Bio Factsheet

Number 52

Data Interpretation Questions: Temperature Regulation

Temperature regulation is one form of **homeostasis**. Birds and animals are endothermic, that is, they are able to maintain a high body temperature by internal heat production. In contrast, the temperature of **ectotherms** depends upon the external environmental temperature. Although endothermy has been removed from some A Level Biology syllabuses, the topic is still tested in data interpretation questions, since it can be used to illustrate several important biological principles.

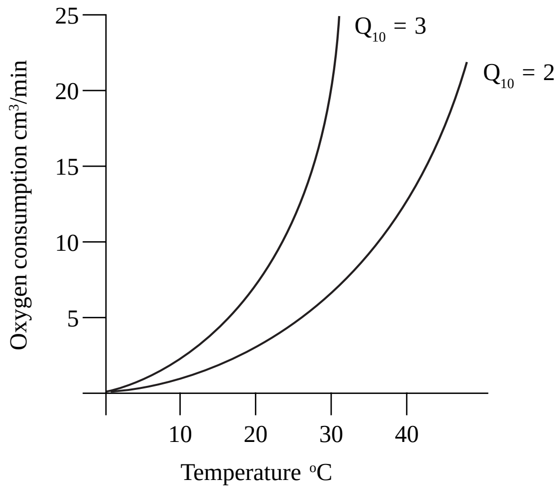
The effect of temperature on metabolic processes

Generally, as temperature increases, the rate of a metabolic process also increases. Since it is difficult to directly measure the actual rate of most metabolic processes, the rate of oxygen consumption is often used as an index of the rate.

The increase in rate caused by a temperature increase of 10°C is known as Q_{10}. For example, if the rate of a process doubles, the Q_{10} would be 2, if it triples it would be 3.

Fig 1 shows the increase in oxygen consumption caused by increased temperature for processes with Q_{10} = 2 and 3. Enzyme controlled reactions, up to the optimum temperature, have a Q_{10} of 2.

Fig 1. Temperature and oxygen consumption



Recall Questions: Answering diagram and application questions is alwalys easier if you know the factual background to a topic. In terms of questions on this topic it is important that you understand how adaptation to regulated body temperature works - the table below lists some of the most commonly examined examples.

Structural	1. Hairs trap air, which is a poor conductor. Long hairs shade skin, e.g. camels. 2. Subcutaneous fat is a poor heat conductor; it therefore acts as an insulator, e.g. polar bears. 3. Sweat glands cool the animal because they use latent heat when sweat evaporates. 4. Counter-current arrangement of arteries and veins in the legs of arctic mammals, e.g. in bears, the veins are wrapped around arteries, so the blood of arteries is cooled by the venous blood, therefore decreasing heat loss.
Physiological	1. Thermoreceptors in hypothalamus and under the skin. 2. Erector muscles enable hairs to become erect, trapping more insulating air. 3. Vasoconstriction of skin arterioles decreases blood volume near skin surface, therefore decreasing heat loss. 4. Shivering – uncontrollable contraction of muscles generates metabolic heat. 5. Reduction of core temperature when in very cold conditions to decrease heat transfer.
Behavioural	1. Hippos/elephants spray water over themselves, which cools them when it evaporates. 2. Avoidance of hottest parts of day, e.g. by staying under cover, burrowing in sand, or, if too cold, huddling together, e.g. penguins, so that their collective surface area is reduced. 3. Raising of feathers and withdrawal of head and feet into feathers to conserve heat in birds, e.g. pigeons.

There are three typical exam questions set on the type of graph shown in Fig 1:

1. Plot a graph given the tabulated data.
2. Calculate the change in the volume of oxygen consumption for a stated change in temperature.
3. Comment on the significance of the change in the volume of oxygen consumed.

1. Plotting the graph

Imagine you are asked to plot the data shown in Table 2.

Table 2.

Temperature (°C)	**Rate of oxygen consumption (cm^3/min)**
0	2.5
10	3.8
20	9.0
30	24.1

There are likely to be at least four available marks:

(i) For using a suitable scale on the x and y axes.

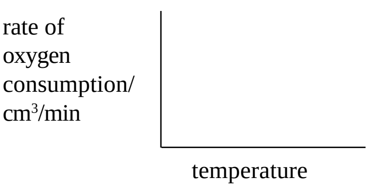
(ii) For labelling the x and y axes correctly.

(iii) For plotting the points correctly.

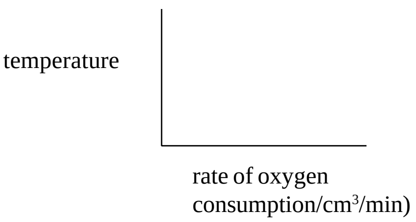
(iv) For joining the points with a **straight** line (Institute of Biology recommendations).

If graph paper is provided, you should ensure that your graph fills half of the page.

Every year a small but significant percentage of students plot the graph the wrong way round. It should be:



but many students will plot:



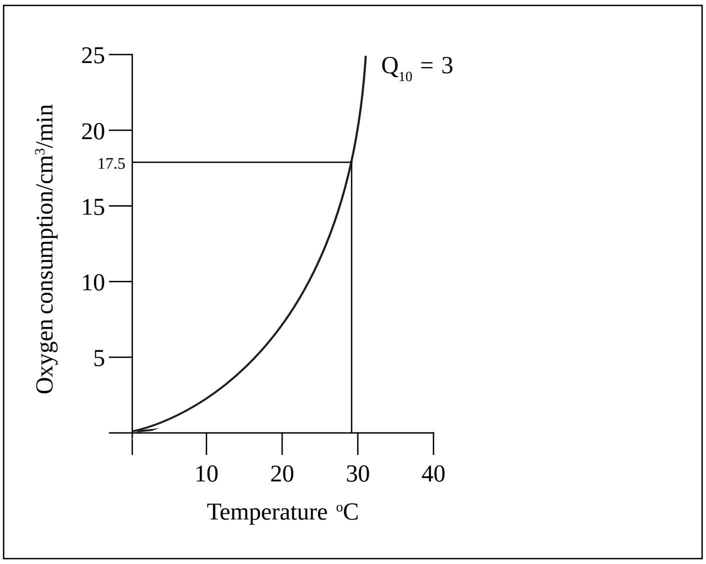
To get it (and every graph in future) the right way round, ask yourself one question: "**Which variable determines/controls/influences the other?**" (Here the two variables are temperature and oxygen consumption.) The determining variable always goes on the x (bottom) axis. Temperature clearly determines oxygen consumption, so it is temperature which goes on the x axis.

2. Calculating the change in oxygen consumption, given a change in temperature

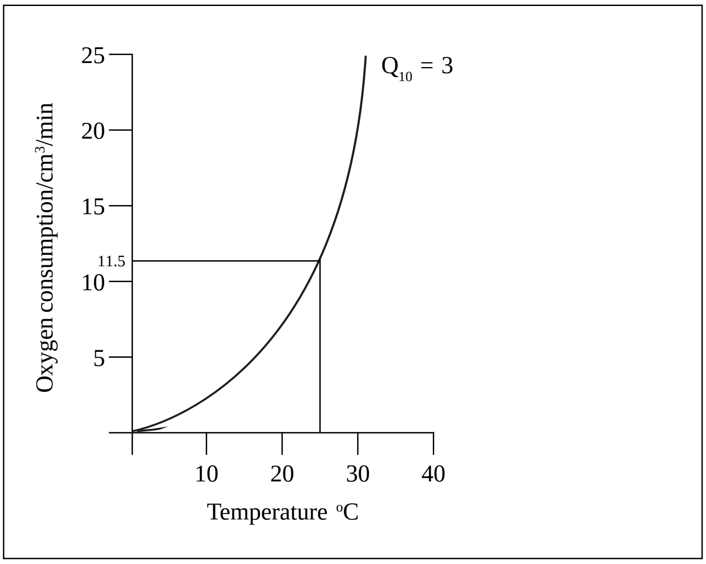
For example, calculate the change in oxygen consumption caused by a temperature change from 25°C to 29°C.

This is simple:

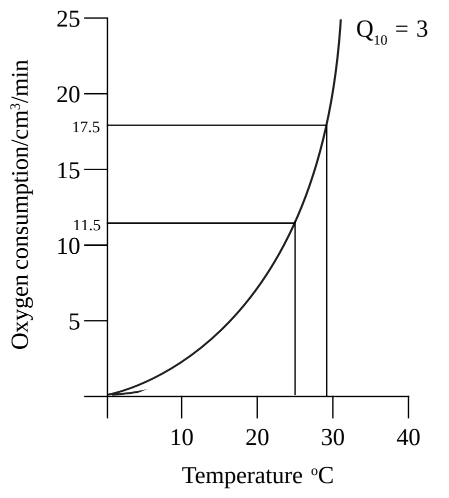
1. Read off the volume of oxygen used at 29°C by drawing a ruler line up from 29°C until it hits the curve and then drawing a line from that point to the left hand axis.



2. Read off the volume of oxygen used at 25°C by drawing a ruler line up from 25°C until it hits the curve and then drawing a line from that point to the left hand axis.



The figure overleaf, on page three shows these two measurements on the same graph.



Thus the changes in oxygen consumption = 17.5 - 11.5 = 6cm^3/min

Note: you may be asked to calculate the **percentage change** in the volume of oxygen consumed when the temperature is increased from 25°C to 29°C. Again, do not panic. Learn off by heart the following rule:

Percentage change in volume of oxygen consumed:

$$= \frac{\text{the change } (17.5 - 11.5)}{\text{the original value } 11.5} \times 100 = \frac{6}{11.5} \times 100 = 52.1\%$$

The most common mistake here is to divide the change (6) by the wrong value for oxygen consumption – **always** use the starting value.

3. The significance

The examiners are usually asking you to comment on the significance of the extra oxygen needed when temperature increases. Aquatic organisms face particular problems. This is because, as water temperature increases, the solubility of oxygen decreases – thus, as the water warms up, it holds less oxygen. This is unfortunate for aquatic organisms whose body temperature rises with the surrounding water – their metabolic process will be speeding up, as will their oxygen consumption, at precisely the same time, as less is available in the water. For this reason, sudden temperature change in ponds, streams and rivers (e.g. if a factory or power station released warm water) can be fatal. The organism may be killed by the lack of oxygen rather than the harmful effects of the warm water on their tissues. The increased temperature of water is also a problem if it contains toxins, because as water temperature increases,

1. The toxin may enter the organism faster;

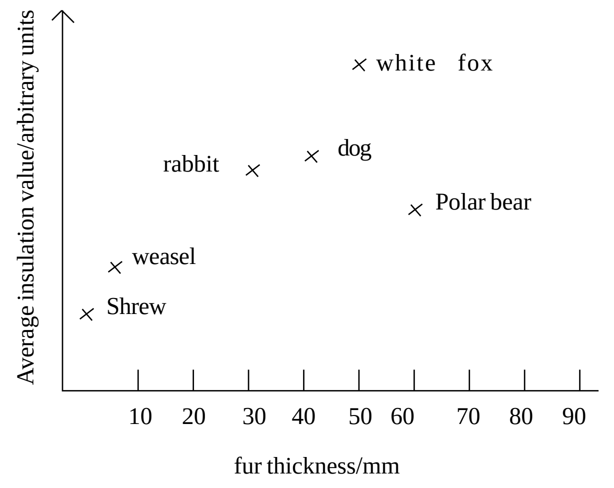
2. Once it has entered the organism's body, it will have a faster effect.

Heat Production

Insulation

Many animals possess fur which is a good insulator because it traps air. Generally, the thicker the fur, the greater the insulation value (Fig 2).

Fig 2. The insulation value of fur

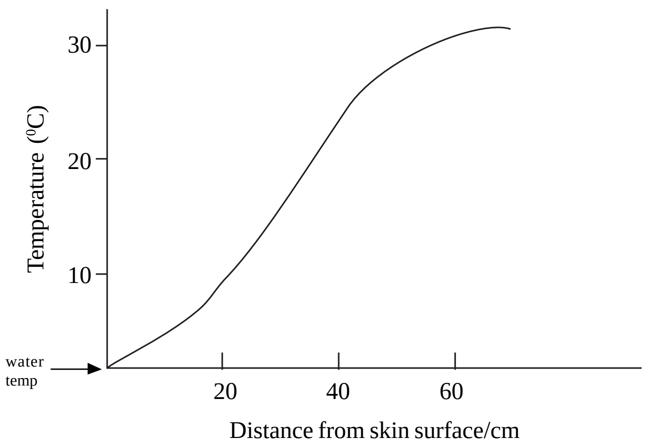


However, there are always going to be exceptions and these sometimes appear in application questions – those where the examiners expect you to apply your knowledge of basic principles to new, unusual situations. In Fig 2, the polar bear has thick fur, but that fur is offering surprisingly little insulation. The examiners may well ask you to suggest why. In these situations you should:

1. look carefully at the information provided. The left hand axis states that these are average values;
2. think about the habits of the organism with the unusual values. The polar bears spend a great deal of time in water. When submerged, the water will displace the insulating air and, indeed, heat loss to the water will be much faster than heat loss to air when the animal is out of the water. Thus, average insulation value is low.

Some aquatic animals use blubber to provide insulation. It is this which allows the polar bear to swim in icy water when its fur is providing no insulation at all. Similarly, the temperature of the skin surface of submerged seals is very similar to the water (Fig 3).

Fig 3. Seal body temperature



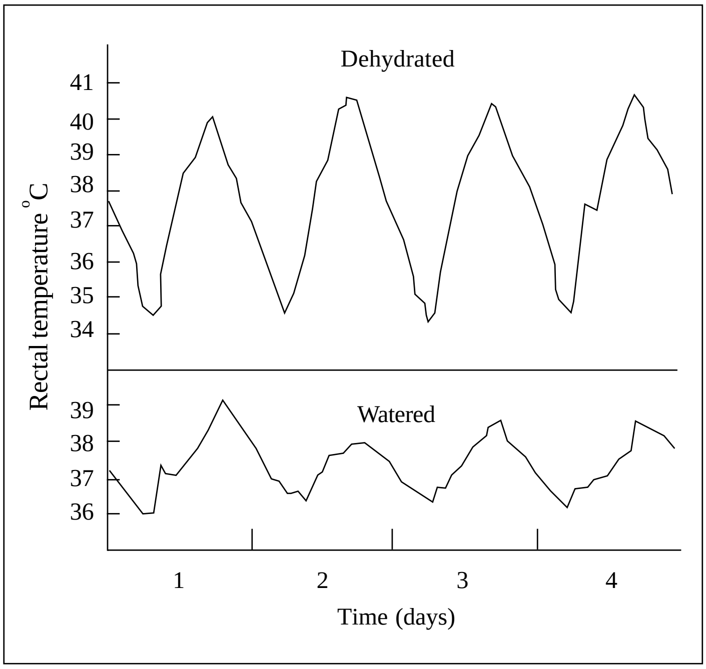
The significance of this is that, if the temperature of the skin is the same as the temperature of the water, then very little heat can be transferred to the water. The blubber beneath the seal's skin allows the body of the seal to remain 30°C warmer just 60cm from the surface of the skin. In contrast, if the seal begins to overheat, more blood is pumped through the blubber to the superficial layer of the skin. This increases heat loss to the environment.

Surface Area

Small animals have a larger surface area : volume ratio than large animals. This is why small, active organisms, such as shrews, need to keep eating – they are continually losing a lot of heat and their metabolic rate needs to be maintained at a high level. This is why most animals which **hibernate** are small – the difficulties of trying to maintain body temperature when the external temperature is very cold and when food is in short supply, are just too great. It is better to avoid the problems by decreasing metabolic rate, heart rate and respiration to a minimum. However, larger organisms still have problems and those that live in deserts have to face the problem of keeping cool whilst losing water.

Fig 4. illustrates daily temperature fluctuations in a well-watered camel and in one which has been deprived of water.

Fig 4. Rectal temperature of a dehydrated and watered camel



Typical exam questions would be:

1. Summarise the data shown.

2. Suggest an explanation for the difference in daily temperature fluctuation between the two camels.

1. "Summarise" means "describe concisely". Look for the trend. The temperature of both camels fluctuates, but the size of the fluctuation is much greater in the camel deprived of water. In other words, dehydration results in the camel having higher body temperature during the day – the camel is storing heat rather than sweating, something which only the well-watered camel can afford to do. Remember also that insulation works both ways – the thick hair of a camel can also reduce heat gain from the (hotter) environment, as well as decreasing heat loss when its own body temperature is higher than the environment.

Acknowledgements;
This Factsheet was researched and written by Kevin Byrne
Curriculum Press, Unit 305B, The Big Peg,
120 Vyse Street, Birmingham. B18 6NF

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