SA:V Ratio and Gas Exchange

A Level
C C C

The surface area to volume (SA:V) ratio of a cell/tissue/organ/organism is an important factor in the determining how efficiently that cell/tissue/organ/organism can exchange gases with its surroundings.

Part A SA:V ratios

Consider two cube-shaped cells: Cell **A** and Cell **B**.

- Cell **A** has a length of $5\,\mu\text{m}$.
- Cell **B** has a length of $10\,\mu\text{m}$.

Fill in the table below to compare their surface areas, volumes, and SA:V ratios. Give your answers as exact values i.e. do not round your answers.

	Length	Surface Area (SA)	Volume (V)	SA:V ratio
Cell A	$5\,\mu\text{m}$			: 1
Cell B	$10\,\mu\text{m}$			: 1

Part B How the SA:V ratio changes with size

Fill in the blanks below to explain how the surface area to volume (SA:V) ratio changes with size.

As the length of a cell/tissue/organ/organism increases, the volume [ ] and the surface area [ ]. However, for a given increase in length, the proportional change in volume is [ ] the proportional change in surface area. This is because volume is proportional to length [ ] whereas surface area is proportional to length [ ].

This means that as the length of a cell/tissue/organ/organism increases, the SA:V ratio [ ].

Using the example above, the length of cell **B** is $2\times$ that of cell **A**, its surface area is [ ] that of cell **A**, and its volume is [ ] that of cell **A**. This means that the SA:V ratio of cell **B** is [ ] that of cell **A**.

Items:

increases	**decreases**	**greater than**	**less than**	**squared**	**cubed**	$0.125\times$	$0.25\times$	$0.5\times$	$2\times$	$4\times$	$8\times$

Part C How the SA:V ratio affects gas exchange efficiency

Which of the following statements correctly describe a larger tissue in relation to a smaller tissue? Select all that apply.

Assume that the larger tissue has the same shape, proportions, and cell density as the smaller tissue, and that they are both the same type of animal tissue.

- [ ] it requires **more** oxygen
- [ ] it requires **less** oxygen
- [ ] it produces **more** carbon dioxide
- [ ] it produces **less** carbon dioxide
- [ ] it has a **larger** surface area, and so **more** gas exchange can occur in a given time period
- [ ] it has a **smaller** surface area, and so **less** gas exchange can occur in a given time period
- [ ] it has **more** surface area per unit volume, and so gas exchange is **more** efficient
- [ ] it has **less** surface area per unit volume, and so gas exchange is **less** efficient

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Part D Maximising the SA:V ratio

Which of the following features of the mammalian respiratory system is an adaptation designed to increase the SA:V ratio of the lungs?

- There is a circulatory system that transports gases (oxygen & carbon dioxide) to and from the lungs, rather than gases simply diffusing between the lungs and the other body tissues.
- The lungs are actively ventilated i.e. air is actively brought in and out of the lungs, rather than simply diffusing in and out.
- Air and blood travel in opposite directions in the lungs, and so gas exchange efficiency is maximised due to countercurrent exchange.
- The lungs are composed of many small air sacs (alveoli) rather than a few large air sacs.

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The Mammalian Respiratory System

A Level

All mammals share the same basic respiratory system structure: a single trachea branches into two separate lungs, each of which consists of progressively smaller branches that eventually end in alveoli, where gas exchange with the bloodstream occurs.

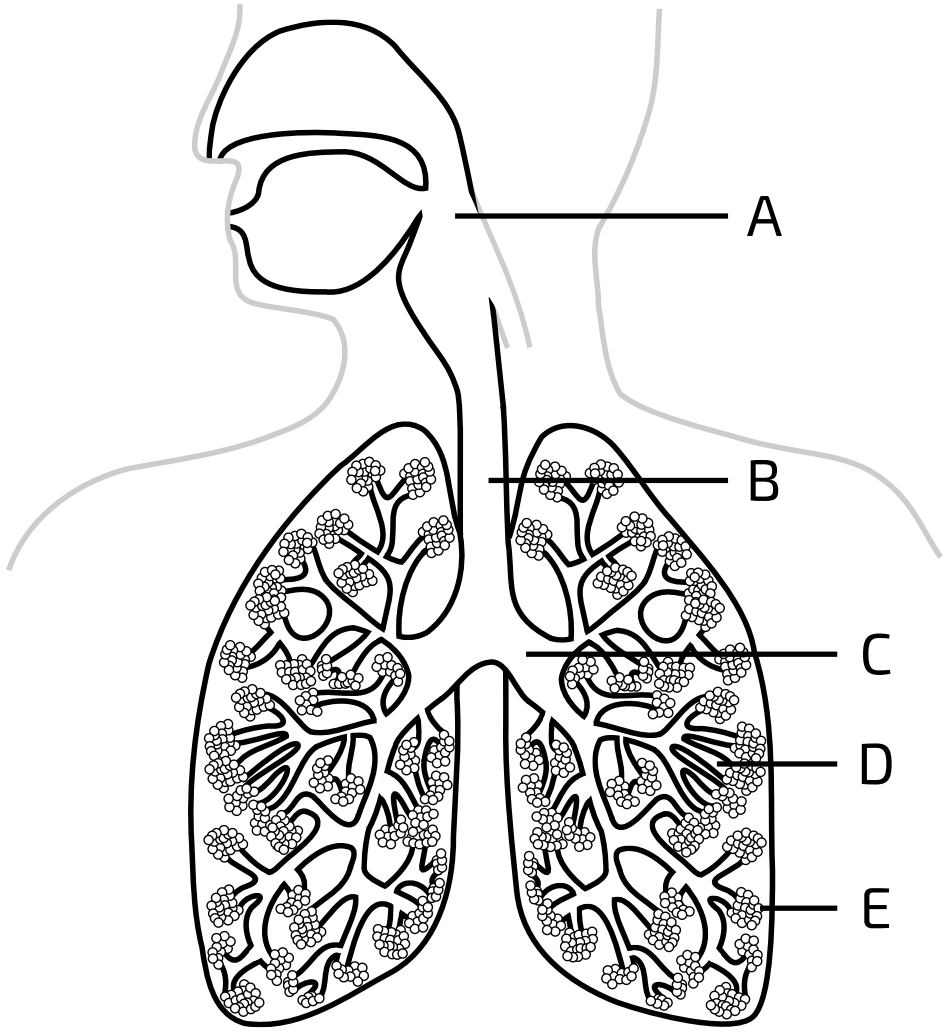

Figure 1: A simplified diagram of the human respiratory system. Specific regions are labelled (A-E). Region "A" separates into two tubes, one of which is the oesophagus (top part shown in grey) which leads to the digestive system (not shown). Structures "E" are not shown to scale.

Part A Respiratory anatomy

Match the name to the label from **Figure 1** in the table below.

Label	Name
A	
B	
C	
D	
E	

Items:

trachea **bronchiole** **alveolus** **pharynx** **bronchus**

Part B Respiratory functions

Match the structure/cell type to the function in the table below.

Function	Structure/cell type
secrete mucus onto the lining of the trachea to trap dust and pathogens	
move mucus upwards (away from the lungs) towards the pharynx	
provide structural support to the trachea and bronchi	
surround the bronchioles and can contract to reduce airflow to the lungs	
surround the alveoli, allowing them to expand during inhalation	
where gas exchange occurs between the air and the blood	

Items:

elastic fibres **ciliated epithelial cells** **cartilage rings** **smooth muscle** **alveoli** **goblet cells**

Part C Gas exchange efficiency

Which of the following statements correctly describe how features of the mammalian respiratory system ensure efficient gas exchange?

Select all that apply.

- [ ] The lungs are composed of many alveoli which **decreases** the surface area to volume ratio.
- [ ] The lungs are composed of many alveoli which **increases** the surface area to volume ratio.
- [ ] The wall of each alveolus is very **thin**.
- [ ] The wall of each alveolus is very **thick**.
- [ ] Each alveolus is covered by a dense network of capillaries, which maximises the amount of gas exchange that can occur.
- [ ] There is countercurrent flow between the blood and the air in the lungs, which maintains a high diffusion gradient.
- [ ] Airflow through the lungs is unidirectional which means that oxygen diffuses into the blood during both inhalation **and** exhalation.
- [ ] The lungs are **actively ventilated** rather than relying on passive diffusion.

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Alveoli

A Level

Alveoli are tiny air sacs found in mammalian lungs. It is here that gas exchange occurs between the blood and the air.

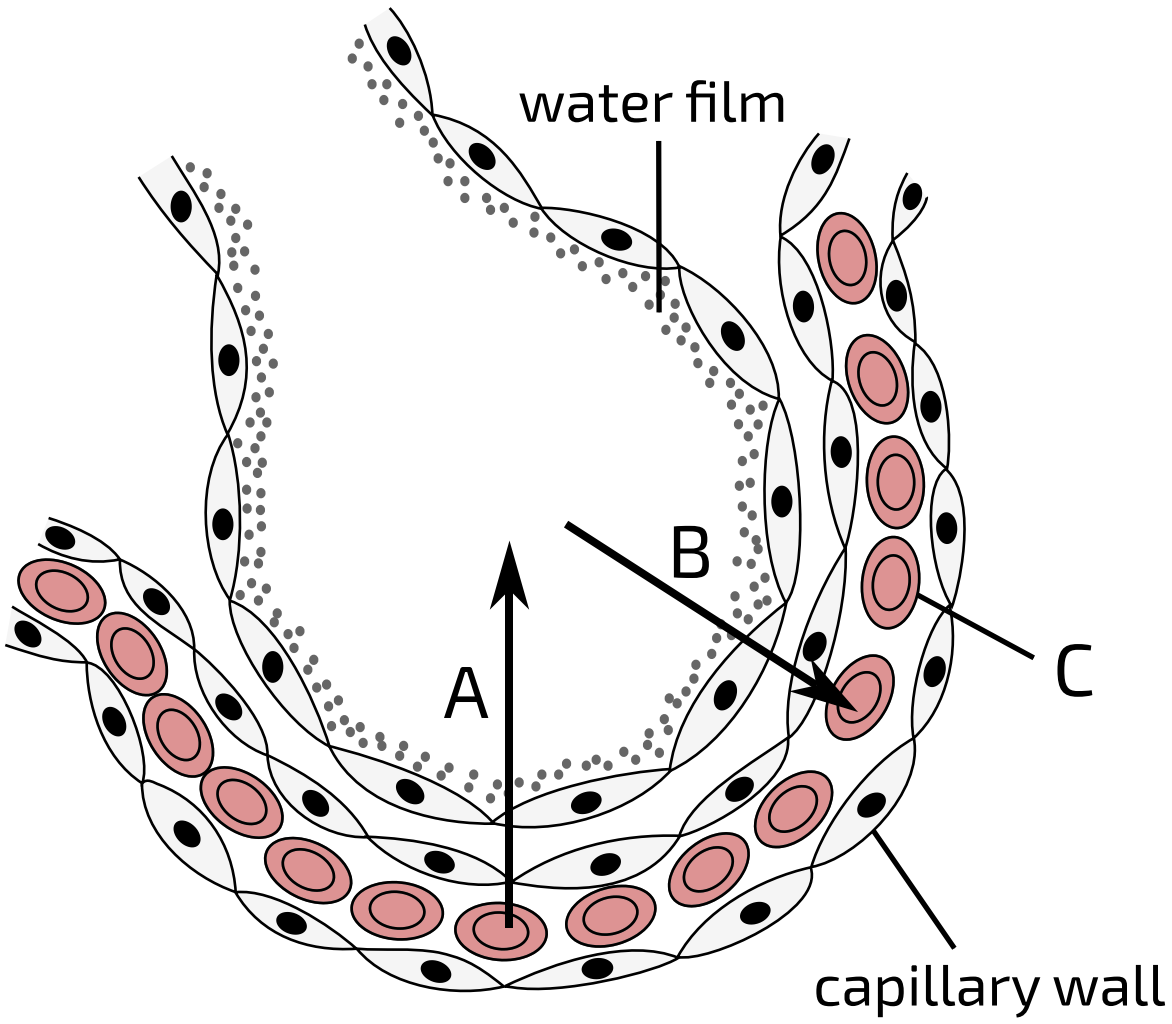

Figure 1: A cross-section of a mammalian alveolus and associated blood capillary. The water film covering the alveolar epithelial cells prevents the cells from drying out. Arrows (A,B) represent the movement of gases.

Part A Gas A

What is the name of the gas that moves in direction **A** in **Figure 1**?

Part B Gas B

What is the name of the gas that moves in direction **B** in **Figure 1**?

Part C Gas exchange

By which process do gases **A** and **B** move between the alveolus and the blood capillary?

- simple diffusion
- facilitated diffusion
- osmosis
- active transport

Part D Cell type

What is the name of cell type **C** in **Figure 1**?

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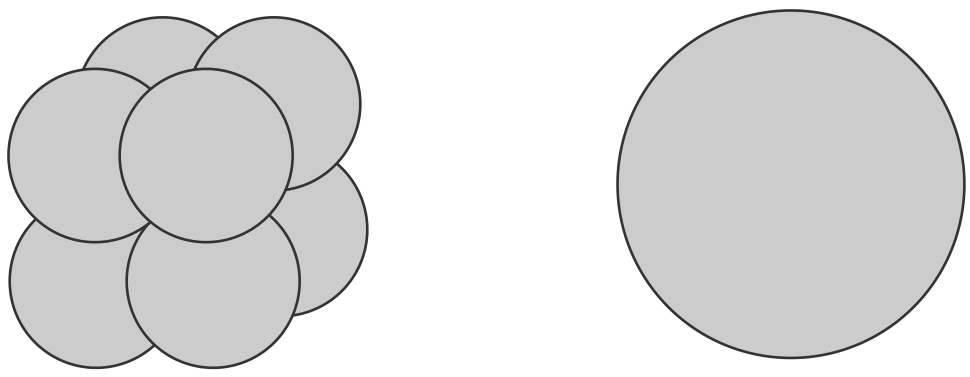
Emphysema

A Level

C C C

In the disease emphysema, the walls of the alveoli break down so that several smaller alveoli fuse to form a single large alveolus. This is shown below in **Figure 1**.



8 healthy alveoli

1 alveolus from a person with emphysema

Figure 1: The effect of emphysema on alveoli. The radius of a healthy alveolus is x, and the radius of an alveolus from a person with emphysema is $2x$. The shape of an alveolus (of both types) can be approximated as a sphere.

Part A SA:V ratios

Calculate the surface area to volume (SA:V) ratio for a healthy alveolus and for an emphysema alveolus.

- Healthy alveolus: [ ] : x
- Emphysema alveolus: [ ] : x

Part B Diffusion rates

Which of the following statements are true? Select all that apply.

- [ ] The surface-area-to-volume ratio of the 8 healthy alveoli is $2\times$ that of the single emphysema alveolus.
- [ ] The surface-area-to-volume ratio of the 8 healthy alveoli is $3\times$ that of the single emphysema alveolus.
- [ ] For the same concentration gradient, the rate of diffusion of oxygen into the blood from a single healthy alveolus will be greater than for a single emphysema alveolus.
- [ ] For the same concentration gradient, the rate of diffusion of oxygen into the blood from a single emphysema alveolus will be greater than for a single healthy alveolus.
- [ ] For the same concentration gradient, the rate of diffusion of oxygen into the blood from 8 healthy alveoli will be greater than for a single emphysema alveolus.
- [ ] For the same concentration gradient, the rate of diffusion of oxygen into the blood from a single emphysema alveolus will be greater than for 8 healthy alveoli.

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The Fish Respiratory System

A Level

The fish respiratory system is made up of complex structures called gills. These highly vascularised structures are able to absorb dissolved oxygen from the surrounding water as it flows past. The diagram below shows part of a fish gill.

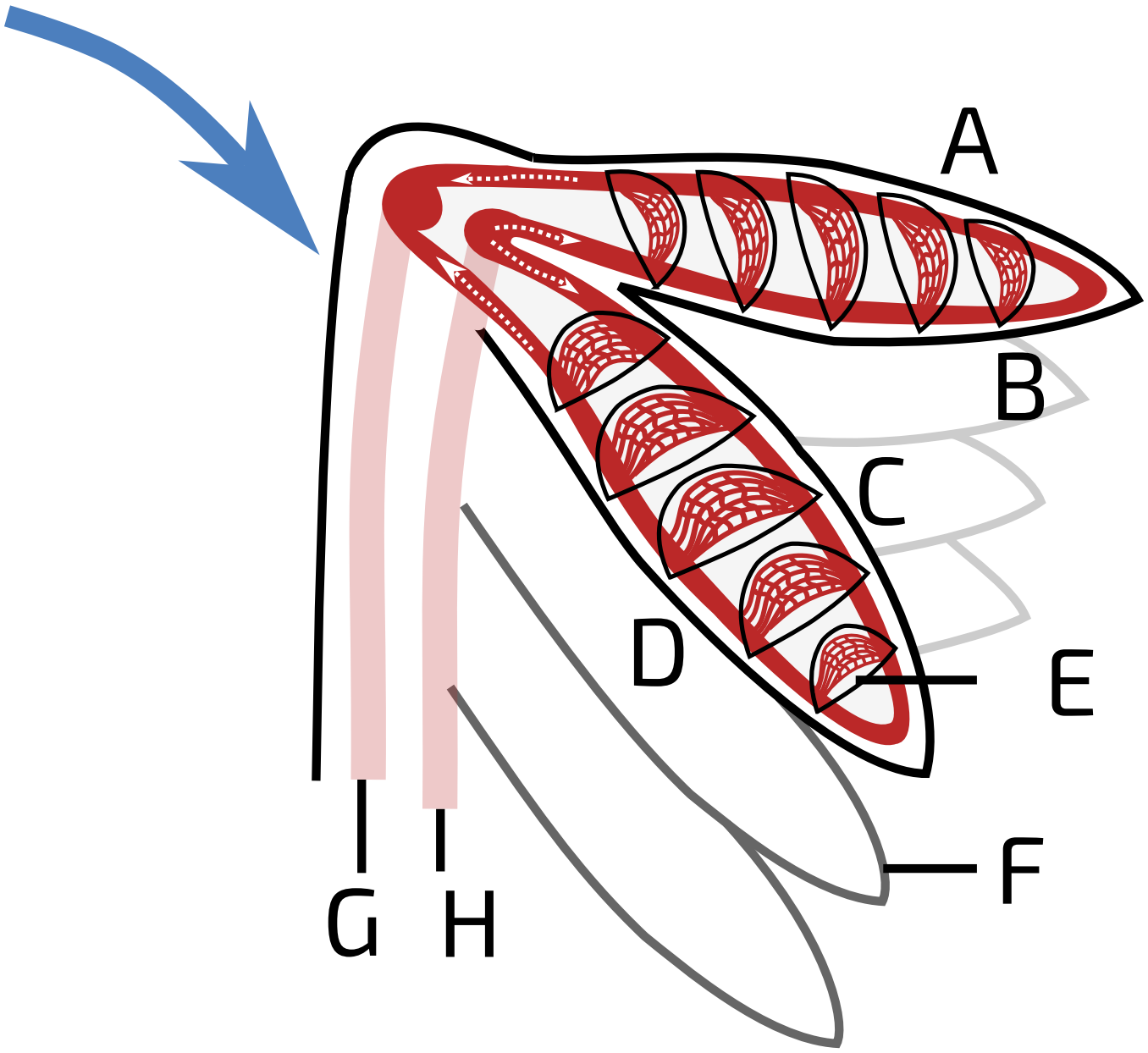

Figure 1: A simplified diagram of part of a fish gill. The blue arrow shows the flow of water towards the gill. Blood vessels are shown in red, with white dotted arrows showing the direction of blood flow. Labels A-D label represent positions in space. Labels E-F represent gill structures. Labels G-H represent gill arteries. The blood vessels and other structures present in the top layer of the gill are also present in every other layer, but are not shown here.

Part A Gill anatomy

Description	Label
Blood flows in the direction of...	
Water flows in the direction of...	
gill filament	
gill lamella	
afferent artery (carrying deoxygenated blood into the gills)	
efferent artery (carrying oxygenated blood out of the gills)	

Items:

A to B & D to C **B to A & C to D** **E** **F** **G** **H**

Part B Gill ventilation

Most fish ventilate their gills by a process called "buccal pumping", in which water is actively drawn in through the _____ and pumped out over the _____. Water moves over the gills in the _____ direction as/to the direction of blood movement through the gills - an example of _____. This maximises the diffusion gradients of oxygen and carbon dioxide between the blood and the water, ensuring that the blood becomes more saturated with _____ than if water and blood moved in the _____ direction.

Fish can also ventilate their gills by a process called "ram ventilation". Instead of actively drawing in water and pumping it out, they keep their mouth open as they swim forwards. Some bony fish (e.g. bluefin tunas) and some cartilaginous fish (e.g. great white sharks) can only ventilate their gills in this way. This means they must keep swimming in order to take in _____.

Items:

buccal cavity (mouth) **carbon dioxide** **same** **gills** **cocurrent exchange** **countercurrent exchange** **oxygen** **opposite**

Part C Gill covering

In most cartilaginous fish, the gills are visible.

However, in bony fish, the gills are covered with a protective bony flap that opens as water is pumped out.

What is the name of this bony flap?

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The Insect Respiratory System

A Level

The insect respiratory system consists of a network of branching tubes that directly connect openings on the outside of the body to the tissues inside the body. One of these tubes is shown in the diagram below.

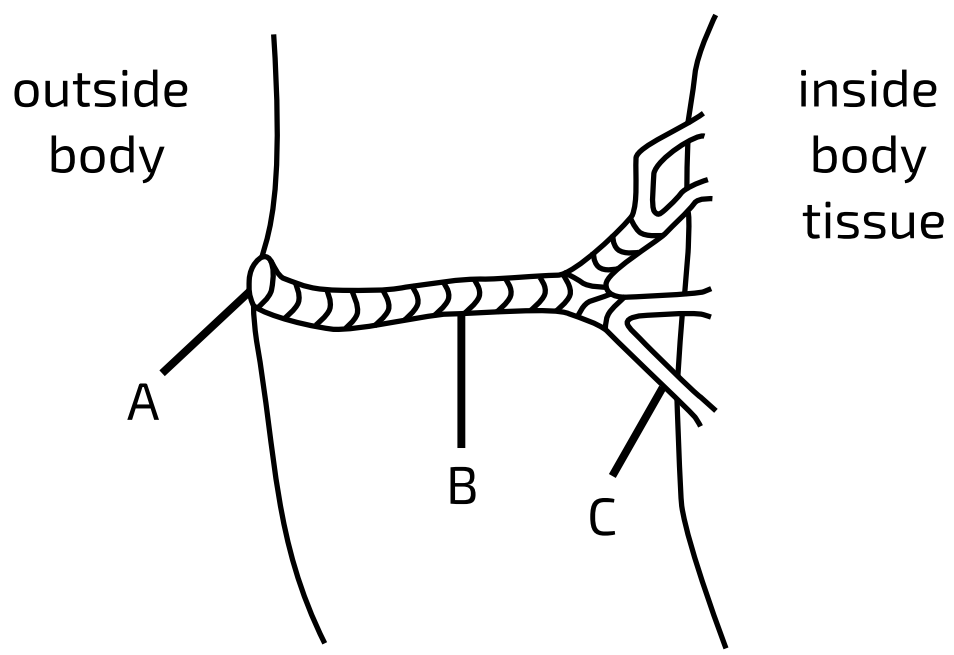

Figure 1: A section of the respiratory system of an insect.

Part A Label the diagram

Match the structure to the letter from **Figure 1** in the table below.

Letter	Structure
A	
B	
C	

Items:

trachea **tracheole** **spiracle**

Part B Oxygen diffusion direction

Drag the items below into the correct order on the right to show the direction in which oxygen will diffuse (from top to bottom), assuming the internal body tissue is actively respiring.

Available items

A

B

C

Part C Carbon dioxide diffusion direction

Drag the items below into the correct order on the right to show the direction in which carbon dioxide will diffuse (from top to bottom), assuming the internal body tissue is actively respiring.

Available items

A

B

C

Part D Insects vs mammals

Which of the following correctly describe and explain the difference(s) between the insect respiratory system and the mammalian respiratory system. Select all that apply.

- [ ] Insects have **one** trachea which directly supplies oxygen (via diffusion) to the internal body tissues, whereas mammals have one trachea that supplies oxygen to a respiratory organ.
- [ ] Insects have **many** tracheae which directly supply oxygen (via diffusion) to the internal body tissues, whereas mammals have one trachea that supplies oxygen to a respiratory organ.
- [ ] Mammals rely entirely on their circulatory system to transport oxygen to their internal body tissues, whereas most insects do not.
- [ ] Mammal hearts pump blood around the circulatory system, whereas insect hearts pump air around the tracheal system.
- [ ] Mammals are larger than insects and therefore have a **higher** SA:V ratio. This means mammals cannot rely on direct diffusion from the air to their internal body tissues, as diffusion would take too long.
- [ ] Mammals are larger than insects and therefore have a **lower** SA:V ratio. This means mammals cannot rely on direct diffusion from the air to their internal body tissues, as diffusion would take too long.

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