Unit 18 · Respiratory 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:** long question (OR): the human respiratory system
- **Our model papers:** Paper 1's long question (how air is drawn in; oxygen delivered and taken up per minute; breathless on Everest, Sherpas); Paper 2 MCQ (CO_2 mostly as bicarbonate)
- **MCQ (1 mark)**
  - unpaired laryngeal cartilage: cricoid
  - trachea lining: pseudostratified
  - pneumocytes: squamous
  - inspiration: external intercostals contract
  - pharynx: food and air separate
  - expiration is passive; diaphragm domes
  - bicarbonate made in RBCs
  - left lung: two lobes
  - surfactant lowers surface tension
  - C-rings open at the back
- **Short and long (in parts)**
  - larynx; why the Adam's apple
  - pulmonary ventilation
  - the lungs' morphology
  - gas exchange in the alveoli, with a diagram
  - transport of O_2 and CO_2
  - label the respiratory organs (A–I)
  - organs of breathing with a labeled diagram (long)
  - ventilation, exchange, transport, internal respiration (long)

Key terms

Respiratory system: organs exchanging gases with the air: O_2 in, CO_2 out.

Breathing (external respiration): air moved in and out; gases exchanged between lung air and blood.

Cellular (internal, tissue) **respiration**: energy released in cells by oxidizing food.

Conducting zone: airways that only carry air; **respiratory zone**: alveoli and the smallest bronchioles carrying them.

Pleura: double membrane round each lung: **visceral** (on the lung), **parietal** (on chest wall); **pleural fluid** between.

Surfactant: fat–protein film from **type II pneumocytes**; lowers alveolar surface tension.

Pulmonary ventilation: air moved into and out of the lungs by the respiratory muscles.

Partial pressure: a gas's share of the total pressure (air O_2 21% of 760 mmHg ≈ 160 mmHg).

Diffusion (respiratory) membrane: alveolar squamous epithelium + capillary endothelium + basement membrane (~0.5 μm).

Bohr effect: high CO_2 (low pH) shifts the curve right; Hb gives up more O_2.

Chloride shift (Hamburger phenomenon): Cl^- into the RBC as HCO_3^- leaves.

Carbaminohemoglobin: CO_2 joined to hemoglobin's $-NH_2$ groups.

Haldane: CO in mine "afterdamp"; **father of oxygen therapy**.

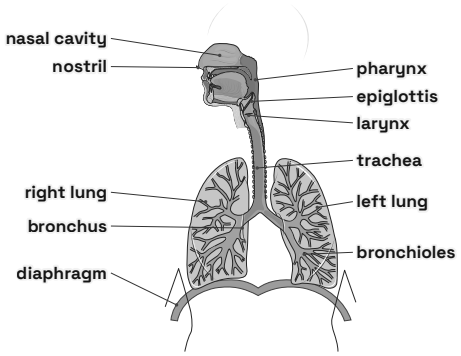
Respiration

	Aerobic	Anaerobic
oxygen	used	not used
where	cytoplasm, then **mitochondria**	cytoplasm only
breakdown	complete: CO_2 + H_2O	partial: lactic acid, or alcohol + CO_2
ATP per glucose	~**38** (classic; 30–32 today)	**2**
in	most organisms	sprinting muscle, yeast, *Taenia*, *Ascaris*

- $C_6H_{12}O_6 + 6\,O_2 \rightarrow 6\,CO_2 + 6\,H_2O + ATP$
- animals: $C_6H_{12}O_6 \rightarrow 2\,C_3H_6O_3$ (lactic acid) + 2 ATP
- yeast: $C_6H_{12}O_6 \rightarrow 2\,C_2H_5OH + 2\,CO_2 + 2$ ATP

The air passages

- nose → pharynx → larynx → trachea → bronchi → bronchioles → alveoli; moved by the respiratory muscles



The human respiratory organs.

Nose

- frame: bone above, cartilage below
- **external nostrils** (nares) → nasal chambers (split by the **nasal septum**) → **internal nostrils** (choanae) → pharynx
- **vestibule**: skin with hairs, **vibrissae**
- **respiratory region**: three **nasal conchae** (turbinates: superior, middle, inferior); **pseudostratified ciliated columnar** epithelium + **goblet cells**; rich blood supply
- **olfactory region** (roof): olfactory receptors → **olfactory bulb**
- **paranasal sinuses** (four pairs): **frontal**, **ethmoidal**, **maxillary** (largest), **sphenoidal**; lighten the skull, voice resonance; sinusitis

Functions of the nose

- stops dust
- **filters, warms, moistens** air
- smell
- vibrissae and mucus trap dust, germs; cilia sweep mucus to the throat
- voice resonance

Pharynx (~12 cm): common passage for food and air

- **nasopharynx**: internal nostrils, **Eustachian tubes**; air only
- **oropharynx**: food and air
- **laryngopharynx**: **trachea** in front, **esophagus** behind
- swallowing: soft palate closes nasopharynx; larynx rises under the epiglottis

Larynx (voice box)

- box of cartilage at the top of the trachea, **C3–C6**
- **nine cartilages**:

Single	Paired
thyroid: largest, two plates, ridge in front	**arytenoid**: on the cricoid; vocal cords fixed to them
cricoid: signet ring, broad at the back; only **complete ring** in the airway	**corniculate**: horns on the arytenoids
epiglottis: leaf of **elastic cartilage**	**cuneiform**: rods in the folds

- jobs: support; protect the cords; change cord tension for sound
- **Adam's apple**: at puberty **testosterone** → boy's larynx grows, thyroid ridge juts; cords lengthen → voice deepens
- **glottis** (opening) closed by the **epiglottis** in swallowing
- **false vocal cords** (upper; no sound); **true vocal cords** (lower): air out between them → **vibrate** → voice; tighter, thinner → higher

Trachea, bronchi, bronchioles

Trachea

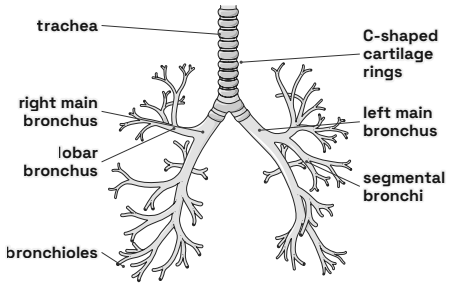
- **~12 cm** long, **2.5 cm** across; C6 → ~T5; in front of the esophagus
- **16–20 C-shaped rings**, stop collapse; open part faces **back** (trachealis smooth muscle) → bolus can bulge the esophagus
- **pseudostratified ciliated columnar** + goblet cells

Bronchi: trachea divides at **T5**

- **right**: wider, shorter (~2.5 cm), more **upright** → inhaled peanuts lodge here
- **left**: ~5 cm; under the aortic arch
- plates and incomplete rings of cartilage; pseudostratified ciliated lining

Branching

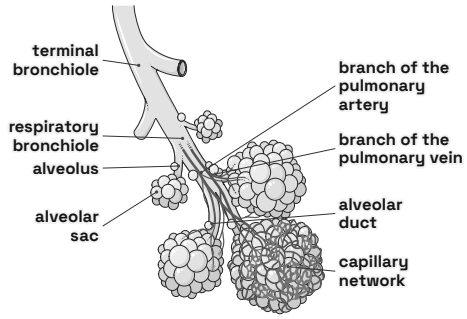
1. **primary bronchi**
2. **secondary (lobar)**: 3 right, 2 left
3. **tertiary (segmental)**
4. **bronchioles**: < 1 mm, **no cartilage**, smooth muscle (narrow in asthma); ciliated columnar → cuboidal
5. **terminal bronchioles** (last that only carry air)
6. **respiratory bronchioles** (a few alveoli)
7. **alveolar ducts** → **alveolar sacs** → **alveoli**



The trachea and the bronchial tree.

The lungs

- pair, soft, spongy, pinkish, cone-shaped; in the thoracic cavity beside the heart
- **base** on the diaphragm; **apex** just above the collarbone
- **right**: larger; two fissures → **3 lobes**
- **left**: smaller; **2 lobes**; **cardiac notch**
- **pleura**: visceral + parietal; **pleural fluid** lets them slide and holds the lung to the chest wall
- **300–500 million alveoli** (~480 million, 2004); each ~0.2 mm; surface ~**70 m²**
- **type I pneumocytes**: thin, **squamous**, ~95% of surface; gases diffuse across
- **type II**: **cuboidal**; **surfactant** (premature babies lack it)
- two blood supplies: **pulmonary arteries** (deoxygenated, to be loaded) + pulmonary veins; **bronchial arteries** (from aorta; feed lung tissue)
- lung capillaries carry **ACE**: angiotensin I → angiotensin II (raises blood pressure)



A respiratory bronchiole, alveolar ducts and sacs with capillaries.

Respiratory muscles

- **diaphragm**: dome of muscle and tendon; contracts → **flattens**; relaxes → **dome**
- **external intercostals**: lift ribs; **internal intercostals**: pull them down
- **accessory**: neck (sternocleidomastoid, scalenes), shoulders, abdomen; only in hard breathing

Pulmonary ventilation

- physiology of respiration: ventilation · gas exchange · O_2 transport · internal respiration · CO_2 transport
- adult at rest: **12–16 breaths/min**, ~0.5 L each
- air flows high → low pressure; muscles change chest size, so lung pressure

Inspiration (always **active**)

1. **external intercostals contract**: ribs, sternum **up and out** (bucket handle)
2. **diaphragm contracts**, flattens, moves down
3. chest grows in all three directions; lungs follow (pleural fluid)
4. **intrapulmonary pressure falls** (~1 mmHg)
5. air **rushes in** until pressures equal

Expiration

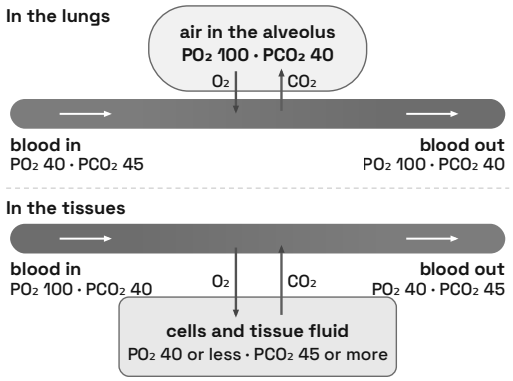
- **quiet**: **passive**: muscles **relax**; ribs down and in; diaphragm **domes**; lungs **recoil** → pressure rises → air out
- **forced**: **active**: **internal intercostals** + **abdominal muscles** contract

Exchange of gases

- in the **alveoli**, by **simple diffusion** down **partial pressure** gradients

	PO_2 (mmHg)	PCO_2 (mmHg)
alveolar air	~100	40
blood to lungs	40	~45
blood leaving lungs	~100	40
tissues	≤ 40	≥ 45

- lungs: O_2 alveoli → blood; CO_2 blood → alveoli
- CO_2 gradient small but CO_2 ~**20 ×** more soluble → as fast
- fast because: huge area; very thin membrane (~0.5 μm); gradients kept by breathing and blood flow; moist surface
- RBC in an alveolar capillary ~0.75 s; loaded in a third of that



Gas exchange in the lungs and tissues, partial pressures in mmHg.

Transport of oxygen

- **100 mL arterial blood carries ~20 mL O_2**
- **dissolved in plasma**: **~1–3%**
- **oxyhemoglobin**: **~97–99%**; each Hb carries **4 O_2** (one per heme iron)
- $Hb + 4\,O_2 \rightleftharpoons Hb(O_2)_4$: **unstable**; forms where PO_2 high
- forming helped by: low PCO_2, lower temperature, higher pH (lungs)
- **dissociation curve**: **S-shaped**; one O_2 on → others bind easier; nearly full over high PO_2; steep middle: small PO_2 fall → much O_2 released
- e.g. 5 L blood/min × 20 mL per 100 mL = 1,000 mL O_2/min delivered; body uses 250 mL → 25% taken up
- Everest summit ~253 mmHg (a third of sea level; Kathmandu ~640): still 21% O_2 but a third as much per breath → breathless; Tibetans, many Sherpas: *EPAS1* gene version (from Denisovans), no blood thickening

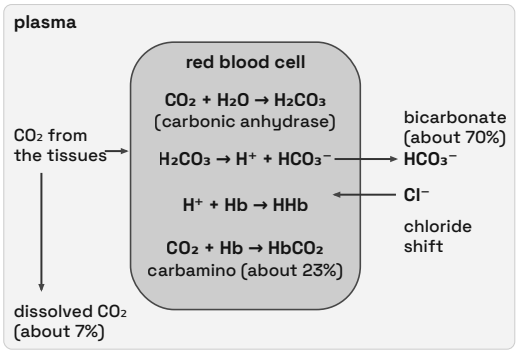
Internal (tissue) respiration

- tissue PO_2 low → $Hb(O_2)_4 \rightleftharpoons Hb + 4\,O_2$ → O_2 diffuses into cells
- helped by **high PCO_2**, **higher temperature**, **low pH** (working muscle): **Bohr effect**
- glucose oxidized in **mitochondria** → ATP
- **carbon monoxide**: binds Hb ~200–250 × more strongly → **carboxyhemoglobin**; let go slowly (faster with pure O_2); closed rooms with charcoal, heaters kill every winter in Nepal

Transport of carbon dioxide

1. **dissolved in plasma**: **~7%**; a little → carbonic acid, slowly (little enzyme in plasma)
2. **bicarbonate**: **~70%**; in **RBCs**, **carbonic anhydrase**:
   - $CO_2 + H_2O \rightarrow H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$
   - H^+ taken up by **hemoglobin** (blood hardly more acid)
   - HCO_3^- diffuses out to the **plasma**; **Cl^- in**: **chloride shift**
   - books: $KHCO_3$ in RBC, $NaHCO_3$ in plasma (really ions)
3. **carbaminohemoglobin**: **~23%**; $Hb{\cdot}NH_2 + CO_2 \rightleftharpoons Hb{\cdot}NHCOOH$

- in the lungs all three reverse (PCO_2 low): HCO_3^- back in, Cl^- out, carbonic anhydrase splits $H_2CO_3 \rightarrow CO_2$ out



How a red blood cell carries carbon dioxide.

COMMON MISTAKES

✗ Expiration always uses the internal intercostals
✓ quiet expiration is **passive** recoil; they work only in **forced** expiration.

✗ The lungs suck air in
✓ the **chest grows**, lung pressure falls, air flows in.

✗ In inspiration the diaphragm becomes dome-shaped
✓ it **flattens**; it domes in expiration.

✗ Oxygen is pumped into the blood
✓ it **diffuses** down its partial pressure gradient.

✗ Most CO_2 goes as carbaminohemoglobin
✓ most (~70%) as **bicarbonate**.

✗ Bicarbonate is made in the plasma
✓ in the **RBCs** (carbonic anhydrase), then moves to plasma.

✗ Surfactant raises surface tension
✓ it **lowers** it, so alveoli don't collapse.

✗ The tracheal rings are open in front
✓ open at the **back**, towards the esophagus.

✗ The left lung has three lobes
✓ **right** three, **left** two.

✗ The epiglottis is hyaline cartilage
✓ **elastic** cartilage.