Unit 19 · Circulatory System

STUDY NOTES

WHAT NEB'S GRADE 12 EXAM ASKS

- **CDC's grid (2078):** Human Biology (Units 17–24 together): 16 of 75 marks; 4 MCQs (knowledge, understanding, application, higher ability), 1 short question (4 marks: knowledge 1, application 2, higher ability 1) and 1 long question (8 marks: understanding 2, application 2, higher ability 4)
- **The paper:** Botany 37 + Zoology 38; each part: MCQs × 1 (5 Botany, 6 Zoology) · 4 short × 4 · 2 long × 8; one OR in each short and long group; 3 hours; 1 mark per expected point
- **CDC's model paper:** MCQ on hemopoiesis
- **Our model papers:** Paper 1's long OR question (how a beat starts and spreads; cardiac output at rest and in a match; why a very fast heart pumps less) and MCQ (why the left ventricle is thickest); Paper 3's short OR question (universal donor; donors' groups from a test; Rh-negative mother's second baby)
- **MCQ (1 mark)**
  - layer closest to the heart: epicardium; cardiac muscle: myocardium
  - musculi pectinati in the atria
  - tricuspid: right atrium–right ventricle
  - foramen ovale: right to left atrium
  - SA node starts each beat; slow beat → pacemaker
  - lubb dub: AV valves then semilunar valves
  - bundle of His → Purkinje fibers
  - O universal donor; left atrium ← pulmonary veins
  - Thebesian valve on the coronary sinus
  - parasympathetic lowers cardiac output; antiserum D for Rh
  - phrenic artery to the diaphragm; saphenous longest vein
- **Short and long (in parts)**
  - external structure of the heart; internal structure, labeled diagram
  - origin and conduction of the heartbeat; SA and AV nodes from a figure, remedy when SA fails
  - blood pressure; hypotension vs hypertension; causes
  - the arterial system; blood groups; the venous system with a diagram
  - myogenic heart: structure and working (long); venous and portal system (long)

Key terms

Circulatory system: carries O_2, nutrients, hormones to tissues; urea, CO_2, toxins away.

Closed circulation: blood stays in heart and vessels (humans); **open**: pumped into the body cavity (insects).

Myogenic heart: beat starts in its own muscle (nodal tissue); **neurogenic**: started by a nerve (many crustaceans).

Systole: contraction; **diastole**: relaxation.

Cardiac cycle: events of one heartbeat; **~0.8 s** at 72/min.

Stroke volume (SV): blood pumped by **each ventricle** per beat, ~70 mL.

Cardiac output (CO): blood pumped by each ventricle per minute.

Double circulation: blood passes through the heart twice per round: pulmonary + systemic.

Blood pressure: pressure of blood on the vessel walls.

Pulse pressure: systolic − diastolic (~40 mmHg).

Heart murmur: abnormal sound of **turbulent** flow through a valve or vessel.

Agglutinogens: antigens A, B on RBCs; **agglutinins**: antibodies anti-A (a), anti-B (b) in plasma.

Agglutination: antibodies clump cells carrying their antigen; then **hemolysis**.

Portal system: vein from capillaries of one organ to capillaries of another (two beds in a row).

The heart

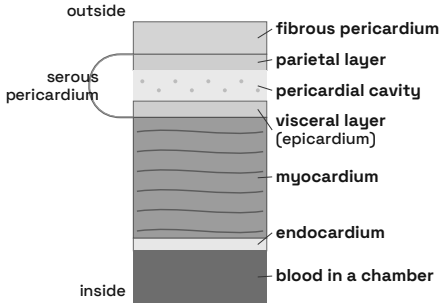
- circulatory system = **blood vascular system** (heart, vessels, blood) + **lymphatic system** (lymph vessels, nodes, lymph)
- hollow, muscular, cone-shaped; **base** up, **apex** down to the left; in the **mediastinum** between the lungs
- fist-sized: **~12 cm**, **~300 g**; from **mesoderm**

Pericardium (double sac)

- **fibrous pericardium**: outer, tough; anchors; stops **over-stretching**
- **serous pericardium**: **parietal** layer (lines the fibrous bag) + **visceral** layer (= **epicardium**)
- **pericardial cavity** between the serous layers: ~15–50 mL **pericardial fluid** → no friction; protects from shocks

Wall

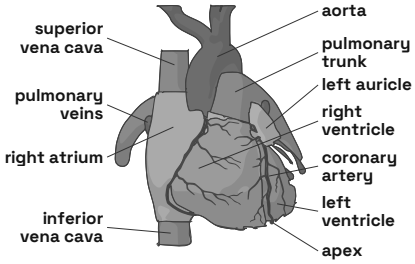
- **epicardium** (visceral pericardium)
- **myocardium**: thickest; **cardiac muscle**
- **endocardium**: endothelium on a basement membrane; continuous with vessel lining



Coverings and wall of the heart.

External features

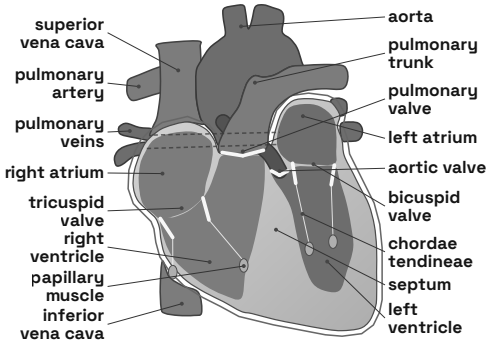
- four chambers: two **atria** (auricles), two **ventricles**
- grooves: **interatrial groove**; **coronary (atrioventricular) sulcus** round the heart; **anterior** and **posterior interventricular sulci**; coronary vessels run in them, in fat
- **right atrium** (larger) ← **SVC** (head, neck, arms), **IVC** (larger; lower body), **coronary sinus** (heart wall)
- **left atrium** (thicker wall) ← **four pulmonary veins**
- each atrium has an ear-like **auricle**
- **ventricles**: thick-walled pumps; **left** wall **~3 ×** the right's (pumps to the whole body, against more resistance; right only to the lungs)
- **pulmonary trunk** (right ventricle) → right and left pulmonary arteries
- **aorta** (left ventricle): ascending (→ **coronary arteries**) · arch (→ brachiocephalic, left common carotid, left subclavian) · descending
- **ligamentum arteriosum**: remains of the fetal **ductus arteriosus** (pulmonary trunk to aorta)



The heart from the front.

Internal structure

- **interatrial septum** separates the atria
- right atrium: openings of SVC, IVC (**Eustachian valve**), coronary sinus (**Thebesian valve**); **fossa ovalis** = the fetal **foramen ovale** (right → left atrium), closes after birth
- left atrium: four pulmonary veins
- **musculi pectinati**: comb-like ridges in the auricles and the right atrium's front
- **valves**:
  - **tricuspid** (3 flaps): right atrium → right ventricle
  - **bicuspid (mitral)** (2 flaps): left atrium → left ventricle
  - **pulmonary** and **aortic semilunar** (3 half-moon pockets each)
- ventricles: thick oblique **interventricular septum**; left longer, thicker
- **papillary muscles** → **chordae tendineae** → AV valve flaps; stop them being pushed up into the atria
- **columnae carneae**: fleshy ridges with fissures
- diagrams: the heart's **right** is on **your left**



The heart cut open lengthwise from the front.

Blood to the heart muscle

- ascending aorta → **right and left coronary arteries** → myocardium
- **coronary veins** → **coronary sinus** → **right atrium**
- clot in a coronary artery → **heart attack** (myocardial infarction)

Course through the heart

1. right atrium ← SVC, IVC, coronary sinus
2. → **tricuspid** → right ventricle
3. → **pulmonary valve** → pulmonary arteries → **lungs** (CO_2 out, O_2 in)
4. pulmonary veins → **left atrium**
5. → **bicuspid** → left ventricle
6. → **aortic valve** → aorta → body

- both atria contract together, then both ventricles

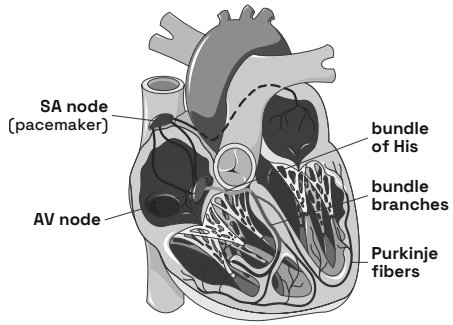
The heartbeat

- **~72/min** at rest; **myogenic** (transplanted heart, nerves cut, still beats); nerves and hormones only change the rate
- **SA node** (**pacemaker**): wall of the **right atrium** near the **SVC** opening; fires ~70–75/min, fastest, sets the pace
- **AV node**: right atrium wall, low on the **interatrial septum**, near the coronary sinus
- **bundle of His**: AV node → interventricular septum → **right and left bundle branches**
- **Purkinje fibers**: network through the ventricle walls

Conduction

1. SA node fires → impulse over both atria → **atrial systole**
2. **AV node**: only way through (a fibrous ring blocks the rest); **delays ~0.1 s** → atria finish emptying
3. bundle of His → branches → Purkinje fibers → all ventricle muscle at once, from the apex
4. **ventricular systole** from the apex up (toothpaste tube)

SA node → atria → AV node (delay) → bundle of His → bundle branches → Purkinje fibers → ventricles



The heart's conduction system.

Control

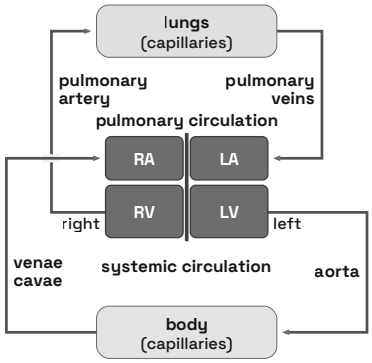
- **cardiac center** in the **medulla oblongata**:
  - **cardio-inhibitory** → **slows**, via **parasympathetic** fibers (**vagus**) to SA, AV nodes
  - **cardio-acceleratory** → **speeds up**, stronger beats, via **sympathetic** fibers
- hormones: **adrenaline**, **noradrenaline** (adrenal medulla; emergencies, "fight or flight") speed and strengthen; **thyroxine** raises rate (raises BMR)

Artificial pacemaker: SA node fails or **heart block** → slow beat, faint, breathless

- under the skin below the **collarbone**, local anesthetic; fires only when the beat is missing or slow
- **pulse generator** (lithium battery, 7–10 years) · **leads** (through a vein to the right heart) · **electrodes**

Double circulation

- **systemic** (greater): left ventricle → aorta → body capillaries → SVC, IVC (and coronary sinus) → right atrium; long way, high resistance
- **pulmonary** (lesser): right ventricle → pulmonary arteries → lungs → pulmonary veins → left atrium; short way
- pulmonary artery: deoxygenated, but an artery: carries blood **away from the heart**



Double circulation as a plan.

Significance

1. oxygenated and deoxygenated blood **never mix** (heart fully divided)
2. **second push**: blood reaches the body at **high pressure**, the lungs at low pressure
3. rich O_2 supply → **high metabolism** → warm-blooded (mammals, birds)

Cardiac cycle

Phase	Events	Time
atrial systole	atria contract, top up ventricles (already ~¾ full)	~0.1 s
ventricular systole	ventricles contract; AV valves shut (**lubb**); semilunar valves open; blood out	~0.3 s
joint diastole	all relax; semilunar valves shut (**dub**); blood fills atria and ventricles	~0.4 s

- 60 ÷ 72 ≈ 0.8 s; atria rest 0.7 s, ventricles 0.5 s
- during ejection only the **semilunar** valves are open
- faster heart: systole barely shortens → filling time shrinks → too fast pumps less

$$CO = HR \times SV$$

CO cardiac output (mL/min), HR heart rate (beats/min), SV stroke volume (mL)
Use: at rest $72 \times 70 = 5040$ mL/min ≈ 5 L/min, about all the blood each minute

- HR rises with exercise, fever, fear, anger; hard run: $180 \times 110 = 19{,}800$ mL/min ≈ 4 × rest

Heart sounds

- heard by **stethoscope**; made mainly by **valves closing**
- **S1 "lubb"**: **AV valves** (tricuspid, bicuspid) close at the start of ventricular systole; **longer** (~0.15 s), **lower**, dull
- **S2 "dub"**: **semilunar valves** close at the end of ventricular systole; **shorter** (~0.1 s), **higher**, sharp
- **S3**: after S2, blood rushes into ventricles; normal in children, young people, athletes; in older adults may mean heart failure
- **S4**: before S1, atria push blood into a **stiff** ventricle
- **murmur**: turbulent flow; leaky semilunar valve → "lubb-dub-shhh"; damaged AV valve changes S1
- valve damage: **rheumatic fever** (untreated *Streptococcus* throat infection), syphilis; "innocent murmurs" in children

Blood pressure

- measured with a **sphygmomanometer**, **auscultatory method**: cuff on the upper arm squeezes the **brachial artery** shut, let down slowly; first tapping = **systolic**, sounds vanish = **diastolic**
- brachial: large, level with the heart, easy to press on bone
- normal ~**120/80 mmHg**: **systolic** ~120 (ventricular systole, highest); **diastolic** ~80 (ventricles relaxed, lowest); pulse pressure ~40
- changes with exercise, emotion, meals, sex, posture, time of day; rises with age
- **Korotkov** (1905) found the **sounds**; instrument older (von Basch 1881, Riva-Rocci's cuff 1896)

	Hypertension	Hypotension
BP	≥ **140/90** (some: 130/80)	< **~90/60**
causes	stress, obesity, salty fatty food, smoking, alcohol, no exercise, kidney disease (nephritis), atherosclerosis; runs in families	blood loss, vomiting, diarrhea, heart problems, widened vessels, some medicines
effects	heart attack, stroke, kidney failure, eye damage; no symptoms ("**silent killer**")	dizziness, fainting on standing, tiredness

Blood groups

- **Landsteiner** (1900–01): A, B, O; **AB** (1902) by **von Decastello** and **Sturli**; Landsteiner **father of blood grouping**, Nobel 1930

Group	Antigen on RBCs	Antibody in plasma
A	A	anti-B (b)
B	B	anti-A (a)
AB	A and B	none
O	none	anti-A, anti-B

Transfusion: donor → recipient; grouped and **cross-matched**

- what counts: **donor's antigens** vs **recipient's antibodies** (donor's antibodies diluted)
- A → A, AB · B → B, AB · AB → AB only · O → all
- **O**: **universal donor** (no A, B antigens); **AB**: **universal recipient** (no anti-A, anti-B)
- mismatch: clumping, burst cells, clots, kidney failure, circulatory failure, death
- hospitals: same group; **O negative** for emergencies

Inheritance: one gene, three alleles $\mathbf{I^A}$, $\mathbf{I^B}$, **i**; I^A, I^B dominant over i, **codominant** with each other; 6 genotypes, 4 groups

- A: I^AI^A or I^Ai · B: I^BI^B or I^Bi · AB: I^AI^B · O: ii

Parents	Children possible	Impossible
O × O	O	A, B, AB
O × A, A × A	O, A	B, AB
O × B, B × B	O, B	A, AB
A × B	O, A, B, AB	none
O × AB	A, B	O, AB
A × AB, B × AB, AB × AB	A, B, AB	O

- A × A → O child possible (both I^Ai)

Rh grouping

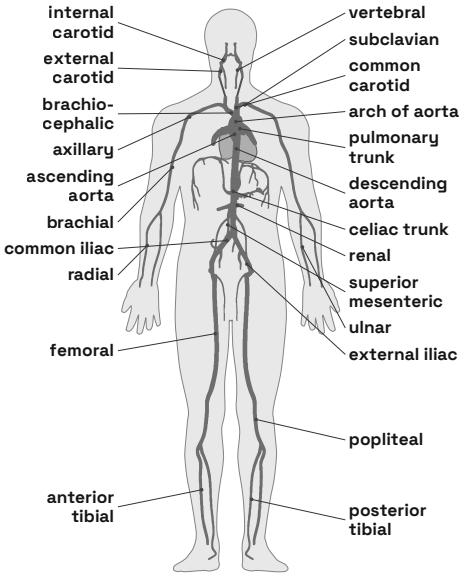
- **Rh (D) antigen**; **Landsteiner and Wiener** (1940): rhesus monkey RBCs into rabbits
- **Rh+** (antigen; **dominant**) or **Rh−**; most South Asians Rh+; ~85% of Europeans
- anti-Rh antibodies **not present from birth**: made only after Rh+ blood enters
- first Rh+ transfusion into Rh−: little harm, but **sensitizes**; second → clumping, may be fatal
- Rh− mother, Rh+ baby: sensitized at birth → **next** Rh+ baby attacked: **erythroblastosis fetalis**; prevented by **anti-D** after each birth

Identifying groups (drop of blood + antisera; clumping = antigen present)

- anti-A clumps A cells; anti-B clumps B cells; **anti-D** clumps Rh+ cells
- e.g. clumps with anti-A and anti-D, not anti-B → **A+**; with none → **O−**; anti-B only → B−

Arterial system

- arteries carry blood **away from the heart**; oxygenated except the **pulmonary arteries**
- **pulmonary trunk** → right and left pulmonary arteries → lungs
- **aorta** (largest, 2.5–3 cm):
  1. **ascending**: right and left **coronary** arteries
  2. **arch**: **brachiocephalic** (→ right common carotid + right subclavian), **left common carotid**, **left subclavian**
     - **common carotid** → **external carotid** (face, scalp, neck, jaw, tongue) + **internal carotid** (brain, eyes, forehead, nose)
     - **subclavian** → **vertebral** (to the brain's base) → **axillary** → **brachial** → **radial** + **ulnar** (wrist pulse: radial)
  3. **descending**: thoracic, then abdominal aorta:
     - posterior **intercostals** · **esophageal** (and bronchial) · **inferior phrenic** (diaphragm)
     - **celiac trunk** → **left gastric**, **splenic**, **common hepatic**
     - **superior mesenteric** (small intestine, cecum, ascending and transverse colon)
     - **renal** · **gonadal** (testicular, ovarian) · **lumbar** (4 pairs)
     - **inferior mesenteric** (descending, sigmoid colon, rectum)
     - at **L4** → right and left **common iliac**
  4. **common iliac** → **internal iliac** (pelvic organs, buttock) + **external iliac** → **femoral** → **popliteal** → **anterior** and **posterior tibial**



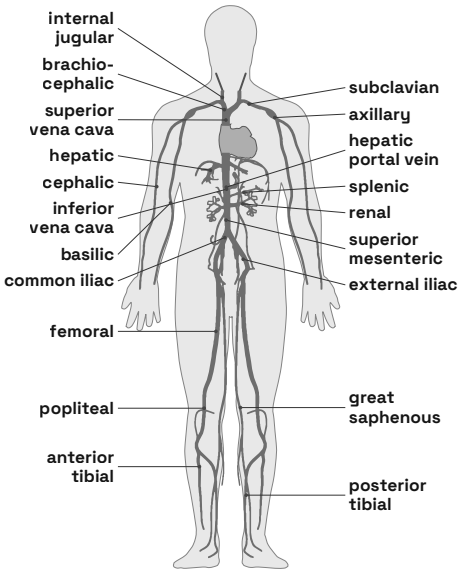
The main arteries of the body.

Venous system

- veins carry blood **back to the heart**; deoxygenated except the **pulmonary veins**

1. **pulmonary veins**: 4 (two each lung) → left atrium
2. **coronary veins** → **coronary sinus** → right atrium
3. **SVC** (precaval): head, neck, arms, chest wall; = right + left **brachiocephalic veins**, each = **internal jugular** (brain, skull, face, neck) + **subclavian** (arm; continues the **axillary**, which gets the **cephalic** and **basilic**); **external jugular** (scalp, face, jaw) joins the subclavian
4. **IVC** (postcaval; **largest vein**): below the diaphragm; = two **common iliacs** at **L5**; receives:
   - common iliac = **external iliac** (whole leg; continues the **femoral** ← popliteal ← anterior and posterior tibial; + **great saphenous**, **longest vein**, inner foot to groin) + **internal iliac** (hypogastric; pelvic organs, buttock)
   - **lumbar** · **gonadal** (left → left renal vein) · **renal** · **suprarenal** (left → left renal) · **hepatic** · **inferior phrenic**

- great saphenous: used for coronary bypass



The main veins; the hepatic portal system in purple.

Hepatic portal system

- **hepatic portal vein**: gut, pancreas, spleen, gall bladder → **liver**; formed behind the pancreas by **superior mesenteric** + **splenic** veins
- receives: **cystic** (gall bladder) · **splenic** (inferior mesenteric usually joins it) · **gastric** · **duodenal** · **mesenteric**
- nutrient-rich, deoxygenated blood → **sinusoids** of the liver → **hepatic veins** → IVC → heart

Significance

1. nutrients to the liver first: stored (glycogen, iron, vitamins A, B_{12}), changed, sent on → steady blood glucose
2. **toxins**, drugs, alcohol **detoxified** first
3. germs killed by **Kupffer cells**
4. **ammonia** → **urea**

COMMON MISTAKES

✗ The fibrous pericardium is the layer next to the heart
✓ the **epicardium** (visceral serous layer) is.

✗ The pericardial cavity is between fibrous and serous layers
✓ between the **two serous** layers.

✗ The heartbeat starts in the brain
✓ the heart is **myogenic**; the **SA node** starts it.

✗ The SA node delays the impulse
✓ the **AV node** delays it (~0.1 s).

✗ Lubb is the semilunar valves closing
✓ lubb = **AV valves**; dub = **semilunar** valves.

✗ Arteries always carry oxygenated blood
✓ an artery carries blood **away from the heart**; pulmonary arteries carry deoxygenated blood.

✗ Stroke volume is the blood of both ventricles
✓ of **each** ventricle per beat.

✗ O is the universal recipient
✓ **O** universal **donor**, **AB** universal **recipient**.

✗ Anti-Rh antibodies are present from birth
✓ made only after **exposure** to Rh+ blood.

✗ Left gastric, splenic and hepatic arteries leave the aorta separately
✓ all three come from the **celiac trunk**.

✗ The femoral vein is the longest
✓ the **great saphenous** vein is.