Respiration

Properties and Transport of gases

External respiration and Ventilation

Vertebrate and Invertebrate breathing
Properties of gases: the total pressure exerted by a mixture of gases

- The **total pressure** of a gas mixture is the sum of the partial pressures of individual gases (Dalton law).
- Each **partial pressure** is independent of the other gases.
- Gases **diffuse** from regions of high partial pressure to low, at a rate proportional to the difference.

<table>
<thead>
<tr>
<th>Gas</th>
<th>Percent of all gas</th>
<th>Partial pressure in atmospheres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen</td>
<td>20.95</td>
<td>0.2095</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>78.09</td>
<td>0.7809</td>
</tr>
<tr>
<td>Argon</td>
<td>0.93</td>
<td>0.0093</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>0.03</td>
<td>0.0003</td>
</tr>
</tbody>
</table>

\[ \Sigma = 1 \text{ atm} \]
Temperature and salinity decrease gas solubility in solutions

• The concentration of a gas is proportional to the partial pressure

• Henry’s LAW: \( C = AP \) (concentration = abs coeff x partial pressure)

• \( A: \) absorption coefficient (solubility of gas in a solution)

• \( \text{CO}_2 \text{ much higher solubility than } \text{O}_2 \)
Transport of Gases


- Gases diffuse more easily in gases than liquids (200,000 for O2) (liquid in lungs)
- Diffusion can supply O2 for distances of 1 mm in tissues
- Only free gas contribute to the gas partial pressure (Hemoglobin)
Transport of gases: Gases move also by convective gas transport

2. **convective gas transport**: a fluid moving from place to place carries along the gas transported in the fluid.

Much more effective than simple diffusion: breathing and pumping of blood.

Movement of fluids: natural or muscle driven.

(a) Two types of convective transport

Unidirectional flow

Tidal flow

(b) Calculation of the rate of convective gas transport

\[ C = \text{Total concentration of gas in flowing fluid (mol/L)} \]
\[ F = \text{Flow rate of fluid (L/second)} \]

**Rate of convective gas transport** = \( C \times F \)

**Hemoglobin**: 50X Transport

**Heart**: 5 liters/min
Gas transport occurs by alternating convection and diffusion

Mechanisms of oxygen transport in the delivery of \( O_2 \) to the mitochondria

**Convective gas transport**: a fluid moving from place to place carries along the gas transported in the fluid.

**Simple diffusion**: high partial press --- low partial press
The oxygen cascade

(a) A cascading stream

(b) The oxygen cascade in people
The physical properties of air and water affect respiration.

Solubility of O₂ in cold water
Higher than warm water

<table>
<thead>
<tr>
<th></th>
<th>Concentration of O₂ (mL O₂ at STP/L) at specified temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0°C</td>
</tr>
<tr>
<td>Air</td>
<td>210</td>
</tr>
<tr>
<td>Freshwater</td>
<td>10.2</td>
</tr>
<tr>
<td>Seawater</td>
<td>8.0</td>
</tr>
</tbody>
</table>

Water more dense: more energy to move it!

A water-breathing animals must work much harder to obtain oxygen!
Processes that affect partial pressures of $O_2$ and $CO_2$ within an environment.
Oxygen supply to the deep waters of a lake

Solubility of O2 in water is only 3-5 %. Changes with Temperature and other factors.

Solubility of O2 in cold water Higher than warm water
Extemal respiration and Ventilation
EXTERNAL RESPIRATION: Generalized features of animal gas exchange

**External respiration** (breathing): transport of gases from and to the environment

**Ventilation**: convecting movement of air or water to and from the gas-exchange membrane

**Diffusion or convection**

**pO₂** → **pO₂**

**CO₂** → **O₂**

**O₂** → **CO₂**

**Environmental medium**

**Internal tissues**

**Gas-exchange membrane**

*Area and thickness Important*
Three types of respiratory structures

**Pulmonary**: lungs — **invaginated**, contain the environment

**Branchial**: gills — **evaginated** into the environment
Lungs are adaptive for terrestrial breathing because of the structural support (water gives structural support to gills).
Oxygen transfer from the environmental medium to the blood

The $O_2$ partial pressure in blood leaving the breathing organ depends on the relation between the flow of the blood and the flow of the air or water.

Unidirectional flow
Respiration

Properties and Transport of gases

External respiration and Ventilation

Vertebrate and Invertebrate breathing
Vertebrate Breathing

1. Total area and thickness of the gas-exchange membrane in the gills or lungs

2. The percentage of $O_2$ and $CO_2$ exchange that occurs across the skin
Vertebrate Breathing

Total area and thickness of the gas-exchange membrane in the gills or lungs

(a) Area of the gas-exchange membrane vs. body size

Key:
- Mammals
- Birds
- Reptiles
- Amphibians
- Fish

Total area

(b) Thickness of the gas-exchange membrane vs. body size

Key:
- Mammals
- Birds
- Reptiles
- Amphibians
- Fish

HOMEOTHERMY
Metabolic rate
The percentage of $O_2$ and $CO_2$ exchange that occurs across the skin

Skin’s desiccation resistance
1. **Continuous breathing**: Mammals, birds, fish

2. **Intermittent breathing (apnea)**: reptiles, amphibians, air-breathing fish.
The branchial breathing system in teleost fish

Countercurrent gas exchange
Breathing in teleost fish

Gill ventilation
Integration of **bucal** and **opercular** pumps

- More gill surface
- Very thin membranes
Regulation of Breathing in fish

Exercise
Decrease of oxygen

Increase Gill ventilation

Increase Lamellar recruitment
Lungfish and their lungs

Alimentary canal adaptations

Florida Gar (*Lepisosteus platyrhincus*)

Highly vascularized swim bladder
Breathing organs of amphibians

(a) Salamander larva with gills

(b) Frog lungs

Simply well vascularized sacs
The development of external respiration in the bullfrog (*Rana catesbeiana*)

![Graph showing the development of external respiration in bullfrog](image)

- **O₂ uptake (%):**
  - Lungs
  - Gills
  - Skin

- **CO₂ excretion (%):**
  - Lungs
  - Gills
  - Skin

**Phases:**
- Aquatic tadpoles
- Air-breathing tadpoles
- Postmetamorphic froglets
- Adults
Lizard lungs

(a) A unicameral lung in a lacertid lizard

(b) Scanning electron micrograph of the wall of a tegu lizard lung

(c) A multicameral lung in a monitor lizard

All respiration by lungs

Lungs filled by suction.
Action thoracic and abdominal muscles

Bronchus: cartilage-reinforced tube
The airways in human lungs

Airways and arteries injected with plastic

(a) The finest airways of the mammalian lung, ending in alveoli

Conducting airways
Respiratory airways

Terminal bronchiole
Respiratory bronchioles
Alveolar duct
Alveolus
Alveolar sac

(b) Scanning electron micrograph of a human lung

Trachea
primary bronchus,
secondary bronchus
higher-order bronchi
Bronchioles
Alveolar ducts
Alveolar sacs
alveoli

300 million alveoli in
the lungs of a human
140 m² surface
Dynamic lung volumes in healthy young adult men

Tidal volume: volume of air inhaled and exhaled per breath

Vital capacity (4800 mL)

Inspiratory reserve volume (3100 mL)

Resting tidal volume (500 mL)

Expiratory reserve volume (1200 mL)

Residual volume (1200 mL)

Volume at the end of resting inspiration (2900 mL)

Volume at the end of resting expiration (2400 mL)

Volume attained by maximal inspiratory effort (6000 mL)

Volume attained by maximal expiratory effort (1200 mL)
Mechanisms of gas transport in final branches of mammalian lungs during inhalation

2400 Vol Exp
500 (170-330)

Conducting airways
Respiratory airways

Terminal bronchiole

KEY

\[
\begin{align*}
\downarrow & \text{ Convection} \\
\Rightarrow & \text{ Diffusion through motionless air}
\end{align*}
\]

Alveolus

\[ pO_2 \]
Airflow in the lungs and air sacs of birds

Fly (high metabolism)!
High elevation (less oxygen)

Fresh air

No mix!

UNIDIRECTIONAL FLOW!

(b) Inhalation

GAS EXCHANGE
Parabronchi and air capillaries: The gas-exchange sites in avian lungs

Greater tidal volumes

High gas exchange surface

Thin gas exchange membrane
A diversity of gills in aquatic invertebrates

(a) Polychaete annelid with gill tufts

(b) Polychaete annelid with tentacular fan

(c) Sea star with branchial papulae and tube feet used as gills

External gills

KEY

- Convection
- Diffusion

Radial canal
Water ring
Sea star showing major parts of water vascular system inside

Radial canal of water vascular system
Digestive cecum
Perivisceral coelom
Gonad
Oral side
The diversification of the breathing system in molluscs

Internal gills

Sheet-gilled = lamellibranchs
The gills and ventilation in a crayfish (Decapod crustacean)

(a) A transverse section through the thorax of a crayfish

(b) A lateral view showing the gills under the carapace
All insects breathe using a tracheal system of gas-filled tubes. The gas-exchange surface is close to each cell.

(b) Major parts of the tracheal system in a flea

Abdominal spiracles 1–7

Abdominal spiracle 8

Thoracic spiracle 1

Spiracle control (desiccation)
Active Ventilation

(c) Air sacs in the abdomen of a worker honeybee

Air sac
Origins of tracheae
Transverse tracheal connective

Spiracle s in the surface
Tracheal Gills
Insect oxygen cascades assuming oxygen transport by diffusion

(a) Ambient air to Inner end of tracheal system

1. Slow O₂ transport
2. Fast O₂ transport

(b) Ambient air to Inner end of tracheal system to Mitochondria in cells

1. Slow O₂ transport
2. Fast O₂ transport