fig. 1.2.

F / N	s / m
3000	88.0
4000	66.0
5000	54.0
6000	45.0
7000	37.5
8000	32.5
10000	27.0
12000	23.0

Fig. 1.2

(i) Use Fig. 1.1 to determine the stopping distance when F = 7000 N. Show your construction. [1]

37.5 m (± 1 m)

(ii) On Fig. 1.3, plot the point corresponding to F = 7000 N and draw the line of best fit. [1]

graph work. also reminder to bring full geometry set for all Physics exams

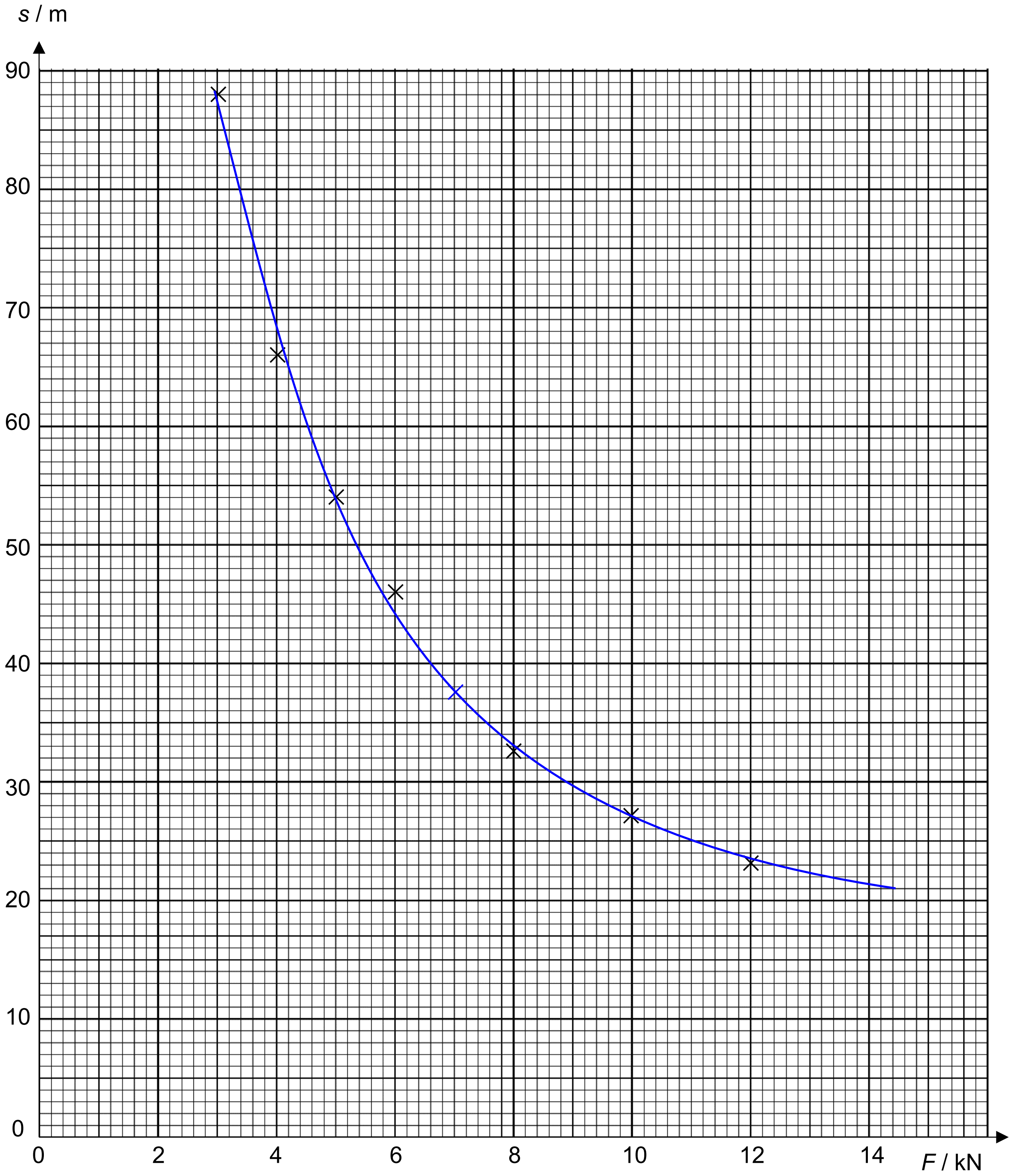


Fig. 1.3

(iii) Use Fig. 1.3 to determine the work done when the maximum braking force is 9000 N. State any assumptions made in your calculations. [2]

graph work: read points accurate to half smallest square

assume constant braking force throughout deceleration

$$\text{work done} = Fs = (9000)(29.5) = 2.66 \times 10^5 \text{ J}$$

(d) (i) A passenger of mass 70 kg was not wearing a seat belt and was sleeping at the front seat of a car. The car of mass 1300 kg was travelling at 20 m s^{-1} when a maximum braking force of 12000 N was applied on it.

Extract info

Using Fig. 1.1 and the equation for braking efficiency, determine the minimum force that the passenger would have to apply to prevent himself from flying off the seat.

Show your working clearly.

also, the last parts are each question are usually more demanding in order to differentiate exam candidates further

car of mass 1300 kg, braking force of 12 000 N, efficiency is 87.5%

$$E = \frac{\text{deceleration of car}}{\text{acceleration of free fall}} \times 100$$

$$87.5 = \frac{\text{deceleration of car}}{9.81} \times 100$$

$$\text{deceleration} = 8.58 \text{ m s}^{-2}$$

$$F_{\text{on passenger}} = m_{\text{passenger}} a_{\text{car}} = (70)(8.58) = 601 \text{ N}$$

(ii) Suggest whether the passenger would be able to prevent himself from flying off the seat. [1]

$$v = u + at$$

$$0 = 20 + (-8.58)t$$

$$t = 2.33 \text{ s}$$

unlikely; passenger only has about 2 seconds to react from sleeping condition to exerting a force that is nearly his whole body weight

Lecture Example 2: Blackbody Radiation

Skills

An object that is at a higher temperature than its surroundings loses thermal energy by emitting electromagnetic radiation. For loss of thermal energy as electromagnetic radiation, the intensity I_λ of the emitted radiation of wavelength λ varies with wavelength λ. Fig. 2.1 shows the variation of I_λ with λ for the body when it is at 1000 K. The distribution of intensity is different at different temperatures, as shown in Fig. 2.2

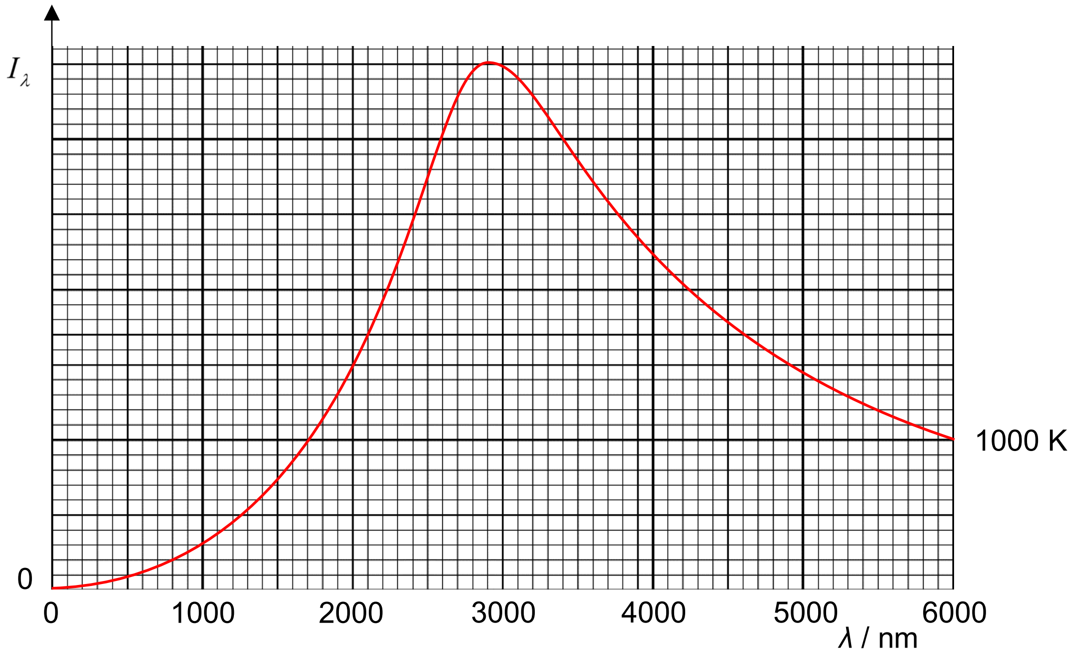

I_λ
0
0
1000
2000
3000
4000
5000
6000
λ / nm
1000 K

Fig. 2.1

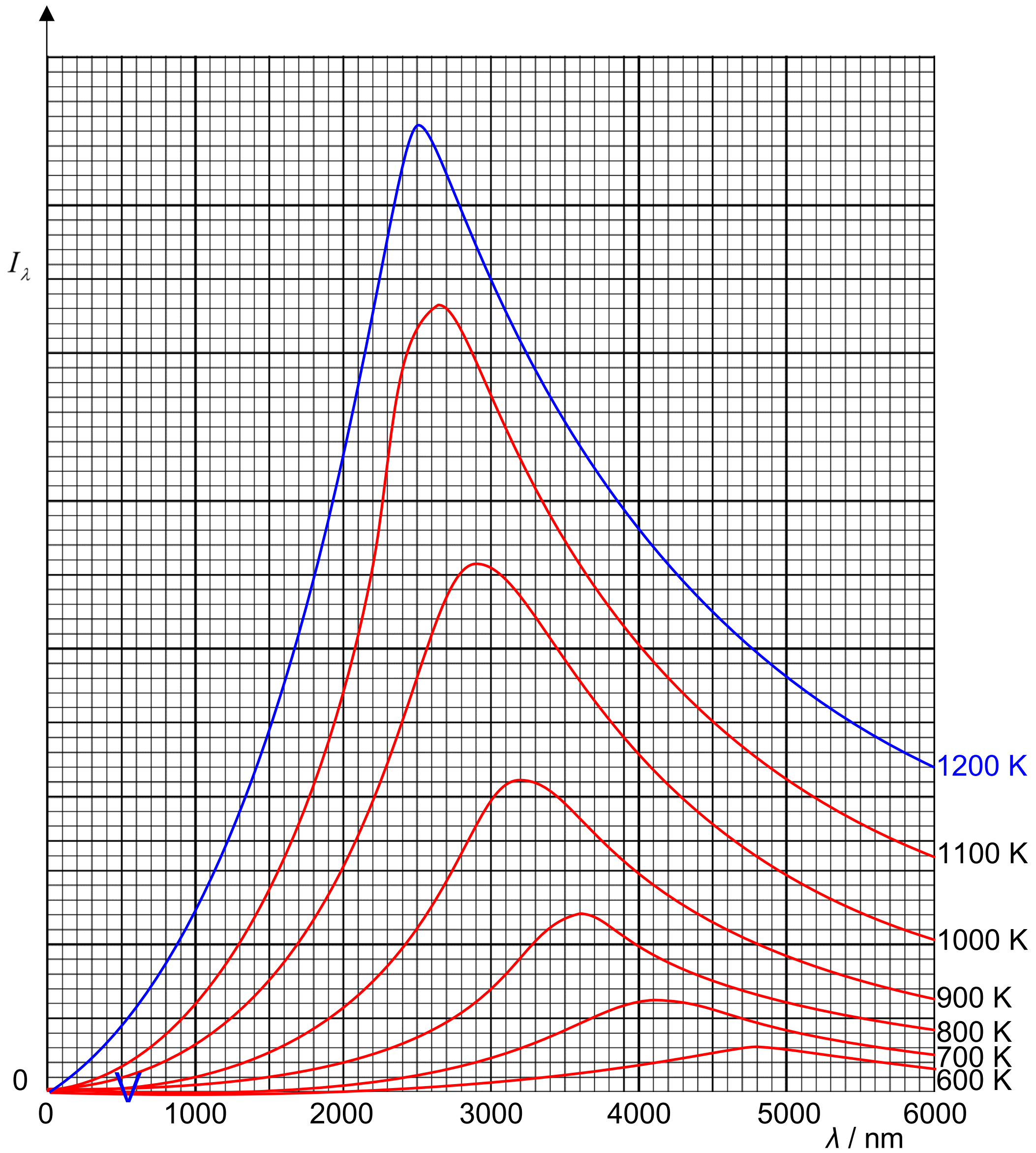

I_λ
0
0
1000
2000
3000
4000
5000
6000
λ / nm
1200 K
1100 K
1000 K
900 K
800 K
700 K
600 K

Fig. 2.2

(a) **(i)** On the horizontal axis of Fig. 2.2, indicate with the letter V a wavelength that is in the visible region of the electromagnetic spectrum. [1]

use existing knowledge (waves)

somewhere between 400 nm – 700 nm

(ii) Hence suggest why, at a temperature of 1100 K, the object would glow with a red colour. [1]

intensity of longer, visible wavelengths at red end from 600-700 nm is much more those below 600 nm.
object will appear predominantly red.

(b) At any temperature T, the graph of Fig. 2.2 shows a peak corresponding to a wavelength λ_{max} and an intensity I_{max}. Data for T and λ_{max} are shown in Fig. 2.3.

T / K	λ_{max} / nm	$T\lambda_{max}$ / K nm
600	4830	2898000
700	4140	2898000
800	3610	2888000
900	3210	2889000
1000	2900	2900000
1100	2630	2893000

Fig. 2.3

(i) Without drawing a graph, show that $T\lambda_{max}$ = constant and determine the constant. [3]

lab skills (verifying constants)

average $T\lambda_{max}$ = 2894000 K nm

values of $T\lambda_{max}$ are consistent at 2900 000 K nm (to 2 s.f.)

$$\frac{\text{max} - \text{min}}{\text{smallest value}} \times 100\% = \frac{2900000 - 2893000}{2893000} \times 100\% = 0.242\%$$

largest percentage deviation in the values is less than 1%
relationship likely valid

(ii) Hence determine the wavelength for maximum intensity at a temperature T of 1200 K. [2]

$$\text{average constant} = 2894000 \text{ K nm}$$

$$\lambda_{max} = \frac{\text{constant}}{T} = \frac{2894000}{1200} = 2412 \text{ nm}$$

(c) The total intensity of emitted radiation from a particular body at temperature T is I_{tot}. Fig. 2.4 shows the values of $\lg(T / \text{K})$ plotted against the corresponding values $\lg\left(I_{tot} / \text{W m}^{-2}\right)$.

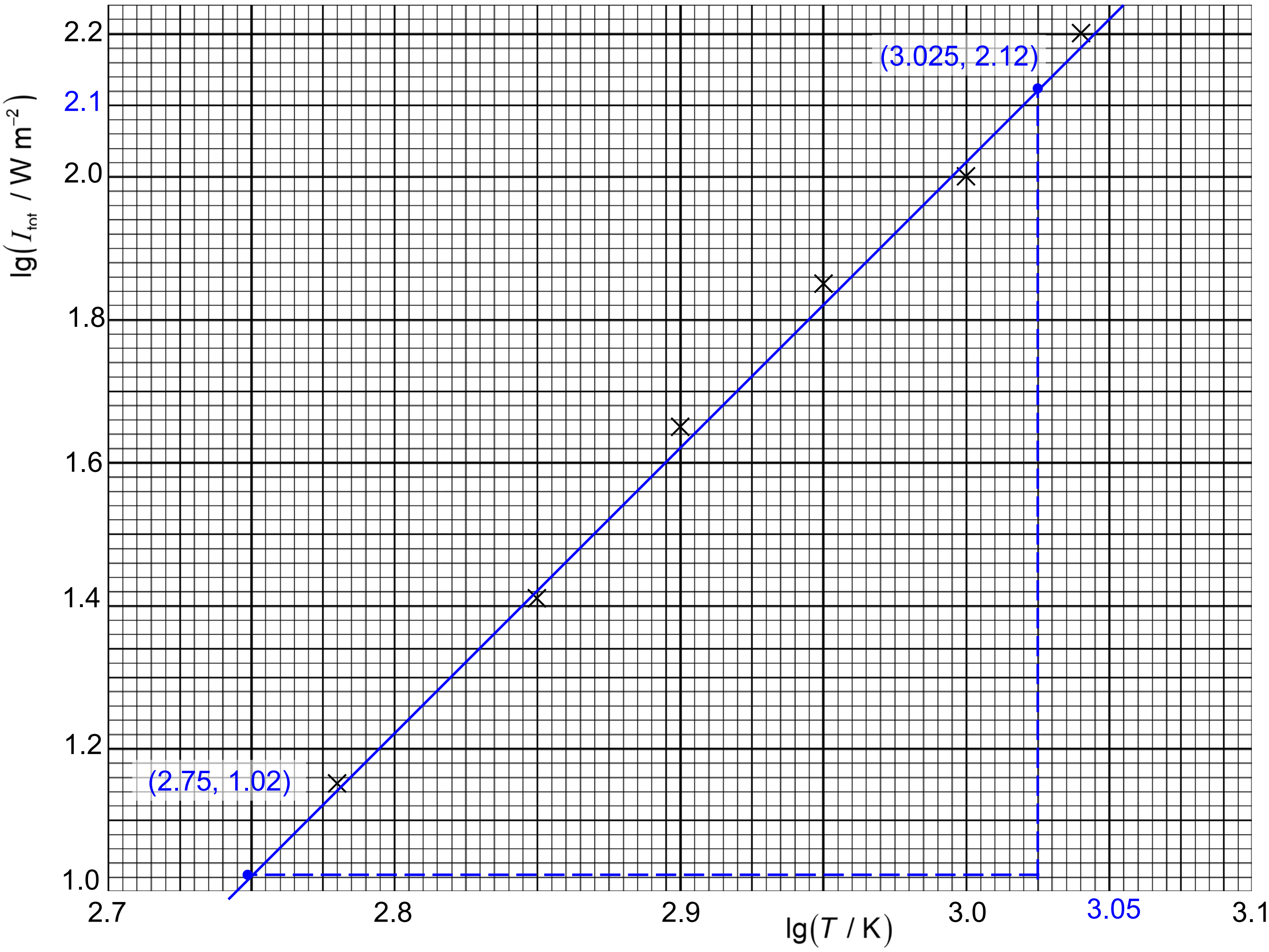


Fig. 2.4

It is known that I_{tot} varies with T according to the relation

$$I_{tot} = cT^n$$

where c and n are constants.

(i) Use Fig. 2.4 to determine a value for n. [3]

graph work. linear equation, draw line of best fit, finding gradient

$$\lg(I_{tot}) = \lg(c) + n\lg(T).$$

Plot of $\lg(I_{tot})$ against $\lg(T)$ will yield a straight line with y-intercept $\lg(c)$ and gradient n

$$\text{gradient} = \frac{y_1 - y_2}{x_1 - x_2} = \frac{2.12 - 1.02}{3.025 - 2.75} = 4.00$$

n = 4.00

(ii) For this body at T = 900 K, I_{tot} is found to be $71\ \text{W m}^{-2}$.

Use these data and your answer to (i) to determine I_{tot} for the body at temperature 1200 K. [3]

taking ratio of $I_{tot} = cT^4$

$$\frac{I_{1200}}{I_{900}} = \left(\frac{1200}{900}\right)^4 \Rightarrow I_{1200} = \left(\frac{1200}{900}\right)^4 (71) = 224\ \text{W m}^{-2}$$

(d) Using your answer to (b)(ii), sketch on Fig 2.2, the variation with wavelength λ for a temperature of 1200 K.

start at origin, intensity consistently higher than graph for 1100 K, peak at λ_{max} = 2412 nm, shaper peak than 1100 K graph, height approx ×3.2 of 900 K graph

(e) The radiation emitted by a hot body may be used as a means of determining the temperature of the body.

(i) Suggest and explain a property of the radiation that could be used for this purpose. [2]

peak wavelength λ_{max} because the higher the temperature, the shorter the wavelength

(ii) Suggest one advantage and one disadvantage of this method for measuring temperature. [2]

advantage: non-contact measurement of temperature

disadvantage: not suitable for temperatures below 600K, intensity is weak so detection may not be accurate

Lecture Example 3: Explosion Fireballs

Skills

A serious hazard for fire-fighters is the explosion of containers of 'liquefied gas' (butane) that have been heated in a fire. When the butane suddenly burns in an explosion, the fire spreads very rapidly in the form of a spherical fireball of increasing radius that is at very high temperature. In order to study such fireballs, a series of experiments is carried out. Some butane of volume 12.5×10^{-3} m^3 is put in a sealed container and is then heated until it explodes. The variation with time *t* of the radius *R* of the fireball is determined. The results are shown in Fig. 3.1.

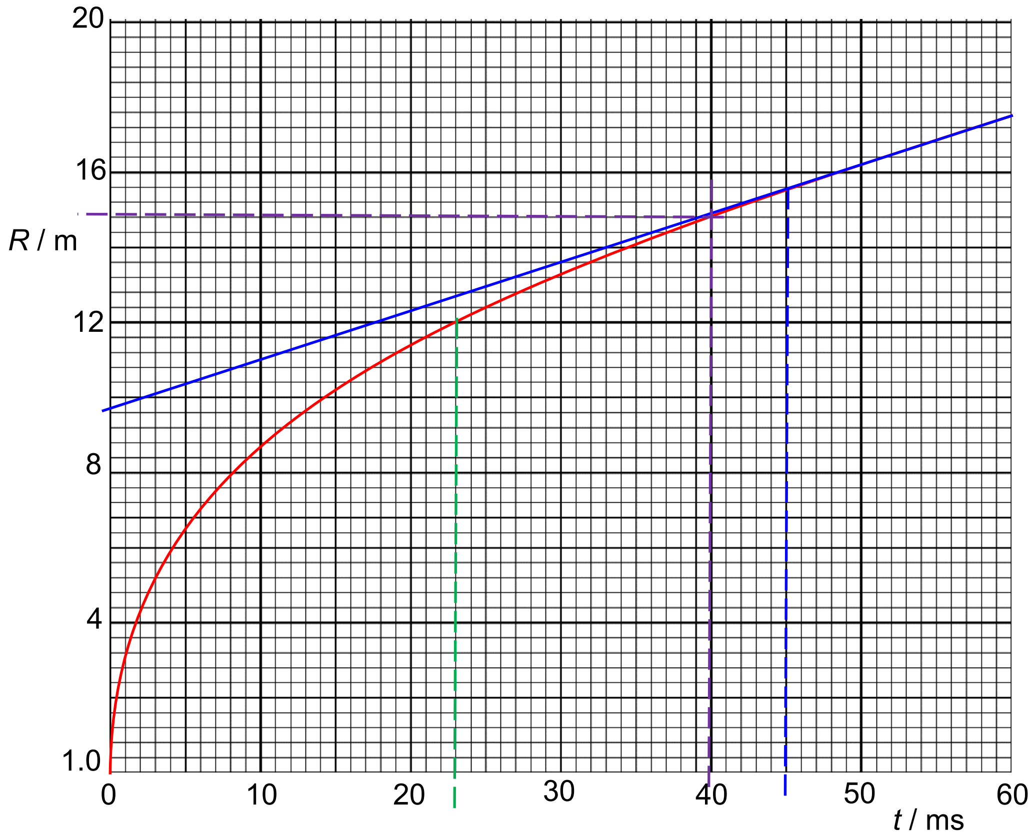


Fig. 3.1

(a) Use Fig. 3.1 to

(i) describe, without any calculation, the variation with time of the rate at which the radius of the fireball increases, [2]

question identified which feature to describe

[graph segment] [description]

from 0 ms to 45 ms, rate of increase decreases with time

from 45 ms to 60 ms, rate of increase is constant

(ii) suggest why, in a room of length 12 m, width 5 m and height 3 m, such an explosion would be very hazardous. [3]

use relevant info

time taken for fireball to engulf whole room

is maximum 23 ms judging by the longest dimension of 12 m;

leaves very little reaction time to escape the room

(b) It is thought that, for a fixed volume of butane, the radius R of the fireball varies with time t according to the expression

$$R^n = kt^m$$

where n and m are integers and k is a constant.

Some corresponding values of lg t and lg R for the data in Fig. 3.1 are plotted on Fig. 3.2.

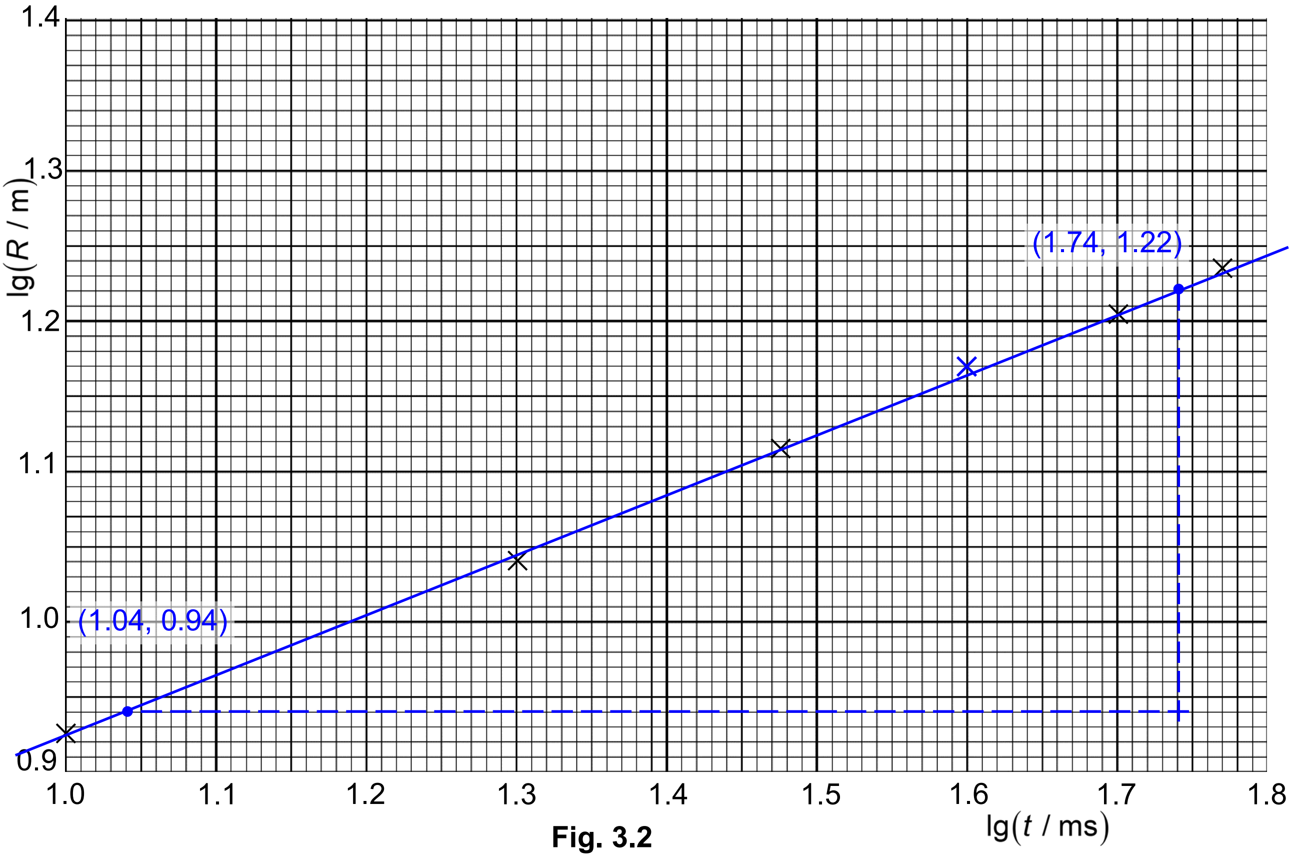


Fig. 3.2

(i) On Fig. 3.2,

1. plot the point corresponding to time t = 40 ms,

$$\log(t) = \log(40) = 1.60;$$

$$\log(R) = \log(14.8) = 1.17$$

2. draw the best-fit line for all the plotted points. [2]

(ii) Determine the gradient of the line drawn in **(i) 2.** [2]

$$\text{gradient} = \frac{y_1 - y_2}{x_1 - x_2} = \frac{1.22 - 0.94}{1.74 - 1.04} = 0.400$$

(iii) Hence suggest values for the integers n and m. Explain your working. [3]

use relevant info

$$R^n = kt^m$$

$$n\lg(R) = \lg(k) + m\lg(t)$$

$$\lg(R) = \frac{\lg(k)}{n} + \left(\frac{m}{n}\right)\lg(t)$$

since $\left(\frac{m}{n}\right) = 0.400$, m can be 2, n can be 5

(c) The experiment is repeated using similar containers but with different volumes of butane. The results are shown in Fig. 3.3.

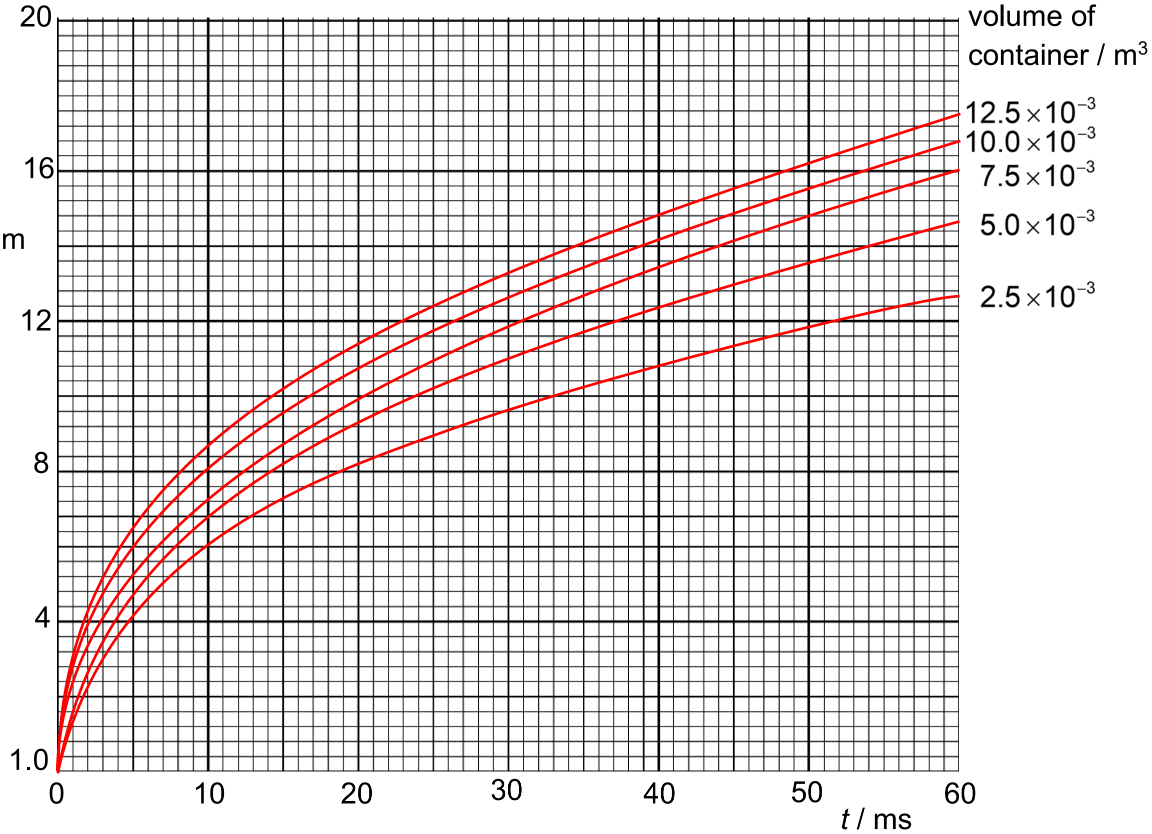


Fig. 3.3

Without drawing a further graph, show that, at time t = 40 ms, the radius R of the fireball is related to the volume V of butane by the expression

$$R^5 = cV$$

where c is a constant. [3]

lab skills (verifying constants)

calculating c for at least 3 sets of data

R / m	V / 10^{-3} m^3	c / 10^3 m^2
14.8	12.5	56800
14.2	10.0	57700
13.4	7.5	57600
12.4	5.0	58600
10.8	2.5	58800

average c = 57900 × 10^3 m^2

$$\frac{\text{max} - \text{min}}{\text{smallest value}} \times 100\% = \frac{58800 - 56800}{56800} \times 100\% = 3.5\%$$

largest percentage deviation in the values is less than 5%
c is likely constant so expression likely valid

(d) (i) The equation in (c) may also be applied to other exploding gases.
Suggest one physical quantity on which the constant *c* will depend. [1]

pressure of gas

(ii) The data were collected for butane in a container in a room.
Suggest one other situation where the theory developed predicts a high level of hazard for firefighters. [1]

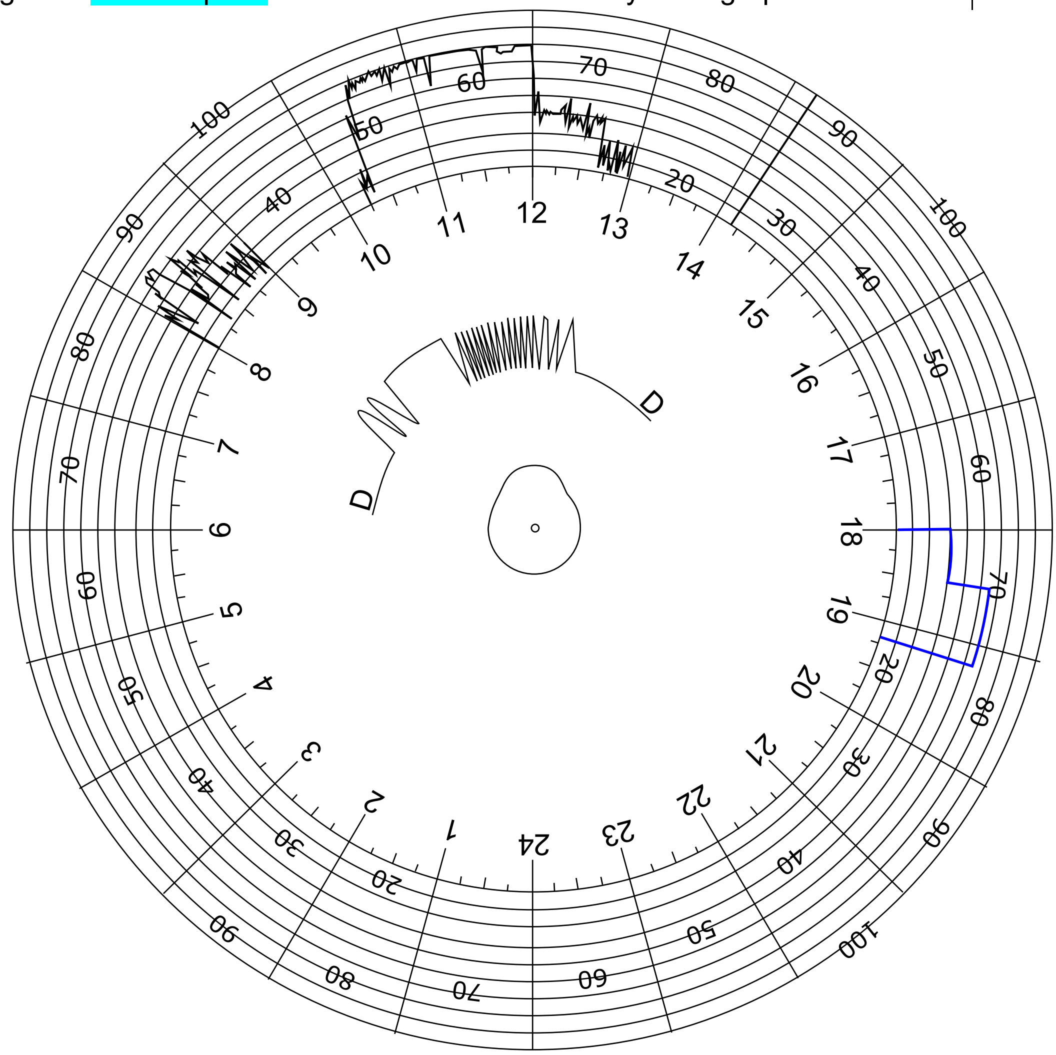
use relevant info

in open space, force of explosion can send fragments and objects with high speeds over large distances

Lecture Example 4: A Lorry's Tachograph

Skills
Extract info

Statistics for road traffic accidents are sometimes interpreted as showing that many occur as a result of speeding or fatigue of the driver. As a result, some countries have introduced laws to limit the speed at which vehicles may travel and also the length of time a person may drive without a rest. In order to enforce these laws, some types of vehicles are fitted with tachographs. A tachograph records, on a circular chart, amongst other information, the times at which the vehicle is being drive, together with its speed. One such chart from a lorry tachograph is shown.



The time of day, using the 24-hour clock, is shown on the inner scale. Each concentric circle represents a speed measured in kilometres per hour (km h^{-1}). For example, at time 1215H, the lorry was travelling at 40 km h^{-1}. — Extract info

(a) Use the Fig. to determine

(i) the speed of the lorry at 1130H, [1] — Extract info

80 km h^{-1}

(ii) the length of time for which the lorry was stationary between 0800H and 1200 noon. [1] — Extract info

1.25 hour (from 0900H – 1015H)

(b) Suggest what evidence is provided between 0800H and 1300H for — Extract info

(i) some device on the lorry which limits its maximum speed, [1]

between 1030H and 1200H, speed does not exceed 80 km h^{-1}

(ii) the lorry being in a congested area with heavy traffic between 1245H and 1300H. [2] — Extract info, deduce logically

between 1245H and 1300H, the average speed is low at about 20 km h^{-1}
speed fluctuates up and down, suggesting frequent stopping and starting

(c) The table below shows data for a particular journey.

time of day	activity
1600H – 1800H	resting
1800H	accelerates to 40 km h^{-1}
1800H – 1830H	continues at 40 km h^{-1}
1830H	accelerates to 65 km h^{-1}
1830H – 1910H	continues at 65 km h^{-1}
1910H	stops

Draw on the tachograph the trace which would be produced for this journey.

(d) The tachograph is one form of speed-time graph.

(i) State how the following information may be obtained from a speed-time graph. — use existing knowledge (kinematics)

1. acceleration [1]

gradient of tangent at that point in time

2. distance travelled [1]

area under graph, in-between desired time interval

(ii) Use the tachograph to estimate the distance travelled by the lorry between 1200H and 1300H. [4]

estimate speed as 45 km h^{-1} between 1200H and 1245H
estimate speed as 20 km h^{-1} between 1245H and 1300H, total 35 km

(e) When the tachograph is switched off, the chart stops rotating and the speed recorded is the maximum for the chart.

(i) State the time at which the tachograph was switched off. [1] — Extract info

just before 1415H

(ii) Suggest why, when the tachograph is switched off, it is desirable for the speed recorded to be the maximum, rather than zero. [2] — deduce logically

distinguishes from times at which lorry is stationary

not possible for lorry to reach 100 km h^{-1} due to speed limiting device

Ending Notes

First, is that DBQs tests more of our **skills** at handling data, weighing costs-vs-benefits in analysis and our aptitude in applying the scientific method. To do so effectively, we should all develop relevant attitudes such as a concern for accuracy and precision, being objective and having academic integrity. These are transferable skills too, skills that will be valued for future studies and employment.

Second, is that we should learn to be **comfortable with unfamiliarity and uncertainty**. The nature of DBQs means that we will never be able to predict the scenario and/or the topics of Physics that that the examiners will deploy in their questions. Counter-intuitively, such methods of working through problems and forcing ourselves to reason through our thinking, actually enables us to learn more effectively, even if it seems more incoherent, more intermittent, more frustrating or more confusing (https://doi.org/10.1073/pnas.1821936116).

Third, is that DBQs **favours the curious**. Many of the DRQs responses require logical deductions. They are natural exercises of "*how to*... ", "*what might result if*...", "*why is it like that*...". It confers natural advantages to those of us who take an active interest in knowing more about the world, from the simple act of reading the product labels on our shampoos, to never backing down from a good intellectual discourse. If we were literature teachers, we'd probably advise you to stop every once in a while to smell the flowers.