# 7.8 Exponential Models with Differential Equations

Name: _____ Class: _____ Date: _____ **Total: 26 marks**

**KEY WORDS** exponential growth • exponential decay • half-life • doubling time • Newton's law of cooling • dose

## Objective

Build the skills to answer exam questions on **exponential models with differential equations** : $\frac{dy}{dt} = ky$, doubling time and half-life, Newton's law of cooling, and repeated doses.

**You must be able to:**

- solve $\frac{dy}{dt} = ky$ as $y = y_0 e^{kt}$
- find $k$ from a doubling time, a half-life or two data values
- use $T = A + (T_0 - A)e^{kt}$ for cooling and heating
- answer "when" questions with logarithms

## 1 Key knowledge and worked examples

### ■ Exponential models

| model | solution |
|---|---|
| $\frac{dy}{dt} = ky$ | $y = y_0 e^{kt}$; growth if $k > 0$, decay if $k < 0$ |
| doubling time $D$ | $k = \frac{\ln 2}{D}$ |
| half-life $H$ | $k = -\frac{\ln 2}{H}$, so $y = y_0 \left(\frac{1}{2}\right)^{t/H}$ |
| two values | $y(t_1) = y_0 e^{kt_1}$ gives $k = \frac{1}{t_1} \ln \frac{y(t_1)}{y_0}$ |
| cooling, room temperature $A$ | $\frac{dT}{dt} = k(T - A)$ gives $T = A + (T_0 - A)e^{kt}$ |
| "when?" | isolate $e^{kt}$, then take ln |

**Worked example 1: doubling.** Bacteria double every 3 hours, starting from 500. Find the number after 7 hours.

1. Known: $k = \frac{\ln 2}{3}$.
2. Rule: $y = 500e^{kt} = 500 \cdot 2^{t/3}$.
3. Numbers: $500 \cdot 2^{7/3}$.
4. Result: **about** 2520 **bacteria**.

**Worked example 2: half-life.** Carbon-14 has half-life 5730 years. What fraction is left after 2000 years?

1. Known: $y = y_0 \left(\frac{1}{2}\right)^{t/5730}$.
2. Rule: fraction $= \frac{y}{y_0}$.
3. Numbers: $\left(\frac{1}{2}\right)^{2000/5730}$.
4. Result: **about** 0.785.

**Answer shapes:** give $k$ exactly (with ln) and then as a decimal; give units for times.

## 2 Practice

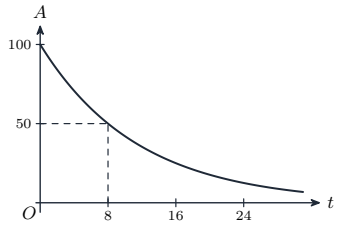
**2.1** $\frac{dy}{dt} = 0.04y$ and $y(0) = 200$. Find $y(t)$ and $y(10)$. [2]

$\frac{dy}{dt} = 0.04y$ $y(0) = 200$

**2.2** A population grows according to $\frac{dP}{dt} = kP$. It grows from 1000 to 1500 in 4 years. Find $k$, and the population after 10 years. [3]

$P(0) = 1000$ $P(4) = 1500$

**2.3** Iodine-131 has a half-life of 8 days. A sample starts with 100 mg; its graph is shown. After how many days does 10 mg remain? [3]








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## 3 Exam-style questions

**3.1** A patient takes 400 mg of a medicine at $t = 0$. The amount $A$ mg in the body satisfies $\dfrac{dA}{dt} = -kA$, and the half-life of the medicine is 6 hours.

(a) Find $k$ and an expression for $A(t)$. [3]

dose 400 mg | half-life 6 h

(b) Find the amount after 15 hours, and the time when 50 mg remain. [4]



(c) A second 400 mg dose is taken at $t = 6$. Find the amount just after the second dose, and the amount at $t = 12$ (before any third dose). Find the rate at which the amount is decreasing at $t = 12$. [5]

(d) The patient takes 400 mg every 6 hours. Let $D_n$ be the amount just after the $n$th dose, so $D_1 = 400$. Show that $D_{n+1} = \frac{1}{2}D_n + 400$. Find $D_2$ and $D_3$, and the level $D$ that the amounts approach, where $D = \frac{1}{2}D + 400$. [6]



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