IGCSE BIOLOGY • EXERCISE SHEET

5.1.1 Enzyme experiments: turning times into rates, and explaining the curve

Name: _____ Class: _____ Date: _____ **Total: 36 marks**

KEY WORDS enzyme 酶 • temperature 温度 • rate 速率 • investigation 探究 • catalyst 催化剂

Objective

Sheet 5.1 taught you what an **enzyme** 酶 is and what heat does to it. This sheet takes you to the questions the exam actually sets on 5.1: nearly every one of them is an **investigation** 探究 – a table of times or volumes, a graph, and two words at the end, *describe* and *explain*. You will turn times into **rates** 速率, read a curve on both sides of its peak, and write the sentences the mark scheme pays for. This sheet covers syllabus 5.1.

You must be able to:

- describe a **catalyst** 催化剂 as a substance that increases the rate of a chemical reaction and is not changed by the reaction
- describe enzymes as **proteins** 蛋白质 that are biological catalysts, involved in all reactions of **metabolism** 新陈代谢
- describe why enzymes matter to every living thing: they raise the reaction rate enough to keep the organism alive
- describe enzyme action using the **active site** 活性位点 being **complementary** 互补 to its **substrate** 底物, and the forming of **products** 产物
- explain enzyme action using active site, **enzyme-substrate complex** 酶底物复合物, substrate and product
- explain why each enzyme is **specific** 专一 to one substrate
- investigate and describe how temperature and pH change enzyme activity, including the **optimum** 最适 value and **denaturation** 变性
- explain the effect of temperature using **kinetic energy** 动能, shape and fit, the frequency of successful **collisions** 碰撞, and denaturation
- explain the effect of pH using shape and fit, and denaturation

1 Worked examples

Study these first. Each one shows a **method** that a question later on this sheet needs.

■ The sentences an enzyme question pays for

Six lines carry almost every recall mark on this subtopic. Learn them as sentences, not as ideas.

1. A catalyst **speeds up a reaction and is not used up** by it, so it can work again and again.
2. Enzymes are **proteins**. They are biological catalysts, made by living cells, and they take part in **all** the reactions of metabolism.
3. Without enzymes those reactions would be **far too slow to keep the organism alive**. That is why enzymes matter.
4. The substrate fits into the **active site**, whose shape is **complementary** to it. An **enzyme-substrate complex** forms, the reaction happens, and the **products** leave. The enzyme is unchanged and free to be used again.
5. Each enzyme is **specific**: only a substrate of the matching shape fits its active site, the way only one key fits a lock.
6. "Denatured" means the **shape of the active site has changed**, so the substrate no longer fits. It does **not** mean the enzyme was killed. Enzymes are not alive.

■ Turning a time into a rate

time falls ↓

time / s	rate = 1000 ÷ time
100	1000 ÷ 100 = 10
50	1000 ÷ 50 = 20
40	1000 ÷ 40 = 25

↓ rate rises

A shorter time always means a faster rate.
Never compare the times themselves.

An enzyme experiment almost always measures a **time**: how long until the starch has gone, until the milk turns clear, until a set volume of gas is collected. A time is not a rate – in fact it runs the other way round, so comparing the times themselves gets the answer backwards.

$$\text{rate} = \frac{1000}{\text{time in s}}$$

Worked example. A reaction takes 100 s at 20 °C and 40 s at 40 °C. How many times faster is it at 40 °C?

1. Turn each time into a rate.

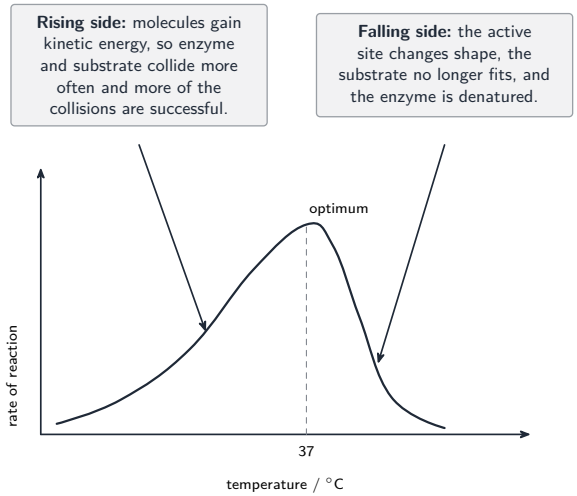
$$\text{rate at } 20\ ^\circ\text{C} = \frac{1000}{100} = 10 \qquad \text{rate at } 40\ ^\circ\text{C} = \frac{1000}{40} = 25$$

2. Divide the larger rate by the smaller.

$$\frac{25}{10} = \mathbf{2.5} \text{ times faster}$$

- For "how many times faster" alone there is a shortcut: divide the **longer time by the shorter time**, $100 \div 40 = 2.5$. Never **subtract** them – $100 - 40 = 60$ is a number of seconds, not a comparison.

Describe, then explain – they are two different jobs



Describe means: say what the graph or table *does*, using numbers off the axes. No reasons.

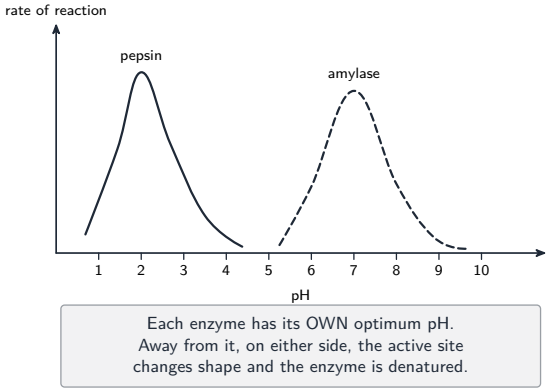
> The rate rises from 10 °C to a maximum at 37 °C, then falls sharply, reaching almost zero by 60 °C.

Explain means: say *why*. The two sides of the curve need **different** reasons, and a sentence that only fits one side throws away the other mark.

side of the peak	what to write
below the optimum	molecules gain **kinetic energy** and move faster, so enzyme and substrate **collide more often** and more of the collisions are successful, so more enzyme-substrate complexes form
above the optimum	the heat **changes the shape of the active site**, the substrate **no longer fits**, so the enzyme is **denatured**; this is permanent

- The peak itself is the **optimum temperature** – the temperature at which the enzyme works fastest. For a human enzyme that is about 37 °C.
- Never write "it works better because it is hotter". That repeats the question and earns nothing.

pH: every enzyme has its own optimum

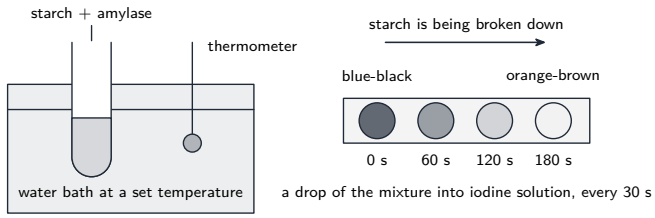


pH has only **one** explanation, and it is the denaturation one – there is no kinetic-energy half:

> Away from its optimum pH the shape of the active site changes, the substrate no longer fits, and the enzyme is denatured.

- **pH 7 is not the answer for every enzyme. Pepsin** 胃蛋白酶 works in the stomach and its optimum is about pH 2; **amylase** 淀粉酶 works in the mouth and small intestine and its optimum is about pH 7.
- Read the optimum off the graph as the pH at the **peak**, and quote it.

Setting the investigation up



What you measure is a TIME: how long until iodine solution stays orange-brown, which is the moment the last of the starch has gone.

Three kinds of variable, and the exam asks for all three:

- the **independent variable** 自变量 is the one you **change** on purpose (temperature, or pH);
- the **dependent variable** 因变量 is the one you **measure** (a time, a volume, a colour change);
- the **control variables** 控制变量 are everything you **keep the same** so the test is fair: the volume and concentration of the enzyme, the volume and concentration of the substrate, and whichever of pH or temperature you are not changing.

method	what is measured
amylase on starch, spotted into **iodine solution** 碘液	the time until the iodine stays orange-brown, which is the moment the last starch has gone
catalase on hydrogen peroxide	the volume of oxygen collected in a set time, or the bubbles per minute
pectinase on crushed apple	the volume of juice that runs through the filter
protease on cloudy milk	the time until the milk turns clear

- A **water bath** 水浴 is what holds the temperature steady, and it is worth a mark on its own.
- To make results more **reliable** 可靠, repeat each reading at least three times and take a **mean** 平均值.

2 Practice

Now use the methods above.

2.1 A student timed how long amylase took to break down all the starch at three temperatures.

temperature / °C	time taken / s
20	100
30	50
40	40

Calculate the rate of reaction at each temperature, using rate = 1000 ÷ time. [3]

2.2 State which temperature gave the fastest reaction, and explain how the times show this. [2]

2.3 Name the independent variable and the dependent variable in this investigation. [2]

2.4 State **two** variables the student must keep the same. [2]

2.5 Explain why the reaction was faster at 40 °C than at 20 °C. Use the words *kinetic energy* and *collisions*. [3]

2.6 The student repeated the experiment at 70 °C. After 10 minutes the iodine solution was still blue-black. Explain this result. [3]

3 Exam-style questions

3.1 An enzyme breaks down its substrate in 250 s at 15 °C and in 50 s at 35 °C. How many times faster is the reaction at 35 °C? [1]

A B
C D

A 0.2
B 5
C 200
D 300

3.2 Pepsin digests protein in the stomach. A student timed how long pepsin took to digest a piece of cooked egg white at four pH values.

pH	time taken / s
1	120
2	60
4	200
7	no change after 600

(a) Calculate the rate of reaction at pH 2 and at pH 4, using rate = 1000 ÷ time. Give each answer to 2 significant figures. [2]

(b) State the optimum pH of pepsin, and give the evidence from the table. [2]

(c) Explain why no protein was digested at pH 7. [2]

3.3 A food company uses the enzyme **pectinase** 果胶酶 to get more juice out of crushed apples. A student investigated how temperature affects pectinase.

She put 20 g of crushed apple and 2 cm^3 of pectinase into each of six test tubes. She kept each tube at a different temperature for 20 minutes, then filtered the mixture and measured the volume of juice collected.

temperature / °C	volume of juice / cm^3
10	3.0
20	5.5
30	9.0
40	12.5
50	6.0
60	0.5

(a) Name the independent variable and the dependent variable. [2]

(b) State **two** variables that were kept the same. [2]

(c) Describe the results shown in the table. [3]

(d) Explain the results between 10 °C and 40 °C. [3]

(e) Explain why almost no juice was collected at 60 °C. [3]

(f) Suggest one change the student could make so that her results are more reliable. [1]

Solutions

Each answer shows the steps, then the **result**.

2.1

- divide 1000 by each time

$$\frac{1000}{100} = \mathbf{10} \qquad \frac{1000}{50} = \mathbf{20} \qquad \frac{1000}{40} = \mathbf{25}$$

- the units are "arbitrary units" here, because 1000 was only chosen to keep the numbers tidy

2.2

- **40 °C**
- it took the **shortest time** (40 s), and a shorter time means a faster rate

2.3

- independent variable: the **temperature**
- dependent variable: the **time taken for the starch to be broken down**

2.4

- any **two** of: the volume or concentration of amylase; the volume or concentration of starch; the pH; the volume of iodine solution used for each test

2.5

- at 40 °C the molecules have more **kinetic energy**, so they move faster
- enzyme and substrate molecules **collide more often**, and more of those collisions are successful
- so more enzyme-substrate complexes form each second and the starch is broken down faster

2.6

- 70 °C is far **above the optimum temperature** for amylase
- the heat has **changed the shape of the active site**, so starch no longer fits it
- the enzyme is **denatured**, and the change is permanent, so no starch was broken down and the iodine stayed blue-black

3.1 B

- turn each time into a rate, or divide the longer time by the shorter one

$$\frac{250\text{ s}}{50\text{ s}} = \mathbf{5}\text{ times faster}$$

- **A** is the division upside down, $50 \div 250$; **C** is the difference $250 - 50$; **D** is the sum $250 + 50$. None of those compares two rates.

3.2

(a)

- divide 1000 by each time

$$\text{pH 2: } \frac{1000}{60} = \mathbf{17} \qquad \text{pH 4: } \frac{1000}{200} = \mathbf{5.0}$$

(b)

- **pH 2**
- it gave the **shortest time**, 60 s, so the fastest rate; the times get longer on both sides of it

(c)

- pH 7 is far from pepsin's optimum pH, so the **shape of the active site has changed** and the protein no longer fits
- the enzyme is **denatured**, so no enzyme-substrate complexes can form

3.3

(a)

- independent variable: the **temperature**
- dependent variable: the **volume of juice collected**

(b)

- any **two** of: the mass of crushed apple (20 g); the volume of pectinase (2 cm^3); the time the tubes were left (20 minutes); the same apple variety; the same filter paper

(c)

- the volume of juice **rises** as the temperature rises from 10 °C to 40 °C, from 3.0 cm^3 to 12.5 cm^3
- the **maximum** volume is at **40 °C**
- above 40 °C the volume **falls sharply**, to only 0.5 cm^3 at 60 °C
- a description quotes figures off the table; it gives no reasons

(d)

- as the temperature rises the molecules gain **kinetic energy** and move faster
- pectinase and its substrate **collide more often**, and more of the collisions are successful
- so more of the pectin is broken down in the 20 minutes, releasing more juice

(e)

- 60 °C is far **above the optimum temperature** of pectinase
- the heat has **changed the shape of the active site**, so the substrate no longer fits
- the enzyme is **denatured**, so almost no pectin was broken down and almost no extra juice was released

(f)

- **repeat** each temperature at least three times and take a **mean** volume