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Circulatory Systems

A Level

Unicellular organisms rely on diffusion, osmosis, and active transport to take in what they need from their environment and expel waste products to their environment. However, most multicellular organisms cannot solely rely on these processes. They have circulatory systems that transport substances throughout the organism.

Part A The need for circulatory systems

Why do larger organisms need a circulatory system? Select all that apply.

- [ ] Diffusion over large distances (e.g. across tissues and organs) would be too slow to provide oxygen/nutrients quickly enough for respiration.
- [ ] Larger organisms have a **higher** surface area to volume (SA : V) ratio, which means that the efficiency of diffusion is lower.
- [ ] Larger organisms have a **lower** surface area to volume (SA : V) ratio, which means that the efficiency of diffusion is lower.
- [ ] Oxygen and carbon dioxide are exchanged by active transport in multicellular organisms, not by diffusion.
- [ ] Multicellular organisms need oxygen for respiration, whereas unicellular organisms do not.
- [ ] Unicellular organisms live in a fluid environment, whereas all multicellular organisms live on land.

Part B Open vs closed circulatory systems

Which of the following are true of an **open** circulatory system? Select all that apply.

- [ ] the transport medium is called blood
- [ ] the transport medium is called haemolymph
- [ ] the transport medium is under **lower** pressure than in a closed circulatory system
- [ ] the transport medium is under **higher** pressure than in a closed circulatory system
- [ ] the transport medium is pumped from the heart through arteries, then capillaries, then veins, and then flows back into the heart
- [ ] the transport medium is pumped from the heart out into the main body cavity of the animal, and then flows back into the heart
- [ ] the transport medium comes into direct contact with the tissues it delivers nutrients to
- [ ] the transport medium does **not** come into direct contact with the tissues it delivers nutrients to
- [ ] found in insects
- [ ] found in vertebrates and annelids

Which of the following are true of a **closed** circulatory system? Select all that apply.

- [ ] the transport medium is called blood
- [ ] the transport medium is called haemolymph
- [ ] the transport medium is under **lower** pressure than in an open circulatory system
- [ ] the transport medium is under **higher** pressure than in an open circulatory system
- [ ] the transport medium is pumped from the heart through arteries, then capillaries, then veins, and then flows back into the heart
- [ ] the transport medium is pumped from the heart out into the main body cavity of the animal, and then flows back into the heart
- [ ] the transport medium comes into direct contact with the tissues it delivers nutrients to
- [ ] the transport medium does **not** come into direct contact with the tissues it delivers nutrients to
- [ ] found in insects
- [ ] found in vertebrates and annelids

Part C Single vs double circulatory systems

Which of the following is true of a **single** circulatory system? Select all that apply.

- [ ] blood is pumped from the heart to the main respiratory organs (e.g. gills/lungs) and then returns back to the heart before being pumped around the rest of the body
- [ ] blood is pumped from the heart to the main respiratory organs (e.g. gills/lungs) and then flows to the rest of the body before returning to the heart
- [ ] blood flows throughout the body at a **lower** pressure and **slower** speed than in a double circulatory system
- [ ] blood flows throughout the body at a **higher** pressure and **faster** speed than in a double circulatory system
- [ ] found in reptiles, birds, and mammals
- [ ] found in fish

Which of the following is true of a **double** circulatory system? Select all that apply.

- [ ] blood is pumped from the heart to the main respiratory organs (e.g. gills/lungs) and then returns back to the heart before being pumped around the rest of the body
- [ ] blood is pumped from the heart to the main respiratory organs (e.g. gills/lungs) and then flows to the rest of the body before returning to the heart
- [ ] blood flows throughout the body at a **lower** pressure and **slower** speed than in a single circulatory system
- [ ] blood flows throughout the body at a **higher** pressure and **faster** speed than in a single circulatory system
- [ ] found in reptiles, birds, and mammals
- [ ] found in fish

Part D Organisms

Match the organism to the characteristic in the table below.

Characteristic	Organism
contains haemolymph	
blood flows in and out of the heart **twice** for every time it reaches a particular tissue	
blood flows in and out of the heart **once** for every time it reaches a particular tissue	
does not contain a circulatory system	

Items:

Amoeba **grasshopper** **pigeon** **goldfish**

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Human Heart Anatomy

A Level

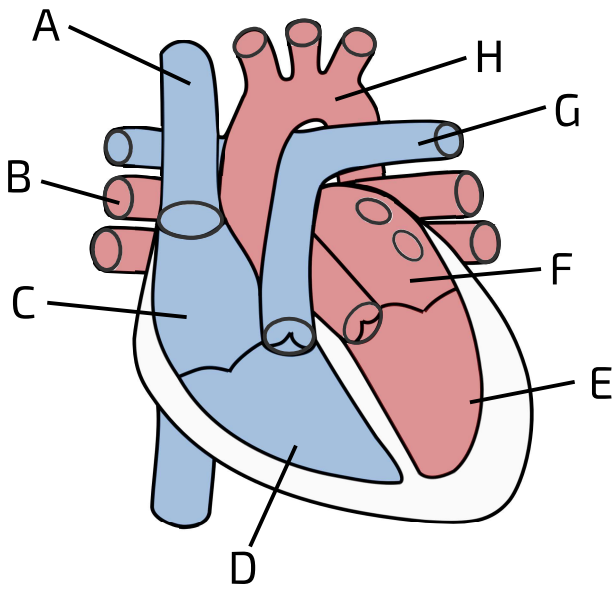

Figure 1: Diagram of the inside of the human heart. Regions are colour-coded by oxygen concentration (blue = low, red = high). The heart is shown in cross-section from the front.

Part A Label the heart

Letter	Structure
A	
B	
C	
D	
E	
F	
G	
H	

Items:

a pulmonary vein | left atrium | a pulmonary artery | right ventricle | vena cava | right atrium | aorta | left ventricle

Part B Direction of blood flow

Drag the letters on the left into the correct order on the right to show the direction of blood flow through the heart. Begin (at the top) with the letter that represents the vena cava.

Available items

- A
- B
- C
- D
- E
- F
- G
- H

Part C Heart valves

What is the general name for the valves that separate **C** from **D** and **F** from **E**?

What is the general name for the valves that separate **D** from **G** and **E** from **H**?

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The Cardiac Cycle

A Level

The cardiac cycle is the sequence of events that a heart undergoes from one heartbeat to the next.

Part A Blood flow

Drag the items below into the correct order on the right to show the path that blood flows through the human body.

Begin (at the top) with "vena cava". You should use all of the available items.

Available items

- vena cava
- aorta
- capillaries in the lungs
- capillaries in the tissues/organs of the rest of the body
- left atrium
- left ventricle
- pulmonary arteries
- pulmonary veins
- right atrium
- right ventricle
- systemic arteries
- systemic veins

Part B Systole & Diastole

There are two main phases of the cardiac cycle: systole (contraction) and diastole (relaxation). Fill in the blanks below to describe the cardiac cycle for an organism with a double circulatory system.

Systole

First, the atria contract (atrial systole) to pump blood into the ventricles. This contraction is caused by electrical excitation spreading from the [ ].

Next, the ventricles contract (ventricular systole), causing the atrioventricular valves to [ ] and the semi-lunar valves to [ ], and forcing blood out of the heart into the aorta and pulmonary artery.

This contraction is caused by electrical excitation in the [ ] that spreads through the bundle of His (a bundle of conducting tissue made up of modified muscle fibres called Purkyne fibres).

The semi-lunar valves then [ ], preventing backflow of blood into the ventricles.

Items:

sino-atrial node (SAN) **atrio-ventricular node (AVN)** **close** **open**

Diastole

During diastole, the atria and the ventricles relax together (though the atria were already starting to relax during [ ]). Blood flows from the vena cava and pulmonary veins into the atria because of this relaxation. This causes the [ ] valves to [ ], allowing blood to flow from the atria into the [ ].

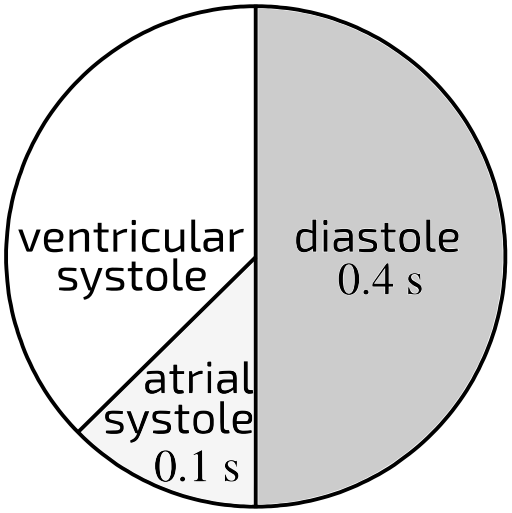
Items:

open **semilunar** **aorta & pulmonary artery** **atrial systole** **atrioventricular** **close**
ventricular systole **ventricles**

Part C Heart rate

The chart below shows the stages of one cardiac cycle for an adult at rest.

Timings are shown for some of the stages.



Calculate the heart rate for this individual in bpm (beats per minute).

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ECG analysis

A Level

An electrocardiogram (ECG) shows the electrical activity of the heart. The graph below shows the changes in the volume of the ventricles, and the ECG tract that accompanies those changes, during two consecutive heart beats in an adult human.

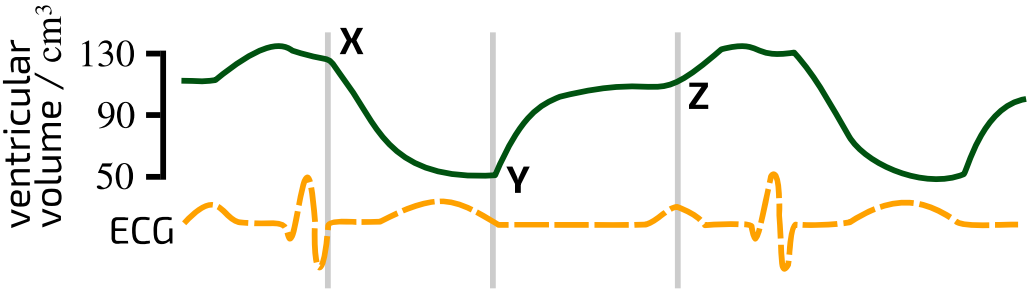

Figure 1: Volume of the ventricles over time and the accompanying ECG trace during two consecutive heart beats in an adult human.

Part A Blood movement

Fill in the blanks below to describe what is happening at points X, Y, and Z in **Figure 1**.

- At **X** blood is being pumped into the [ ]
- At **Y** valves between atria and ventricles are [ ]
- At **Z** the chambers of the heart that are contracting are the [ ]

Items:

atria **aorta & pulmonary artery** **aorta & pulmonary vein** **pulmonary artery only** **pulmonary vein only**

ventricles **open** **closed**

Part B Diastole & systole

Match the heart process to the point in **Figure 1** and the corresponding ECG wave(s) in the table below.

Diastole/systole	Figure 1 occurrence	Corresponding ECG wave(s)
Diastole		
Atrial systole		
Ventricular systole		

Items:

between X and Y **between Y and Z** **between Z and the point after Z that is equivalent to X** **P wave**

QRS complex **T wave**

Part C Blood circulation

Based on **Figure 1**, how long would it take to pump all of the blood round the entire circulatory system?

Assume that

- the total blood volume is $5\,\text{litres}$
- the heart rate is $60\,\text{bpm}$ (beats per minute)
- both ventricles pump out equal volumes of blood during ventricular systole

Give your answer to the nearest minute

Adapted with permission from NSAA 2020 Section 1 Q75

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Oxygen Dissociation Curves: Llamas vs Camels

A Level

The oxygen saturation of red blood cells is the percentage of haemoglobin binding sites in red blood cells with oxygen bound to them.

Camels and llamas have evolved from the same ancestor. Camels live at low altitude and llamas live at high altitude.

The graph below shows the effect of oxygen concentration on the oxygen saturation of red blood cells in camels and llamas.

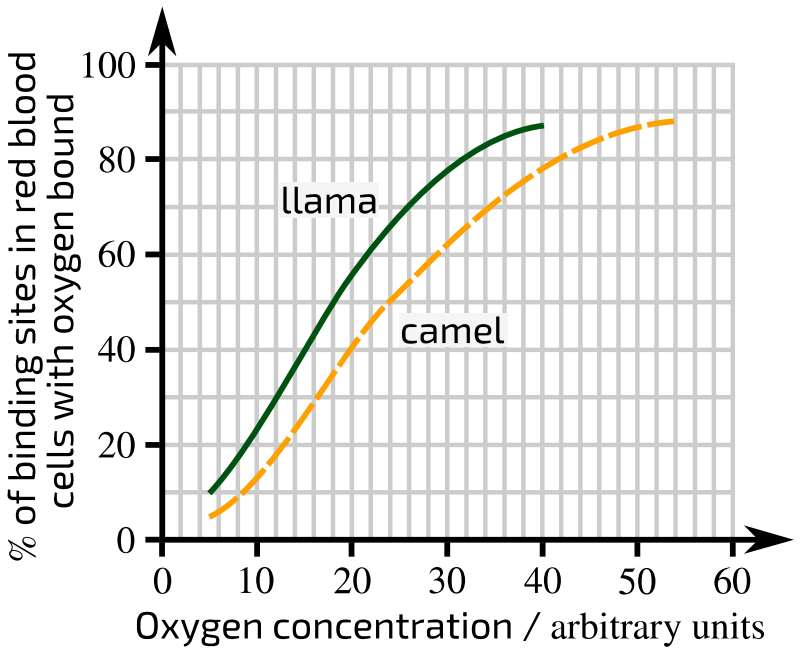

Figure 1: Oxygen dissociation curves of llama haemoglobin and camel haemoglobin.

Part A Saturation points

At what oxygen concentration will llama red blood cells be 50% saturated?

At what oxygen concentration will camel red blood cells be 50% saturated?

Part B Saturation statements

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

- [ ] The different oxygen binding properties evolved because of mutations caused by different oxygen concentrations.
- [ ] The different oxygen binding properties in llamas may have evolved because the **low** oxygen concentrations at high altitudes acted as a selective pressure.
- [ ] The different oxygen binding properties in llamas may have evolved because the **high** oxygen concentrations at high altitudes acted as a selective pressure.
- [ ] 50% oxygen saturation of llama red blood cells occurs at $\frac{3}{4}$ of the oxygen concentration required for 50% oxygen saturation of camel red blood cells.
- [ ] For oxygen concentrations between 5 and 40 arbitrary units, the oxygen saturation of camel red blood cells is higher than that of llama red blood cells.
- [ ] To reach the same levels of oxygen saturation, the oxygen concentration must be higher for camel red blood cells than for llama red blood cells.

Part C Pros and cons

The sigmoid (S shape) nature of haemoglobin oxygen dissociation curves means that within intermediate oxygen concentration levels, haemoglobin is very sensitive to changes in oxygen concentration and will work efficiently (i.e. it will easily release oxygen when it is in tissues with a low oxygen concentration, and will easily absorb oxygen when it is in tissues with a high oxygen concentration). However, at extreme concentrations (very high or very low), it does not work efficiently.

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

- [ ] In a **high** altitude environment, a **camel's** red blood cells would be **less efficient** at absorbing and releasing oxygen than a llama's red blood cells.
- [ ] In a **high** altitude environment, a **llama's** red blood cells would be **less efficient** at absorbing and releasing oxygen than a camel's red blood cells.
- [ ] In a **low** altitude environment, a **camel's** red blood cells would be **less efficient** at absorbing and releasing oxygen than a llama's red blood cells.
- [ ] In a **low** altitude environment, a **llama's** red blood cells would be **less efficient** at absorbing and releasing oxygen than a camel's red blood cells.

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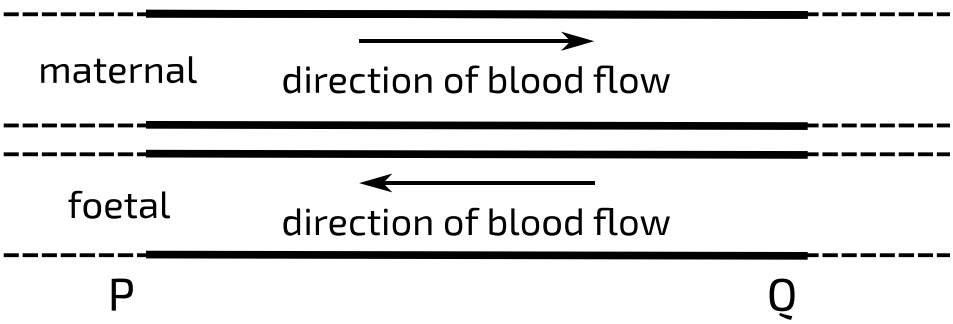
Placental Circulation

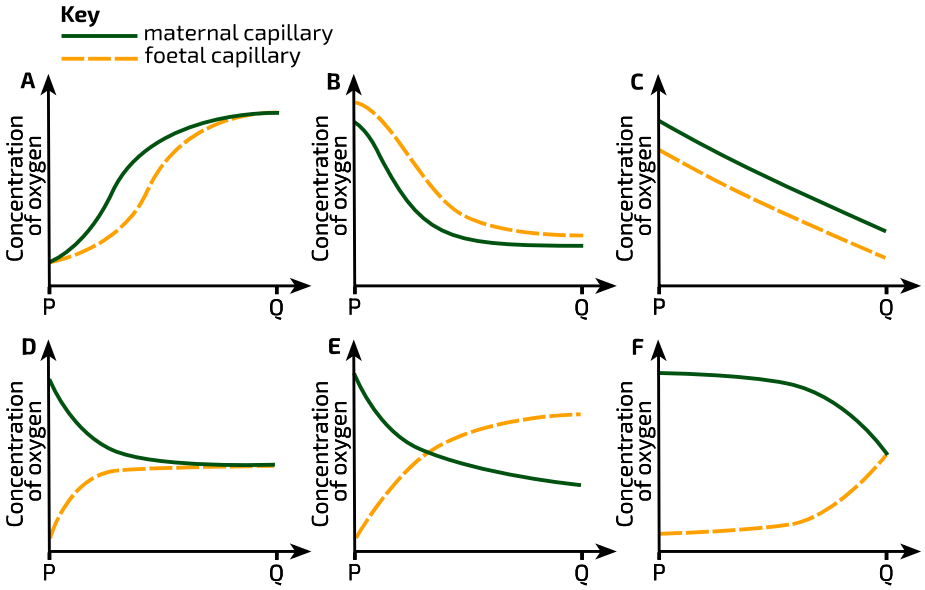
A Level

The placenta is an organ that develops during pregnancy. One function of the placenta is to allow the exchange of gases between the mother and the developing foetus.

The diagram below represents the maternal and foetal blood flow between **P** and **Q** in a section of the placenta of a healthy small mammal. The concentration of oxygen in both maternal and foetal blood was measured at regular distances along this section.



Part A Which graph?



Which graph illustrates the concentration of oxygen in both maternal and foetal blood between P and Q?

- A
- B
- C
- D
- E
- F

Which graph would illustrate the concentration of oxygen in both maternal and foetal blood if the two flowed in the same direction (from P to Q)?

- A
- B
- C
- D
- E
- F

Part B Opposite directions

What is the name of this type of system, in which two substances flow in opposite directions to maximise efficiency of exchange?

What other animals use this type of system to maximise blood oxygen uptake?

Part C Circulation statements

How does this type of system benefit the foetus?

Select all that apply.

- [ ] More red blood cells are able to cross from foetal blood into maternal blood.
- [ ] A diffusion gradient of carbon dioxide is maintained over a longer distance, which means that the foetus gets rid of more carbon dioxide than if the foetal blood flowed in the same direction as the maternal blood.
- [ ] Because the two bloodstreams are flowing in opposite directions, they slow each other down when they mix, which allows more time for carbon dioxide to diffuse from the foetal blood into the maternal blood.
- [ ] More red blood cells are able to cross from maternal blood into foetal blood.
- [ ] Diffusion of oxygen would not occur if foetal blood flowed in the same direction as maternal blood. This system ensures that diffusion of oxygen from the mother to the foetus does occur.
- [ ] Because the two bloodstreams are flowing in opposite directions, they slow each other down when they mix, which allows more time for oxygen to diffuse from the maternal blood into the foetal blood.
- [ ] Diffusion of carbon dioxide would not occur if foetal blood flowed in the same direction as maternal blood. This system ensures that diffusion of carbon dioxide from the foetus to the mother does occur.
- [ ] A diffusion gradient of oxygen is maintained over a longer distance, which means that the foetus receives more oxygen than if the foetal blood flowed in the same direction as the maternal blood.

Adapted with permission from NSAA 2020 Section 1 Q76

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Cardiac Output Calculations

A Level

Part A Human daily cardiac output

The Stroke volume of a particular person is $70\,\mathrm{cm}^3$, and their average heart rate is $75\,\mathrm{bpm}$.

Calculate the daily cardiac output of this person.

Part B Blue whale stroke volume

The average heart rate of a particular blue whale is $15\,\mathrm{bpm}$. The cardiac output of this whale is $1200\,\mathrm{dm}^3\,\mathrm{min}^1$.

What volume of blood is pumped out of the left ventricle during a single heart beat?

Part C Hummingbird heart rate

The cardiac output of a particular hummingbird is $108\,\mathrm{ml}\,\mathrm{min}^{-1}$, and its stroke volume is $90\,\mu\mathrm{l}$.

Calculate the average heart rate of this hummingbird in beats per minute (bpm).

Part D Another human's cardiac output

Immediately before ventricular Systole, the combined volume of blood in both ventricles of a particular person is $280\,\mathrm{ml}$.

Immediately after ventricular systole, the combined volume of blood in both ventricles is $100\,\mathrm{ml}$.

Ventricular systole in this person takes $0.3\,\mathrm{s}$, which represents 40% of their cardiac cycle duration.

Calculate the cardiac output of this person in $\mathrm{dm}^3\,\mathrm{min}^{-1}$.

Assume that both ventricles pump out equal volumes of blood during ventricular systole.
