UNIT 1

The heart

Structure of the human heart

The heart pumps blood around the body. The heart is two pumps side by side:

- left side receives blood from the lungs and pumps it to the body
- right side receives blood from the body and pumps it to the lungs.

Blood enters the two atria which contract and force blood into the two ventricles. The ventricles then contract and blood is pumped out into the arteries. The right ventricle pumps blood into the pulmonary artery and up to the lungs (the pulmonary circulation). The left ventricle pumps blood into the aorta and round the body (the systemic circulation). The atria contract together and the ventricles contract together throughout life.

Key words
- cardiac cycle
- myogenic
- sinoatrial node
- atrioventricular node
- ECG
- Purkyne tissue
- cardiac output
- stroke volume
- pulse rate

The cardiac cycle

The cardiac cycle is one complete cycle of events beginning with diastole, followed by atrial systole, and finally ventricular systole. The cycle is repeated about 72 times per minute.

<table>
<thead>
<tr>
<th>Name</th>
<th>Event</th>
<th>Outcome</th>
<th>Valves</th>
<th>Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diastole</td>
<td>Heart muscle is relaxed</td>
<td>The atria fill with blood, opening the atrioventricular (AV) valves, and blood enters ventricles</td>
<td>Semilunar valves close AV valves open</td>
<td>Low but slowly rises as blood enters Low in arteries (diastolic pressure)</td>
</tr>
<tr>
<td>Atrial systole</td>
<td>Atrial muscle contracts</td>
<td>Blood pushed into ventricles Atria are emptied</td>
<td>AV valves pushed fully open</td>
<td>Rises in both atria and ventricles as blood enters</td>
</tr>
<tr>
<td>Ventricular systole</td>
<td>Ventricular muscle contracts</td>
<td>Blood forced into the arteries (right ventricle into pulmonary artery and left ventricle into aorta)</td>
<td>AV valves snap shut Heart tendons hold valves in place Semilunar valves pushed open as blood enters arteries Valves pushed open when ventricular pressure is greater than arterial pressure</td>
<td>Atrial pressure falls Ventricular pressure rises steeply as muscle contracts Continues to rise for 0.1 second but falls as empties Artery pressure is high (systolic pressure)</td>
</tr>
</tbody>
</table>

Examiner tip

Make sure you learn the heart structure from the diagrams. The flow of blood through the heart is shown as arrows on the internal structure diagram.

Quick check 1

Quick check 2

Hint

Closure of the valves prevents backflow. The AV valves snapping shut gives first part of heart sound (lub). Closure of semilunar valves gives second (dub) part of heart sound.
The heart

An ECG

- The heart wall is made of special muscle – cardiac muscle – it is **myogenic** and needs no stimulation to contract.
- The **sinoatrial node** in the right atrial wall generates an electrical impulse that travels across the atria and triggers atrial systole.
- The **atrioventricular node** detects this and, after a short delay, relays it onto the ventricles via **Purkyne fibres** in the septum. The impulse then spreads across the ventricles to trigger ventricular systole. Systole is always followed by diastole – the period when the heart muscle is recovering and relaxed.
- An **ECG** (electrocardiogram) monitors the electrical impulse as a trace. Differences in the trace indicate heart problems.

**Cardiac output** is the volume of blood pumped out of the left ventricle per minute.

Cardiac output = stroke volume (the volume pumped with each beat) × heart rate

Increase in cardiac output will result during strenuous exercise as the body muscles contract more and require more oxygen for aerobic respiration.

Heart rate can be measured by taking the **pulse rate**. The pulse is the expansion and elastic recoil of the artery wall as the blood is pumped out of the heart under pressure. It is measured at the wrist or in the neck.

**QUICK CHECK QUESTIONS**

1. Why is the heart described as a double pump?
2. Describe the complete passage of a single blood cell through the body.
3. Use the graph to find the time taken for one heartbeat in the cardiac cycle and calculate the heart rate.
4. Explain what information can be gained from an ECG.
5. Explain heart rate and describe how changes in rate will result in changes in cardiac output.
Circulatory system

Mass transport

The human circulatory system acts as a transport medium by mass flow.

A closed and double circulatory system

Transport in humans needs a circulatory system because diffusion alone is not adequate to deliver enough oxygen and nutrients to all respiring cells. The diffusion path is too long to allow enough substances such as glucose to move quickly enough.

The circulatory system is described as a closed double system as seen in the diagram.

Deoxygenated blood returns from the body to the heart and then on to the lungs. Oxygenated blood from the lungs returns to the heart and then on to the body.

Structure and function of arteries, veins and capillaries

<table>
<thead>
<tr>
<th>Blood vessels</th>
<th>Structure</th>
<th>Function</th>
<th>Blood flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arteries</td>
<td>Thick wall of smooth muscle and elastic fibres</td>
<td>Keeps pressure high; blood is distributed throughout circuit. Artery wall stretches and recoils</td>
<td>Leaves the heart. Rapid flow with high pressure which pulses</td>
</tr>
<tr>
<td>Veins</td>
<td>Thin wall with a small amount of smooth muscle and elastic tissue. Semilunar valves along the length</td>
<td>Returns blood to the heart. Valves prevent backflow and keep flow moving on</td>
<td>To the heart. Flow is slow with low pressure. No pulse</td>
</tr>
<tr>
<td>Capillaries</td>
<td>No elastic or muscle tissue. Wall of single layer of cells of squamous epithelium. Lumen only 7–10 µm wide</td>
<td>Form a network within tissues and organs. Allow exchange of metabolites between the blood and surrounding tissues</td>
<td>Connect arterioles and venules. Slow rate of flow. Low pressure</td>
</tr>
<tr>
<td>Arterioles</td>
<td>Thin wall mainly of smooth muscle and some elastic fibre</td>
<td>Carry blood between arterioles and capillaries. Regulate flow and distribution</td>
<td>Smooth muscle contracts to narrow (constrict) the lumen and decrease the flow to certain tissues or relaxes to widen (dilate) the lumen to increase the blood flow</td>
</tr>
<tr>
<td>Venules</td>
<td>Very thin wall of muscle and elastic fibres</td>
<td>Carry blood from capillaries back to the veins</td>
<td>To veins from capillaries</td>
</tr>
</tbody>
</table>
### Circulatory system

**Relationship between different blood vessels**

**Blood pressure**

Blood pressure in the arteries rises when the ventricles contract and drops when they relax. Elastic recoil of the artery walls gradually smooths out the pressure when the blood reaches the arterioles. Blood pressure drops as the blood moves through the capillaries. In the veins, blood returns to the heart under very low pressure.

**Sphygmomanometer**

Blood pressure is measured using a sphygmomanometer. The units used are kilopascals (kPa) using an electronic instrument, but most doctors prefer to use a manometer calibrated in millimetres of mercury (mmHg). Blood pressure is taken in the arm using an inflating cuff attached to the instrument and a stethoscope. The readings are given as two values, e.g. 120/80 mmHg. The top value is the systolic and the bottom value the diastolic reading.

High blood pressure is called hypertension.

**Key definition**

Doctors use a sphygmomanometer to measure blood pressure. It is an instrument using a column of mercury to measure the pressure and is considered to be very accurate. A stethoscope is used to listen for the sounds of the blood flowing within the artery to indicate the systolic and diastolic pressure. A reading of pressure as mmHg is obtained. Electronic blood pressure monitors are available and measure pressure in kPa. However the readings are not as accurate for a single reading.

**QUICK CHECK QUESTIONS**

1. State the advantages of a double circulation and a closed system.
2. How do arterioles regulate blood flow to tissues? Give an example in the skin.
3. Explain the features that allow nutrients and gases to diffuse across the capillaries efficiently.
4. How does elastic recoil in the artery wall smooth out the pulsing of the blood?
5. What is hypertension and what blood pressure values would suggest hypertension?
### Cells, tissues and organs

In animals, cells are specialised to carry out a specific function and are grouped together into a **tissue**.

Tissues are grouped into **organs**. Humans have many different organs, e.g. heart, lung and kidney.

### Tissue types

There are several important tissues in the lungs.

- **Squamous epithelial** tissue is flattened and reduces the diffusion distance for efficient gas exchange. It forms the single layer of the alveoli walls.
- **Ciliated epithelial** tissue contains ciliated cells; these have many cilia which beat in rhythm to move particles trapped in mucus out of the lung. It also contains goblet cells which produce a glycoprotein and secrete it in mucus, which traps dirt and bacteria in the air breathed in.
- Ciliated cells and goblet cells form the layer lining the trachea and bronchi. Ciliated cells line the bronchioles.

### Lung structure

Air breathed in moves down the trachea into two bronchi. It then moves into the many branches of the bronchioles and on into the blind ends, the air sacs. These are a cluster of alveoli.

Follow the air passage in the diagram.

### Surface area to volume ratio

The ratio between surface area and volume determines the rate of diffusion. A high ratio gives faster diffusion. Large organisms have a small ratio and a long diffusion distance. However, organs such as the lung provide the additional surface area (cells in contact with the environment) needed to allow rapid gas exchange.
Gas exchange surface of lungs

Alveoli are the gas exchange surface. They have a single layer of squamous cells for rapid diffusion and elastic fibres for expansion and recoil during breathing.

A good gas exchange site has:
- a large surface area
- a thin layer giving a short diffusion distance
- a steep diffusion gradient maintained by ventilation and a good blood supply.

Measuring lung capacity

A spirometer measures lung capacity. The actual volume of air breathed in depends on the size of your lungs, your health and your activity levels. Asthmatics may need to check the rate they breathe out with a peak flow meter.

Respiratory arrest

This is when a person stops breathing. It may be due to:
- respiratory conditions, e.g. asthma or pneumonia
- an airway blockage
- drug overdose or an accident making the person unconscious.

Quick check questions

1. State the definitions for tissues and organs and give two examples of each.
2. Explain why larger organisms have a long diffusion distance.
3. Describe the features of alveoli making them a highly efficient gas exchange site.
4. Describe the features of the lung providing an efficient gas exchange surface.
5. How can a peak flow meter be used to check the condition of an asthmatic?
End-of-unit questions

1. In the UK, scientists working for the National Blood Transfusion Service must have a detailed knowledge of red blood cells and their membrane properties.

   (a) Briefly describe the structure of the red blood cell membrane. (3)

   (b) The four definitions below refer to ways in which molecules and ions may pass through a red blood cell membrane.

      A: the movement of water down a water potential gradient through a partially permeable membrane.

      B: the net movement of molecules or ions down a concentration gradient.

      C: movement against the concentration gradient, which requires an input of energy from the cell.

      D: passive movement across a cell membrane with the aid of transport proteins.

   Name the processes A to D. (4)

   (c) The National Blood Transfusion Service has to be able to store blood products for use in emergency situations.

      Under normal conditions in the body, red blood cells actively pump potassium ions into and sodium ions out of the cell.

      If blood is kept in cold storage, red blood cells lose potassium ions to the external plasma.

   Suggest why potassium ions may accumulate in the plasma in cold storage. (2)

   (d) Before storage, blood is screened for HIV and hepatitis. A prospective donor will be asked questions before giving blood to see if they are suitable.

      (i) As part of the screening process, the donor’s blood will be mixed with antigens for HIV and hepatitis. If the donor has come into contact with HIV or hepatitis, their blood will react with the antigens.

         Explain why a reaction occurs when blood is mixed with HIV or hepatitis antigens. (2)

      (ii) Suggest two reasons, other than exposure to HIV or hepatitis, why a prospective donor may not be allowed to give blood. (2)

2. (a) Figure 1 shows the structure of an alveolus.

   (i) Name cells A and B. (2)

   (ii) Surfactant is found on the inner surface of the alveoli. Explain the role of surfactant on the inner surface of the alveoli. (2)
(b) Cyclists in the Tour de France spend some time at altitude in the Alps during the competition. Figure 2 shows two spirometer traces from the same cyclist, taken before and after the longest climb in the competition, Alpe d'Huez.

(i) State the differences in breathing shown on the two traces. (1)

(ii) What is the number of breaths per minute recorded on trace D? (1)

(iii) State two safety precautions which must be taken when using a spirometer. (2)

(iv) Suggest why both traces slant downwards. (2)
Glycogen is a \textbf{polysaccharide} made from hundreds of \textbf{glucose} molecules. In order to join these molecules together, \textbf{glycosidic} bonds are formed by a reaction called \textbf{condensation}. This type of reaction requires the removal of a molecule of \textbf{water}. We store glycogen in liver cells and \textbf{muscle} cells. These glycogen molecules are a short-term \textbf{carbon} store that the body can use when muscle cells are working hard. The glycogen molecules can easily be broken down to their constituent monosaccharides. Each glycogen molecule has lots of ends and its subunits are easily broken off for use in \textbf{respiration}.

3 In the past, some athletes have used a banned technique called blood doping to improve performance. This involves increasing the number of red blood cells just before competition, which increases the oxygen-carrying capacity of the blood. Authorities can test for this by measuring the concentration of haemoglobin in the blood as a method of determining the number of red blood cells present. Describe a procedure which may be used to determine the number of red blood cells in a human blood sample. (7)

In this question, one mark is available for the quality of use and organisation of scientific terms. (1)

4 Glycogen is an important storage molecule in the body. Figure 3 shows part of a glycogen molecule.

![Glycogen molecule diagram]

Complete the following passage about glycogen by using appropriate words from the list to fill the gaps.

\textbf{sugar} condensation \textbf{polysaccharide} ester \textbf{glucose} muscle \textbf{glycosidic} hydrolysis water sucrose \textbf{fat} respiration \textbf{energy}

Glycogen is a \ldots made from hundreds of \ldots molecules. In order to join these molecules together, \ldots bonds are formed by a reaction called \ldots This type of reaction requires the removal of a molecule of \ldots We store glycogen in liver cells and \ldots store that the body can use when muscle cells are working hard. The glycogen molecules can easily be broken down to their constituent monosaccharides. Each glycogen molecule has lots of ends and its subunits are easily broken off for use in \ldots
5. Aspirin is a well known painkiller and was introduced in 1899. However, not until recently have other possible uses been suggested for this drug.
   - Aspirin and similar drugs work by inhibiting the production of prostaglandins.
   - Prostaglandins are local hormones produced from phospholipids.
   - Prostaglandins increase blood flow to an infected area, so that there are more blood cells to combat infection.
   - Aspirin also inhibits the enzyme cyclo-oxygenase (COX. A2 only); this reduces the amount of prostaglandins produced. Prostaglandins are known to increase blood clotting.

   (a) Name a white blood cell that combats infection. (1)
   (b) How may reducing prostaglandins decrease heart disease caused by blood clots? (5)
   (c) Outline the normal process of blood clotting. (4)
   (d) Suggest why low doses of aspirin, taken regularly, may be used to treat patients with coronary heart disease (A2 only). (2)

6. (a) Explain what is meant by cardiac output. (2)
   (b) Table 1 shows the percentage of total blood volume delivered to various organs during light, moderate and maximum exercise.

<table>
<thead>
<tr>
<th>Exercise level</th>
<th>Brain</th>
<th>Muscles</th>
<th>Skin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light</td>
<td>8</td>
<td>47</td>
<td>15</td>
</tr>
<tr>
<td>Moderate</td>
<td>4</td>
<td>71</td>
<td>12</td>
</tr>
<tr>
<td>Maximum</td>
<td>3</td>
<td>88</td>
<td>2</td>
</tr>
</tbody>
</table>

   Describe and explain the trends shown by the data in the table. (3)
   (c) Table 2 shows measurements from four 21-year-old students from the same university. Three were training for specific sporting events, whilst one did not train.

<table>
<thead>
<tr>
<th>Sporting event</th>
<th>Heart septum (mm)</th>
<th>Left ventricle wall (mm)</th>
<th>Stroke volume (cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>800 metre run</td>
<td>11.0</td>
<td>12.0</td>
<td>160.0</td>
</tr>
<tr>
<td>Swimming</td>
<td>10.9</td>
<td>10.6</td>
<td>181.0</td>
</tr>
<tr>
<td>Shot putt</td>
<td>11.0</td>
<td>12.0</td>
<td>110.0</td>
</tr>
<tr>
<td>Did not train</td>
<td>9.5</td>
<td>10.5</td>
<td>82.0</td>
</tr>
</tbody>
</table>

   (i) Calculate the percentage increase in size of the left ventricle wall between the 800 metre runner and the student who did not train. Show your working. (2)
   (ii) Training increases stroke volume. Suggest why training increases stroke volume. (2)
   (iii) Suggest two reasons why it is unfair to make any valid comparison between the four students. (2)