Modelling with Logarithms (& Exponentials)

(AS & A Level Mathematics)

Pearson Edexcel

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GUMLEY HOUSE
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- 35 years' experience of teaching & training
- Former Head of Department
- Mentored over 55 ITT trainees and NQTs
- Delivered training courses at St Mary's University College, Strawberry Hill
- Acted as a case study for an awarding body
- Assisted in the writing of the GCSE 2010 Modular, Linked Pair Pilot & A-Level (2017) Schemes of Work
- Nominated for a National Teaching Award

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Modelling non-linear relationships using logarithms

Note:-
Some of the examples in this presentation and activities have not been moderated for use in live examinations.
They are intended solely as T & L questions.
Also some of the exam questions are taken from the International A-Level Examinations.

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Using Logs to reduce to linear form

If, from an experiment, we have a set of values of x and y that we think may be related we often plot them on a graph.

If the relationship can be approximated by a straight line, a line of best fit can easily be drawn through the data.

However, it is not easy to draw a curve through data.

If we think that a relationship of the form

$$y = ax^n \quad \text{or} \quad y = ab^x$$

fits the data, where a and b are constants, we can use logs to obtain a straight line.

Using Logs to reduce to linear form

Form 1

Suppose we <u>believe</u> a relationship of the form $y = ax^n$ exists between x and y. Then,

$$y = ax^n$$

Take logs: $\log y = \log(ax^n)$

Simplify: $\log y = \log a + \log x^n$ (Law 1)

$\Rightarrow$ $\log y = \log a + n \log x$ (Law 3)

This equation now represents a straight line

$$Y = c + mX$$

where $Y = \log y$

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This equation now represents a straight line

$$Y = c + mX$$

where $Y = \log y$ $X = \log x$

and $c = \log a$ $m = n$

We plot $\log y$ against log x.

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Using Logs to reduce to linear form

Form 2 For a relationship of the form $y = ab^x$ we work in a similar way.

Take logs: $y = ab^x$

$$\Rightarrow \quad \log y = \log(ab^x)$$

$$\Rightarrow \quad \log y = \log a + \log b^x$$

$$\Rightarrow \quad \log y = \log a + x \log b$$

$$Y = c + X m$$

so, $Y = \log y$ (as before)

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Using Logs to reduce to linear form

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so, $Y = \log y$ (as before) but $X = x$

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Using Logs to reduce to linear form

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The gradient, $m = \log b$

Using Logs to reduce to linear form

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$$Y = c + X\,m$$

so, $Y = \log y$ (as before) but $X = x$

The gradient, $m = \log b$ and $c = \log a$

We plot $\log y$ against x.

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Using Logs to reduce to linear form

SUMMARY

➢ The relationships $y = ax^n$ and $y = ab^x$ can both be reduced to straight lines by taking logs.

- For $y = ax^n$,

$$\log y = \log(ax^n)$$
$$\Rightarrow \quad \log y = \log a + \log x^n$$
$$\Rightarrow \quad \boxed{\begin{array}{ccccc} \log y & = & \log a & + & n\log x \\ Y & = & c & + & mX \end{array}}$$

- For $y = ab^x$,

$$\log y = \log(ab^x)$$
$$\Rightarrow \quad \log y = \log a + \log b^x$$
$$\Rightarrow \quad \boxed{\begin{array}{ccccc} \log y & = & \log a & + & x\log b \\ Y & = & c & + & Xm \end{array}}$$

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Logarithms

Power laws are common in nature

Use logarithmic graphs to estimate parameters in relationships of the form $\boldsymbol{y = ax^n}$

A company make models in different sizes of an iconic building. The table gives information about the costs and heights of the models.

Height(h cm)	**10**	**15**	**20**	**30**	**50**
Cost (\$$y$)	**3**	**8**	**20**	**70**	**300**

Trip Advisor

Assuming the relationship between cost (\$y) and height (h cm) is $y = ah^n$

(a) Draw a suitable straight line graph

(b) Use your graph to find an estimate for n and an estimate for a.

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Logarithms

Use logarithmic graphs to estimate parameters in relationships of the form $y = ax^n$

Height (h cm)	**10**	**15**	**20**	**30**	**50**
Cost (\$$y$)	**3**	**8**	**20**	**70**	**300**

Log h	**1.00**	**1.18**	**1.30**	**1.48**	**1.70**
Log y	**0.40**	**0.93**	**1.30**	**1.83**	**2.49**

$y = ah^n$

$\log y = \log a + n \log h$

$Y = \log a + n X$

Gives a straight line graph in the (X, Y) plane with **gradient *n*** and **intercept** on the 'Y-axis' of **log *a***

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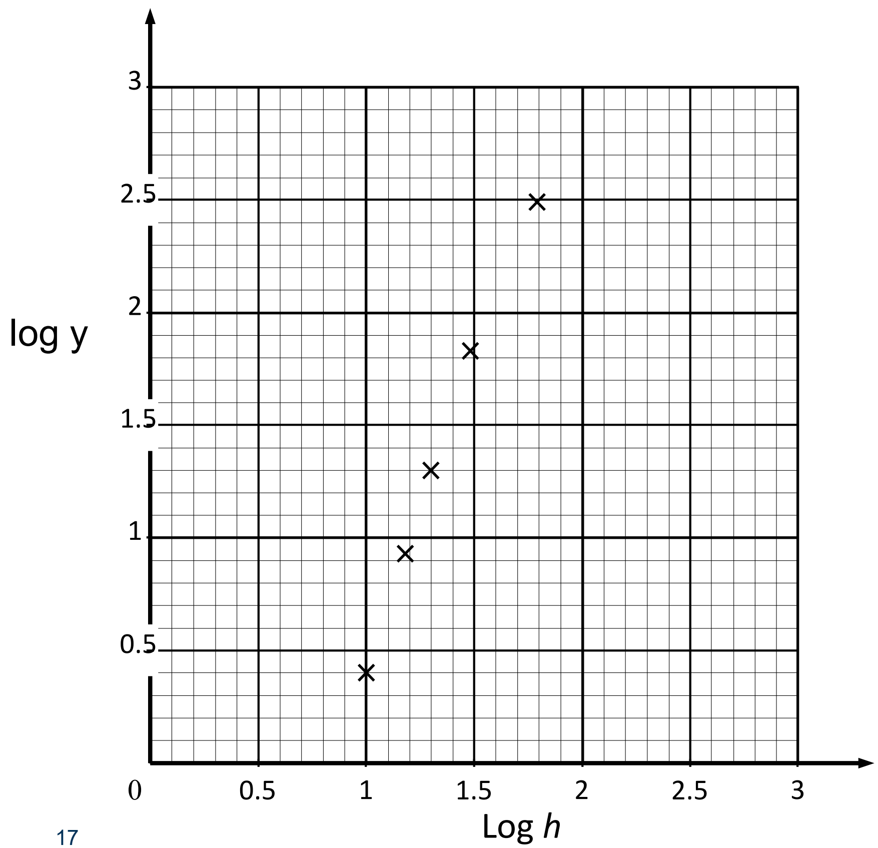
Logarithms

Use logarithmic graphs to estimate parameters in relationships of the form $\boldsymbol{y = ax^n}$

Log h	1.00	1.18	1.30	1.48	1.70
Log y	0.40	0.93	1.30	1.83	2.49



$y = ah^n$

$\log y = \log a + n \log h$

$Y = \log a + n X$

Gives a straight line graph in the (X, Y) plane with **gradient *n*** and **intercept** on the 'Y-axis' of **log *a***

The points lie near to straight line. Draw the best straight line by judgment

It will not be possible to read of the intercept on the log y axis from the graph…….

Logarithms

Use logarithmic graphs to estimate parameters in relationships of the form $y = ax^n$

Log h	1.00	1.18	1.30	1.48	1.70
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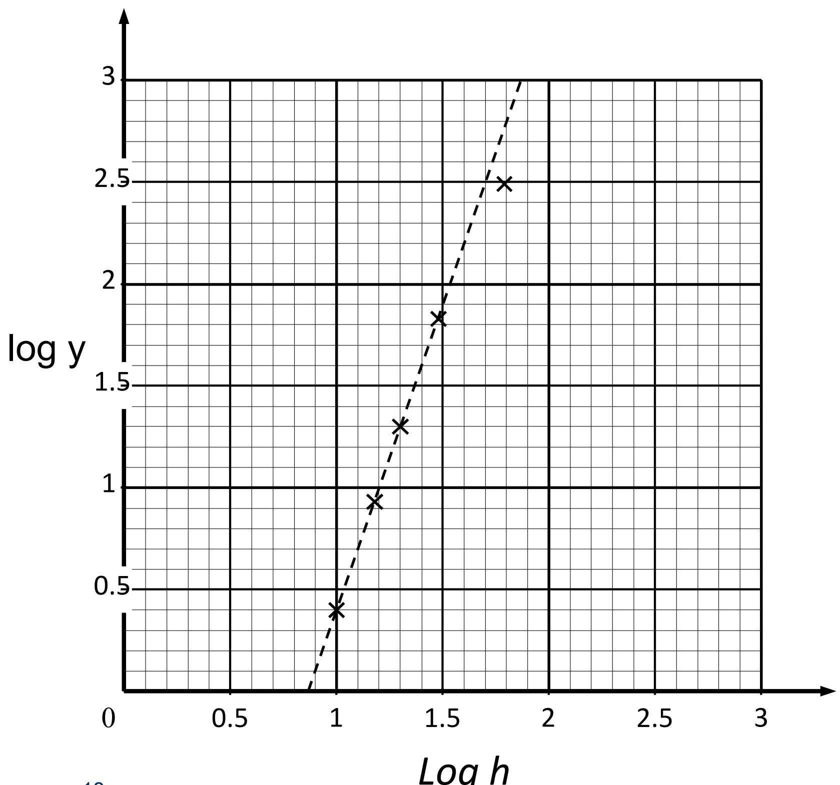

Gradient = $\dfrac{2.5 - 0.1}{1.7 - 0.9} = 3$

It will not be able to read of the intercept on the log y axis from the graph

This will happen when $0<a<1$

So pick a suitable value of (X, Y) on the line to calculate an estimate log a

I chose (1, 0.4) so that $0.4 = \log a + 3 \times 1$

$\log a = -2.6$ so $a = 10^{-2.6} = 0.0025$ (2 d.p.)

So, $y = 0.0025h^3$

We then could (but shouldn't) predict the cost of a one metre tower.

Try the next example after the course

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Logarithms

Use logarithmic graphs to estimate parameters in relationships of the form $y = ab^x$

These are essentially exponential increase and decrease laws

t (hours)	20	40	60	80	100	120
Mass (grams)	8.11	6.57	5.33	4.32	3.50	2.84

The table shows the mass (m grams) of radioactive molybdenum 99 in a container after *t* hours.

Given that the relationship is thought to be of the form $m = ab^t$
draw a suitable graph to confirm this and estimate the values of *a* and *b*

Estimate the initial mass of molybdenum 99

This is one for you to try after the course

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Logarithms

Use logarithmic graphs to estimate parameters in relationships of the form $y = ab^x$

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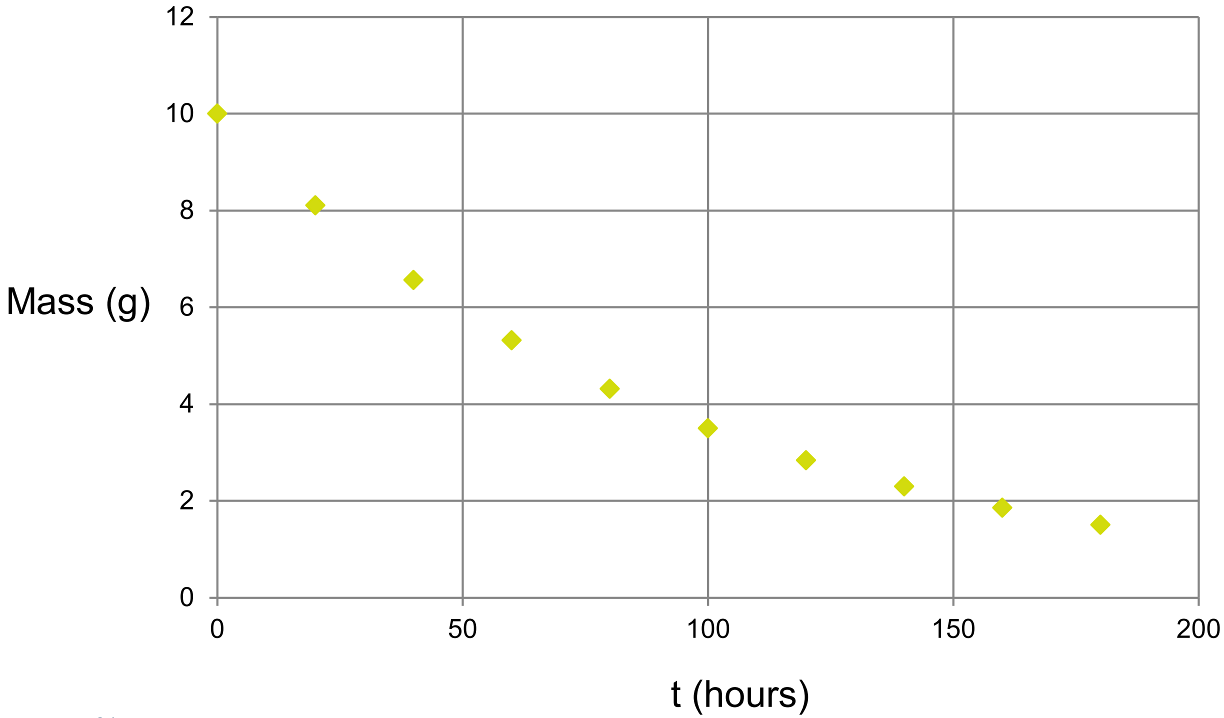

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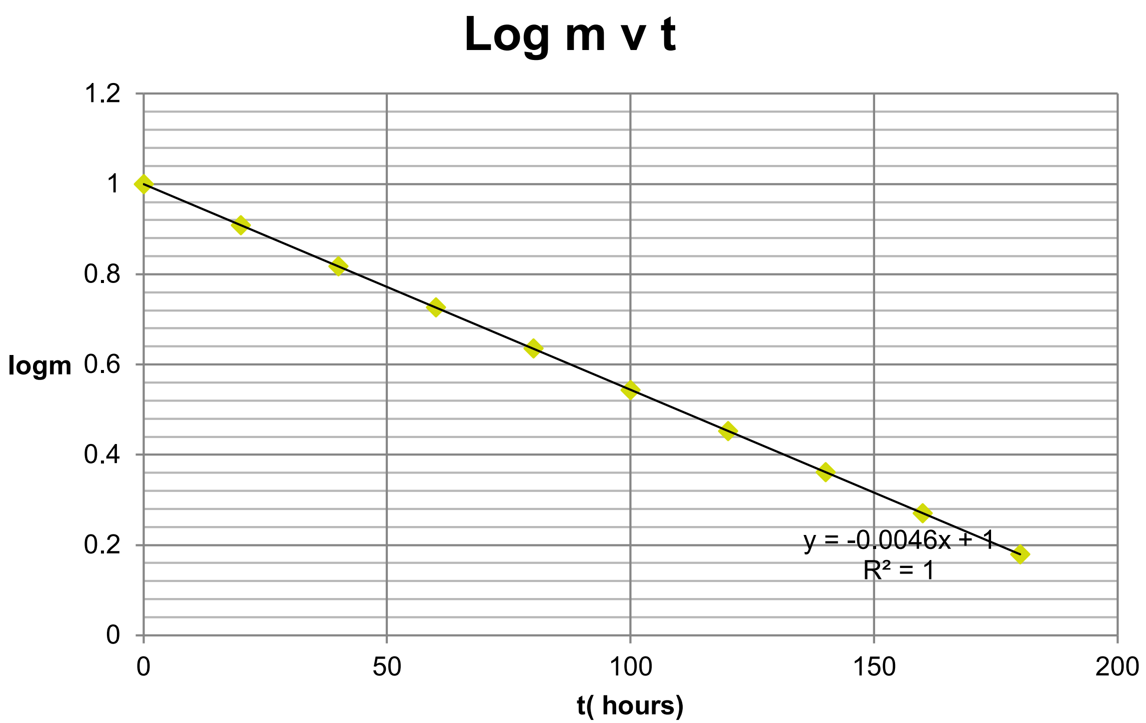
Logarithms

Use logarithmic graphs to estimate parameters in relationships of the form $y = ab^x$



Intercept = 1
Slope = -0.0046

a = 10
log b = -0.0046
b = 0.99

So, $\mathbf{m = 10\ (0.99)^t}$

Say **5 marks**
2 for the correct form to plot
2 for finding *a* and *b*
1 for accurate values of *a* and b

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Example (from Dr Frost)

[Textbook] The table below gives the rank (by size) and population of the UK's largest cities and districts (London is number 1 but has been excluded as an outlier).

City	B'ham	Leeds	Glasgow	Sheffield	Bradford
Rank, *R*	2	3	4	5	6
Population, *P*	1 000 000	730 000	620 000	530 000	480 000

The relationship between the rank and population can be modelled by the formula:

$R = aP^n$ where a and n are constants.

a) Draw a table giving values of $\log R$ and $\log P$ to 2dp.

b) Plot a graph of $\log R$ against $\log P$ using the values from your table and draw the line of best fit.

c) Use your graph to estimate the values of a and n to two significant figures.

a

?

b

?

c

?

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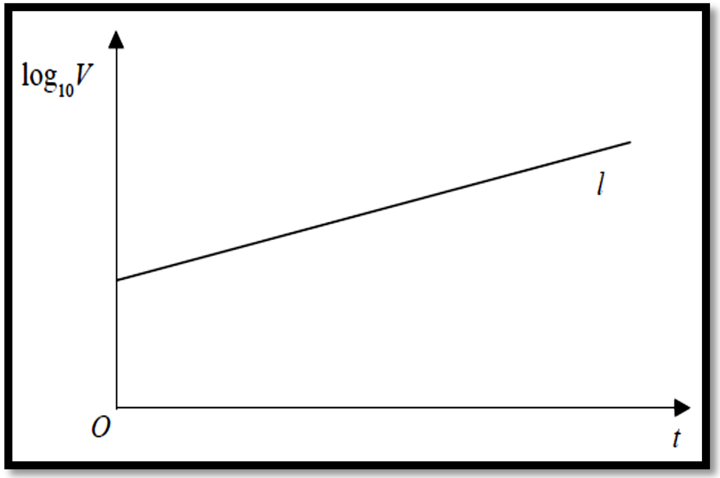
June 2018 AS Pure Paper



The value of a rare painting, £V, is modelled by the equation $\boldsymbol{V = pq^t}$, where p and q are constants and t is the number of years since the value of the painting was first recorded on 1st January 1980.

The line l shown in Figure 3 illustrates the linear relationship between t and $\log_{10}V$ since 1st January 1980.

The equation of line l is $\boldsymbol{\log_{10}V = 0.05t + 4.8}$.

(a) Find, to 4 significant figures, the value of p and the value of q. **(4)**

(b) With reference to the model, interpret

(i) the value of the constant p,
(ii) the value of the constant q. **(2)**

(c) Find the value of the painting, as predicted by the model, on 1st January 2010, giving your answer to the nearest hundred thousand pounds. **(2)**

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June 2018 AS Pure Paper (Student-friendly Answers)

Part	Working or answer an examiner might expect to see	Mark	Notes
(a)	$V = 10^{\frac{1}{20}t+4.8}$	M1	This mark is awarded for a method to find V
	$V = 10^{\frac{1}{20}t} + 10^{4.8}$	M1	This mark is awarded for a method for forming an equation in the form $V = pq^t$
	$p = 10^{4.8} = 63100$	A1	This mark is given for an evaluation of p to 4 significant figures
	$q = 10^{\frac{1}{20}} = 1.222$	A1	This mark is given for an evaluation of q to 4 significant figures
(b)	The value of the painting on 1 January 1980	B1	This mark is given for a correct statement
	The proportional increase in the value of the painting each year	B1	This mark is given for a correct statement
(c)	$V = 63100 \times 1.122^{30}$	M1	This mark is given for finding an expression for V
	$= £1.99$ million	A1	This mark is given for a correct answer only

In a controlled experiment, the number of microbes, N, present in a culture T days after the start of the experiment were counted.

N and T are expected to satisfy a relationship of the form

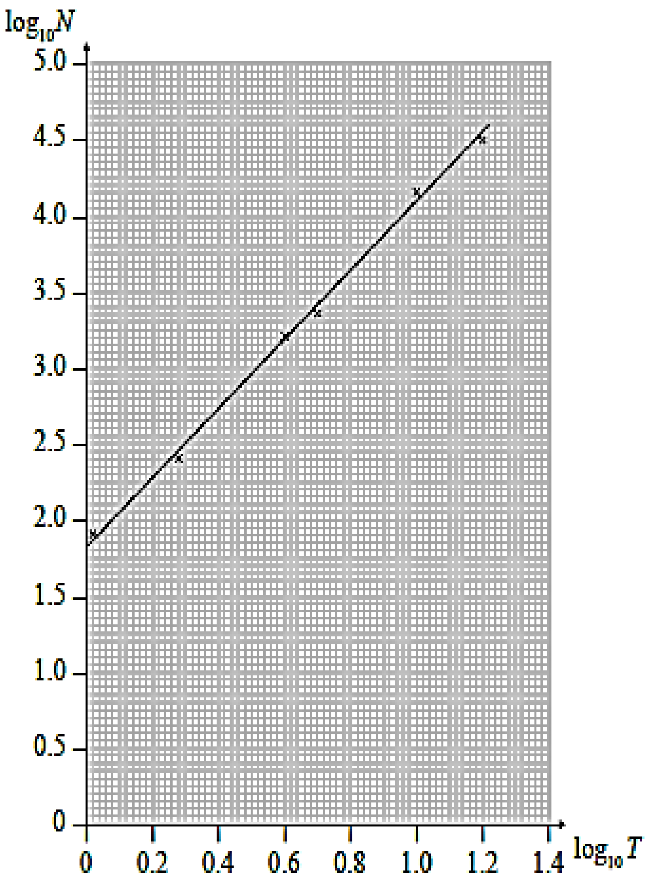
$$N = aT^b \qquad \text{where } a \text{ and } b \text{ are constants}$$

(a) Show that this relationship can be expressed in the form

$$\log_{10} N = m \log_{10} T + c$$

giving m and c in terms of the constants a and/or b.

(2)



IAL P3 SAMs

Figure 2 shows the line of best fit for values of $\log_{10} N$ plotted against values of $\log_{10} T$

(b) Use the information provided to estimate the number of microbes present in the culture 3 days after the start of the experiment.

(4)

(c) With reference to the model, interpret the value of the constant a.

(1)

Graph and line of best fit drawn

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IAL P3 SAMs

Question	Scheme	Marks
8(a)	$N = aT^b \Rightarrow \log_{10} N = \log_{10} a + \log_{10} T^b$	M1
	$\Rightarrow \log_{10} N = \log_{10} a + b\log_{10} T$ so $m = b$ **and** $c = \log_{10} a$	A1
		(2)
(b)	Uses the graph to find either a or b $a = 10^{\text{intercept}}$ **or** $b =$ gradient	M1
	Uses the graph to find both a and b $a = 10^{\text{intercept}}$ **and** $b =$ gradient	M1
	Uses $T = 3$ in $N = aT^b$ with their a and b	M1
	Number of microbes ≈ 800	A1
		(4)
(c)	States that 'a' is the number of microbes 1 day after the start of the experiment.	B1
		(1)
		(7 marks)

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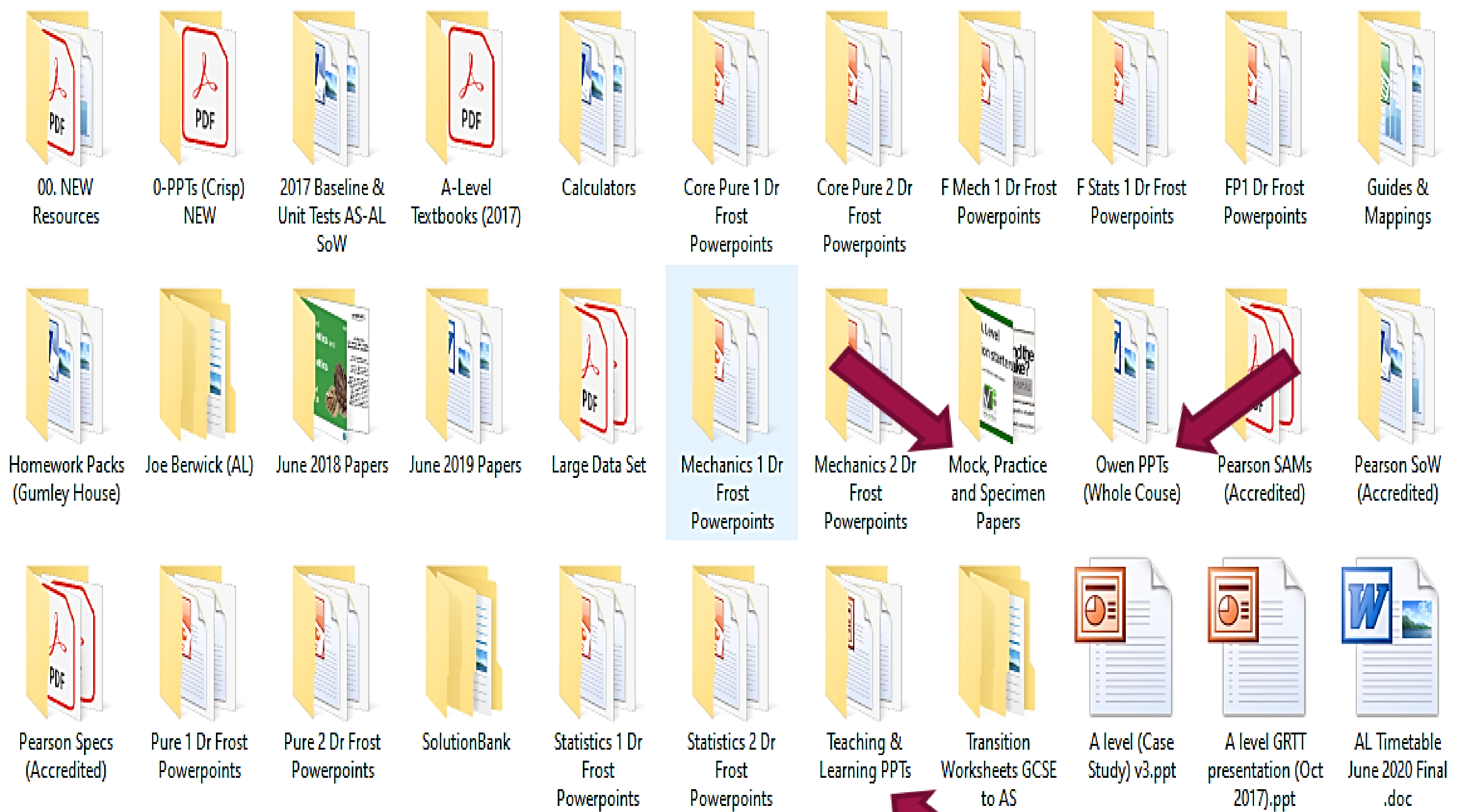
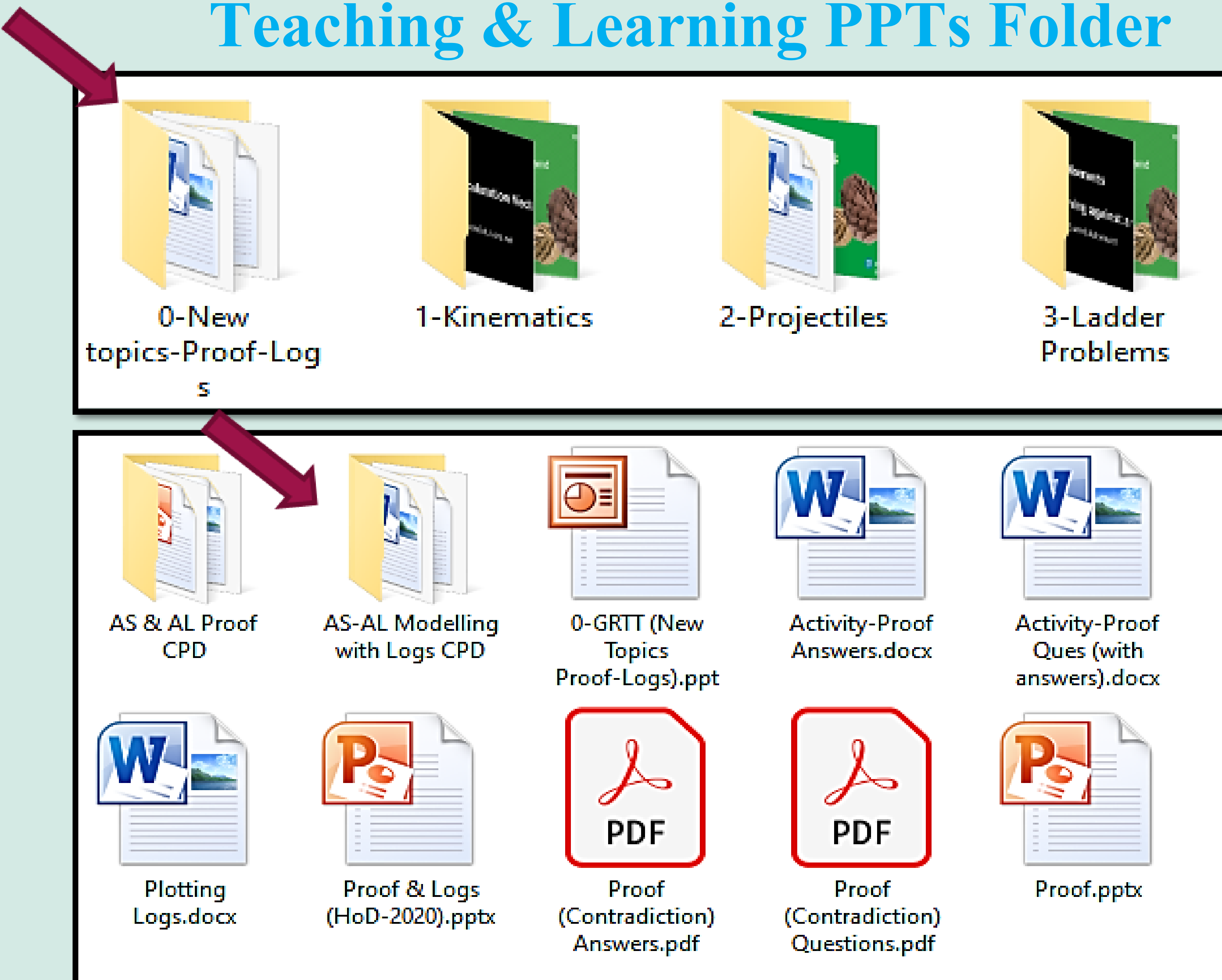
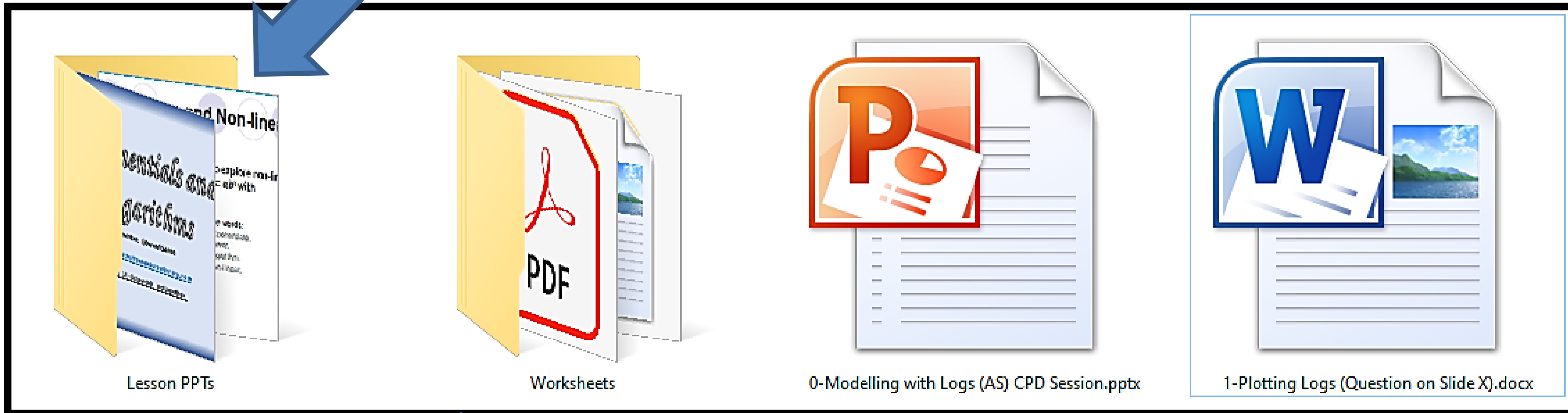
A-Level (2017) Folder

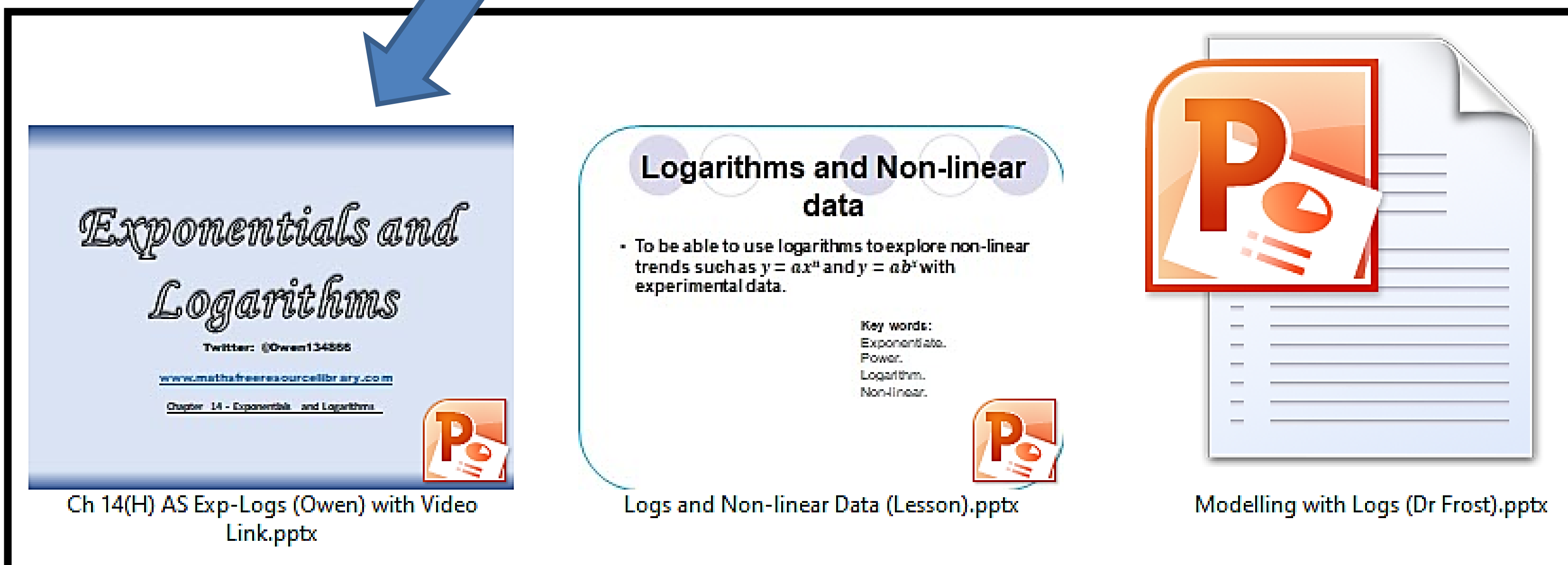


Teaching & Learning PPTs Folder



AS-AL Modelling with Logs CPD Folder





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$y = ax^n$ | $\log y = \log a + n\log x$ | $y = ab^x$ | $\log y = \log a + x\log b$

Exponentials and Logarithms

Logarithms can be used to manage and explore non-linear trends in data

The graph shown represents the growth of a population of bacteria, P over a period of t hours. The graph has a gradient of 0.6 and meets the vertical axis at (0,2) as shown.

A scientist suggests that this growth can be modelled by the equation $\boxed{P = ab^t}$, where a and b are constants to be found.

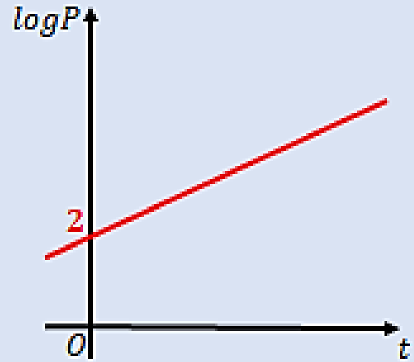
a) Write down an equation for the line

$\log P = 2 + 0.6t$

b) Using your answer to part a or otherwise, find the values of a and b, giving them to 3sf where necessary

$P = 100 \times 3.98^t$

c) Interpret the meaning of the constant a in this model



$$\log P = 2 + 0.6t$$

Write without the logarithm

$$P = 10^{2+0.6t}$$

Separate using index laws

$$P = 10^2 \times 10^{0.6t}$$

Rewrite the right part as a bracket

$$P = 10^2 \times (10^{0.6})^t$$

Calculate each power

$$\boxed{P = 100 \times 3.98^t}$$

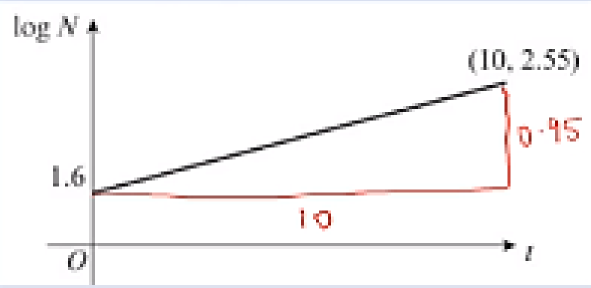
You can compare this with the form suggested earlier…

$a = 100 \qquad b = 3.98$

Your Turn – Page 331 - Exercise 14H

Q8) A scientist is modelling the number of people, N, who have fallen sick with a virus after t days. From looking at this graph, the scientist suggests that the number of sick people can be modelled by the equation $N = ab^t$, where a and b are constants to be found.

Type 2



The graph passes through (0,1.6) and (10,2.55)

a) Write down the equation of the line

b) Find the values of a and b.

c) Interpret the value of a

$y = mx + c$

$\frac{\Delta y}{\Delta x} = 0.095$

$\log(N) = 0.095t + 1.6$

b) $\log(a) = 1.6$ $\quad$ $a = 39.8$ ✓

$\log(b) = 0.095$ $\quad$ $b = 1.245$ ✓

$N = 39.8 \times 1.245^x$

24·5% increase every day.

c) $t = 0$, $N = 39.8$

therefore in

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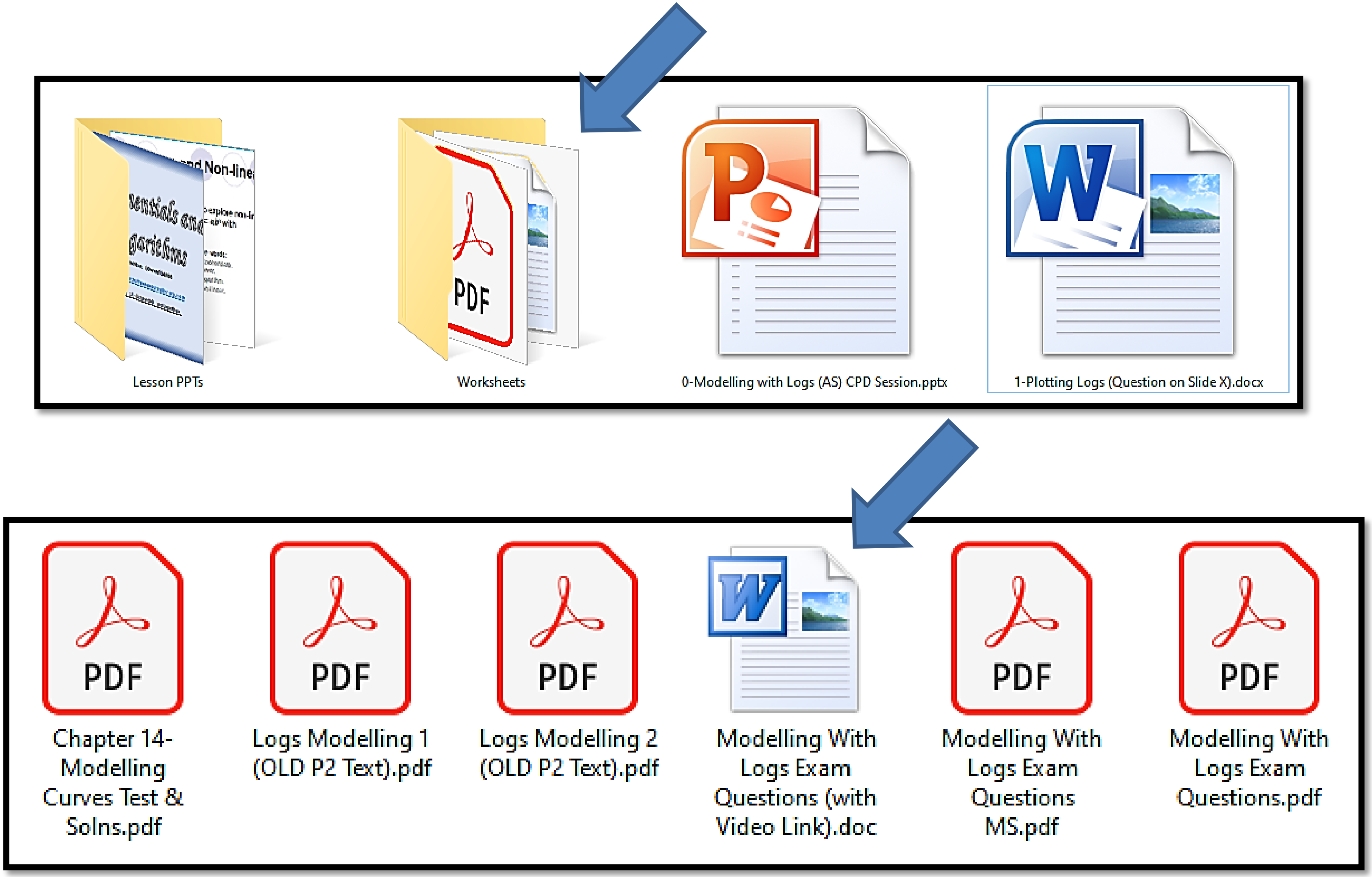

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Fig. 6 shows the relationship between $\log_{10} x$ and $\log_{10} y$.

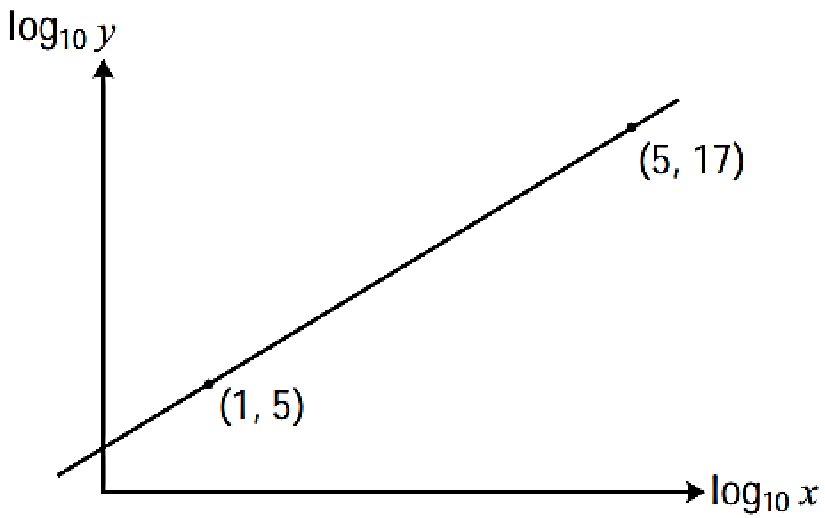

Fig. 6

Find y in terms of x. **[5]**

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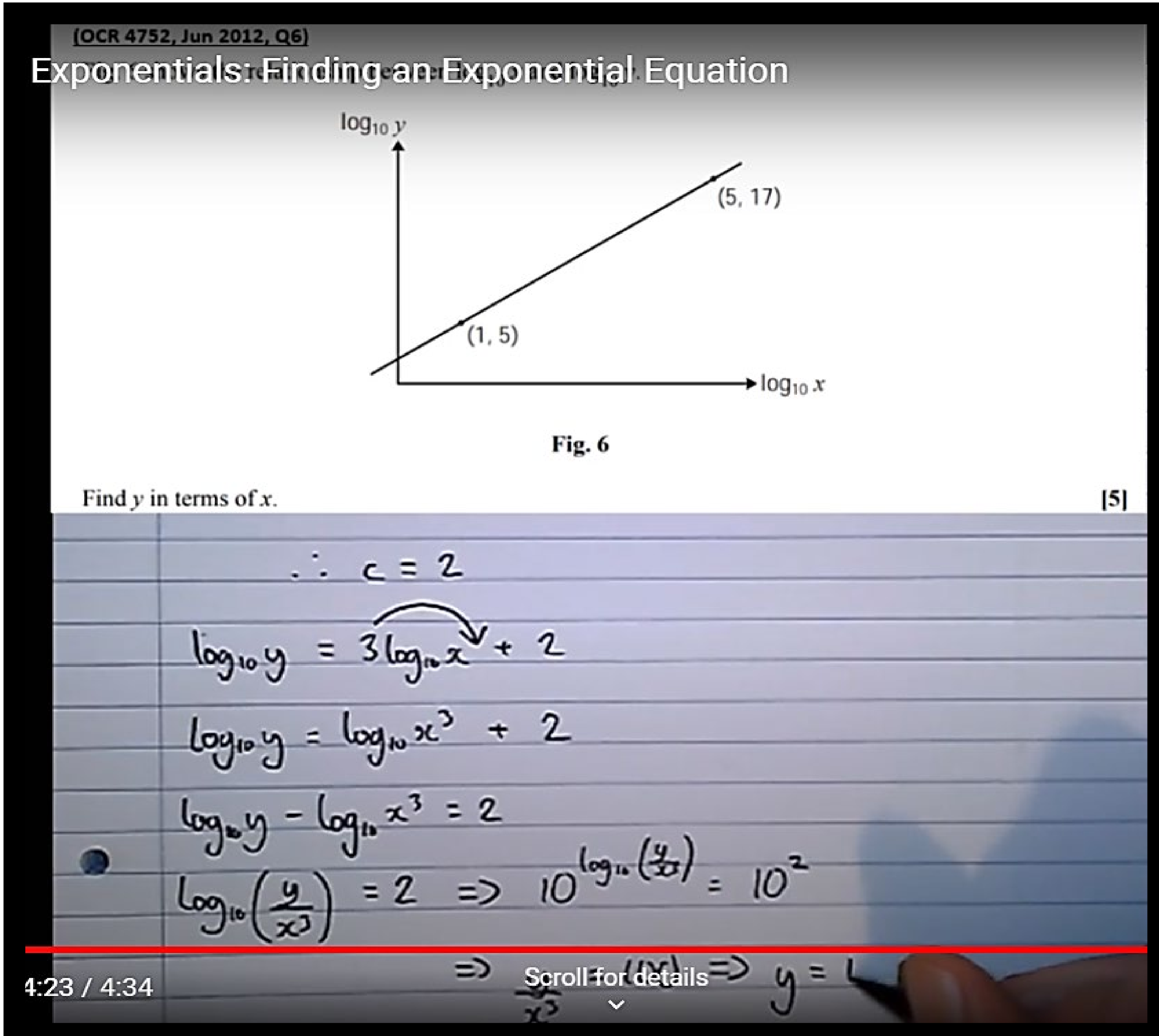

Developing the Concept:

Modelling with Exponentials

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Modelling with Exponentials

Here is an example of modelling a population

A rare species of mammal is being studied. The population P, t years after the study started, is modelled by the formula

$$P = \frac{900e^{\frac{1}{4}t}}{3e^{\frac{1}{4}t} - 1}, \qquad t \in \mathbb{R}, \qquad t \geqslant 0$$

$t \geq 0$

Students should be able to:

Work out the population at a given time

Find the rate of change of population at a given time

Find the maximum (or minimum) population and the time at which it occurs
(Not for this particular model, of course!)

Modelling with Exponentials

A colony of ants is being studied. The number of ants in the colony is modelled by the equation

$$P = 200 - \frac{160e^{0.6t}}{15 + e^{0.8t}} \qquad t \in \mathbb{R}, t \geqslant 0$$

where P is the number of ants, measured in thousands, t years after the study started.

A sketch of the graph of P against t is shown in Figure 5

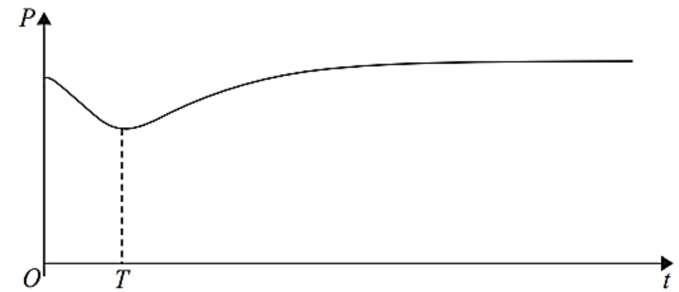

Figure 5

Taken from C34
June 2017 mark scheme

(a) Find the initial number of ants in the study.

(b) Show that P has a **minimum** at time *T*.

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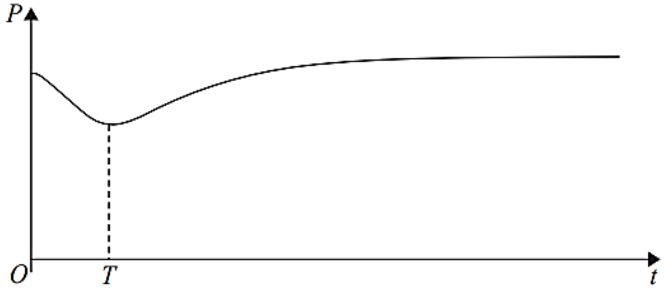

Figure 5

(a) Find the initial number of ants in the study.

T = 0 , P = 200 – 160/(15 + 1) = 190

Taken from C34 June 2017 mark scheme

(b) Show that P has a **minimum** at time *T.*

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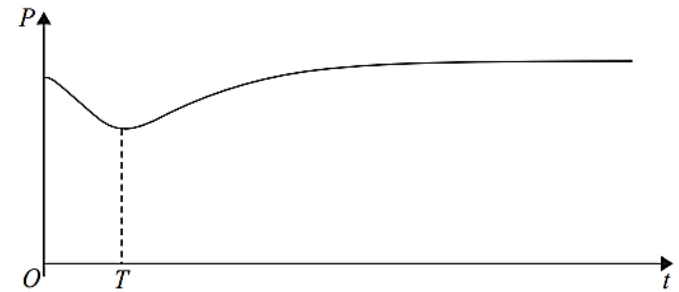

Figure 5

(a) Find the initial number of ants in the study.

T = 0 , P = 200 – 160/(15 + 1) = 190

Taken from C34 June 2017 mark scheme

(b) Show that P has a **minimum** at time *T*.

$$\frac{dP}{dt} = -\frac{(15+e^{0.8t})\times 96e^{0.6t} - 160e^{0.6t}\times 0.8e^{0.8t}}{(15+e^{0.8t})^2}$$

$$\text{Sets } \pm\frac{(15+e^{0.8t})\times 96e^{0.6t} - 160e^{0.6t}\times 0.8e^{0.8t}}{(15+e^{0.8t})^2} = 0 \Rightarrow e^{0.8t} = 45$$

$$\Rightarrow T = \frac{\ln 45}{0.8} = 4.76$$

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Modelling with Exponentials

Understand and use exponential growth and decay. Students should be familiar with terms such as 'initial' and be able to explore behaviour for large values of *t* or to consider whether the range of values predicted is appropriate.

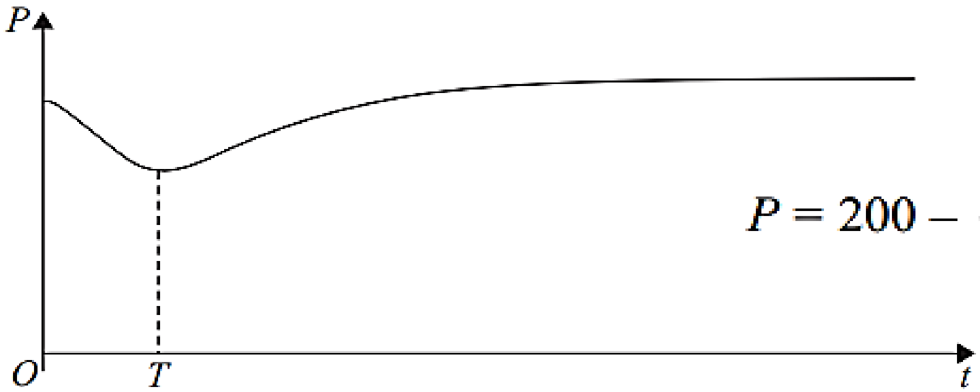

Figure 5

$$P = 200 - \frac{160e^{0.6t}}{15 + e^{0.8t}} \qquad t \in \mathbb{R}, t \geqslant 0$$

Taken from C34 June 2017

(c) What happens to the value of *P* as *t* increases beyond *T*?

Taken from C34 June 2017 mark scheme

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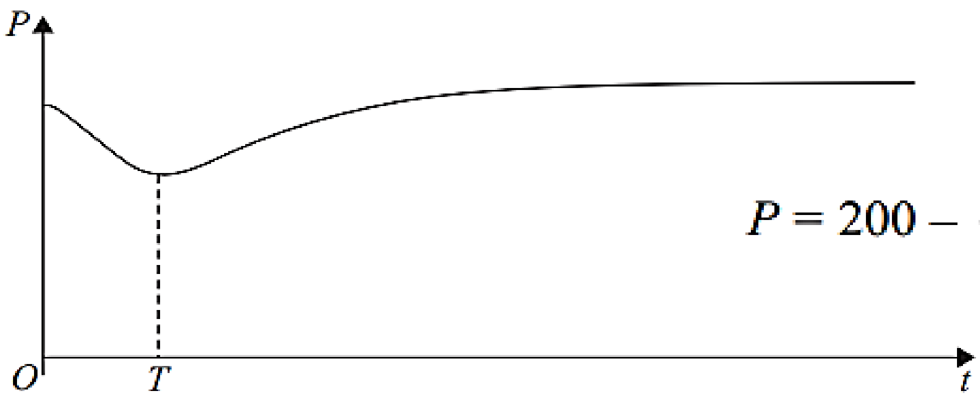


Figure 5

Taken from C34 June 2017

$$P = 200 - \frac{160e^{0.6t}}{15 + e^{0.8t}} \qquad t \in \mathbb{R}, t \geqslant 0$$

(c) What happens to the value of *P* as *t* increases beyond *T*?

Taken from C34 June 2017 mark scheme

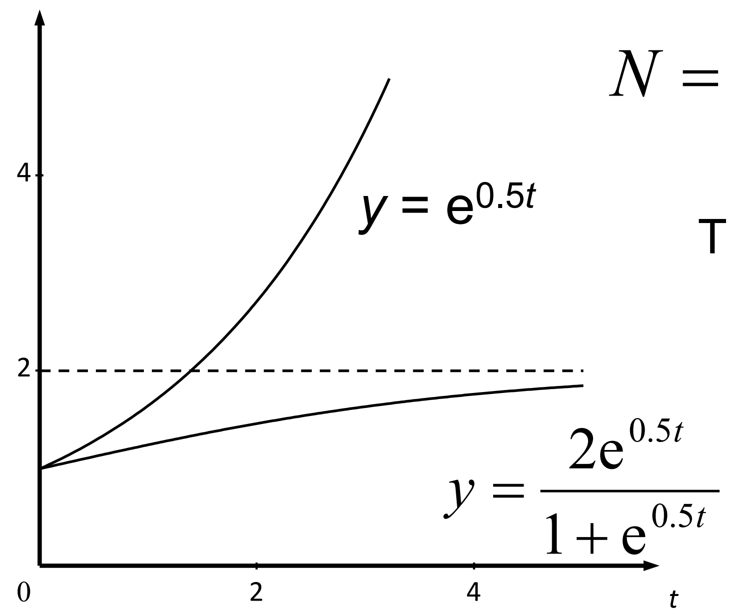
For large values of *t* , *P* behaves like $200 - 160e^{-0.2t}$
so tends towards 200 from below
(as, in fact shown in the figure)

Modelling with Exponentials

Understand and use exponential growth and decay.
Consideration of a second improved model may be required.

The simple model of exponential growth $N = N_o e^{kt}$ predicts **unrestricted** growth as *t* increases.

A more sophisticated model with $k > 0$ is shown below



$$N = \frac{Ae^{kt}}{1 + Be^{kt}}$$

The initial value of N is $A/(1 + B)$

N tends to A/B as t gets large.

AL June 2019 Paper 1 (Qu 12)

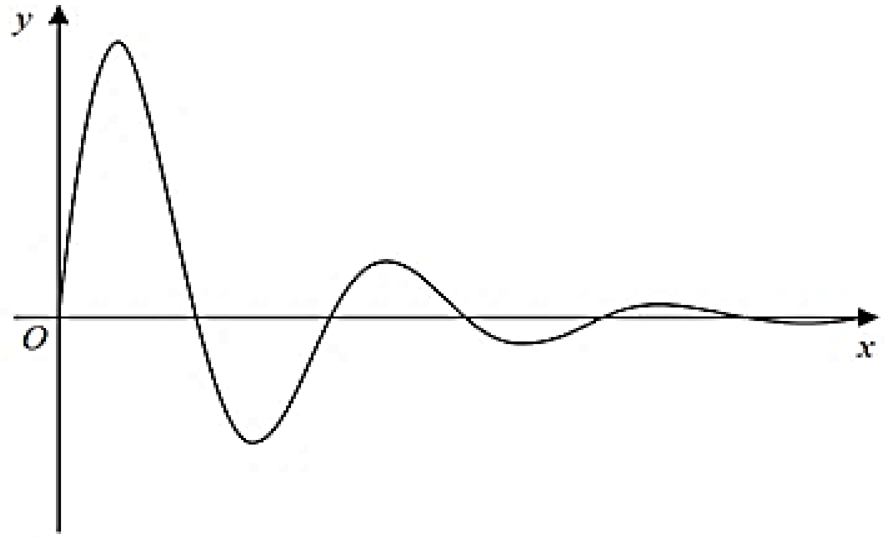


Figure 3

Figure 3 shows a sketch of part of the curve with equation $y = f(x)$.

(*b*) Sketch the graph of H against t where

$$H(t) = |10e^{-0.25x} \sin t| \qquad t \geq 0$$

showing the long-term behaviour of this curve.

(2)

The function $H(t)$ is used to model the height, in metres, of a ball above the ground t seconds after it has been kicked.
Using this model, find

(*c*) the maximum height of the ball above the ground between the first and second bounce. **(3)**

(*d*) Explain why this model should not be used to predict the time of each bounce. **(1)**

Paper 1 Qu 12 - Analysis

12. $$f(x) = 10e^{-0.25x} \sin x, \quad x \geqslant 0$$

(a) Show that the x coordinates of the turning points of the curve with equation $y = f(x)$ satisfy the equation $\tan x = 4$

(4)

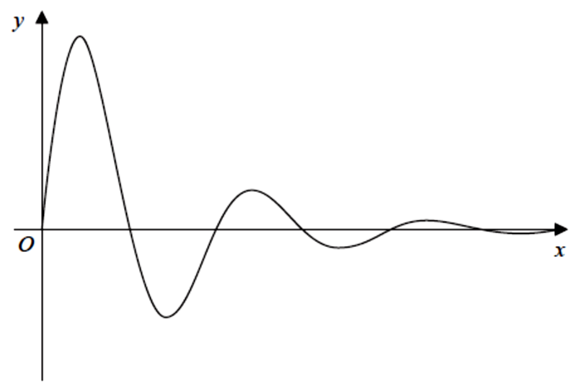


Figure 3

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The function $H(t)$ is used to model the height, in metres, of a ball above the ground t seconds after it has been kicked.

Using this model, find

(c) the maximum height of the ball above the ground between the first and second bounce.

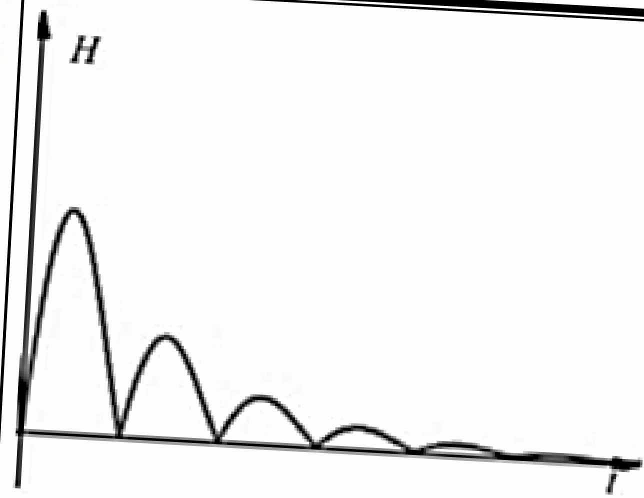
(3)

(d) Explain why this model should not be used to predict the time of each bounce.

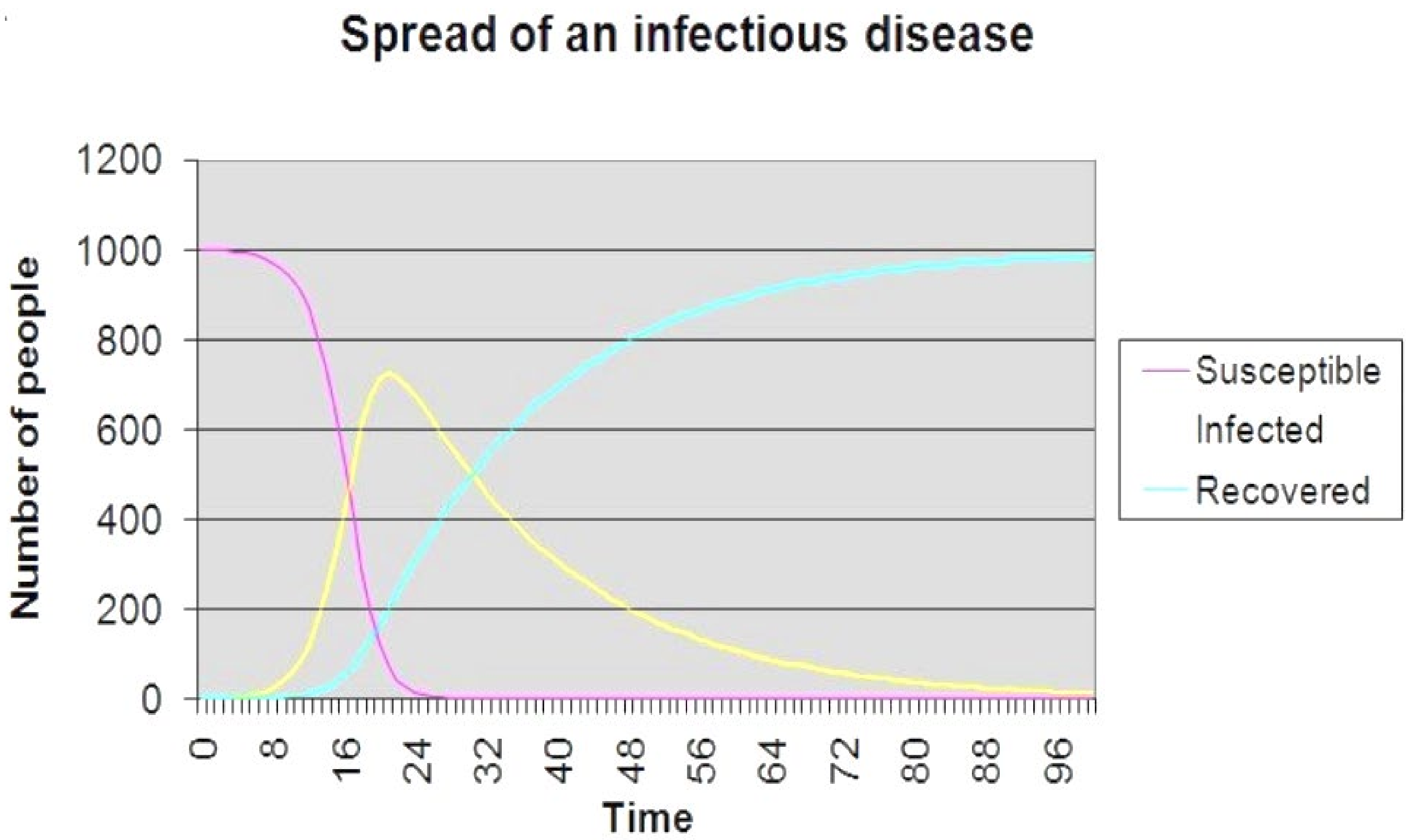
(1)

Question	Mean score	Max score	Mean %	Modal score
12	4.15	10	42	0

AL June 2019 Paper 1 (Qu 12)

10 (b)		M1 A1	This mark is given for a graph with a correct shape This mark is given for a graph with heights > 0
(c)	$\tan x = 4$, $x = 1.326$ $t = \pi + 1.326 = 4.47$	M1	This method is given for finding a value for t between the first and second bounce
	$H(4.47) = \lvert 10e^{-0.25\times 4.47}\sin 4.47\rvert$	M1	This mark is given for substituting the value of $t = \pi + \arctan 4$ into $H(t)$
	$= \lvert 3.27 \times -0.97\rvert$ $= 3.17$ metres	A1	This mark is given for finding the maximum height of the ball
(d)	The time between each bounce should not stay the same when the heights of each bounce are getting smaller	B1	This mark is given for a valid explanation of why the model should not be used the predict the time of each bounce

Plenary



Spread of an infectious disease
1200
1000
800
600
400
200
0
Number of people
0
8
16
24
32
40
48
56
64
72
80
88
96
Time
Susceptible
Infected
Recovered

Support Docs

GUMLEY HOUSE
Convent School F.C.J.

Google Drive Link

Free Resources for Legacy, IAL and 2017 A-Level Courses

http://tinyurl.com/yaqj3jao

Pearson
Edexcel

2017 Baseline & Unit Tests AS-AL SoW
Calculators
Core Pure 1 Dr Frost Powerpoints
Core Pure 2 Dr Frost Powerpoints
F Mech 1 Dr Frost Powerpoints
F Stats 1 Dr Frost Powerpoints
Guides & Mappings
Homework Packs (Gumley House)

Joe Berwick (AL)
June 2018 Papers
Large Data Set
Mechanics 1 Dr Frost Powerpoints
Mechanics 2 Dr Frost Powerpoints
Pearson SAMs (Accredited)
Pearson SoW (Accredited)
Pearson Specs (Accredited)

Mock, Practice and Specimen Papers
Pure 1 Dr Frost Powerpoints
Pure 2 Dr Frost Powerpoints
SolutionBank
Statistics 1 Dr Frost Powerpoints
Statistics 2 Dr Frost Powerpoints
Teaching & Learning PPTs
Transition Worksheets GCSE to AS

A level (Case Study) v3.ppt
A level GRTT presentation (Oct
Formulae and Statistical Tables.pdf
Owen PPTs (whole Couse).zip
STEP-AEA-MAT-Database.docx
Timetable June 2019 - Final (maths and stats

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Thank you for your attention

Q & A Session

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ALWAYS LEARNING