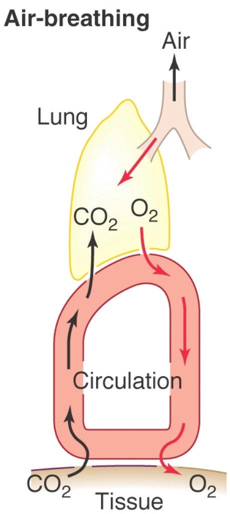
Gas Transfer and Lung Function

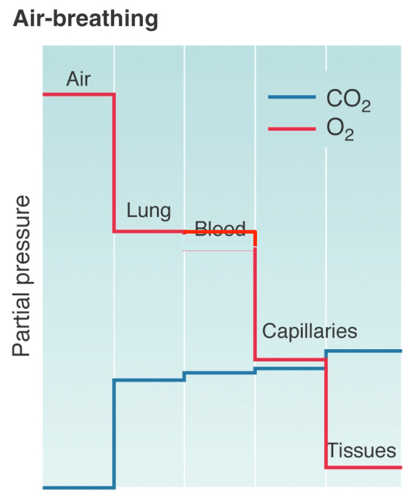
Overview: Air Breathing

- Goal:
  - Transfer of gases from environment to/from blood
- Needs:
  - Bidirectional air movement
  - Protect lung surface
  - Manage water loss

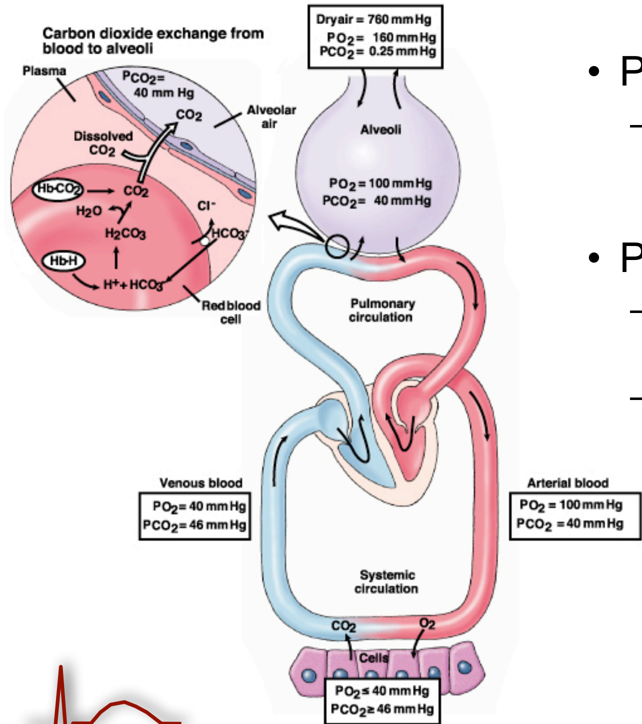
(a) Flow of respiratory gases



(b) P_{O_2} and P_{CO_2} at comparable sites



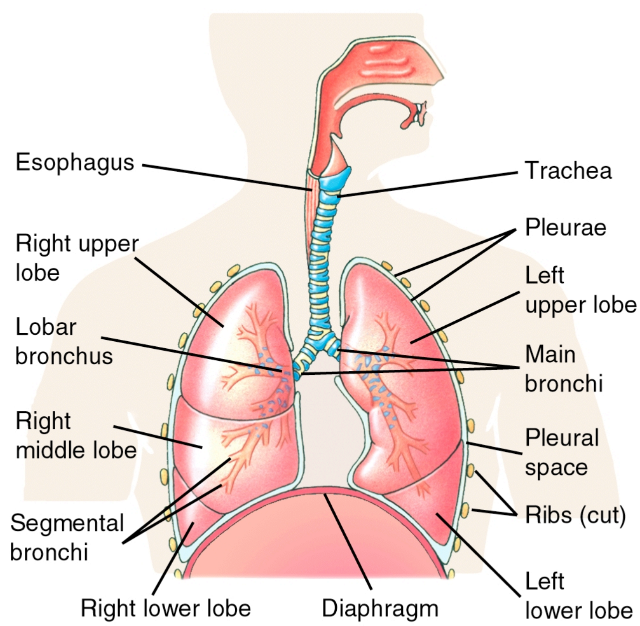
Summary of Mammalian Respiration



- PO_2 concentrations
  - lower in alveoli than room air
    - vapor pressure
    - dead space
- PO_2 and CO_2 concentrations
  - reach equilibrium in alveoli and blood
  - reach equilibrium in tissue and blood
    - flow-limited diffusion

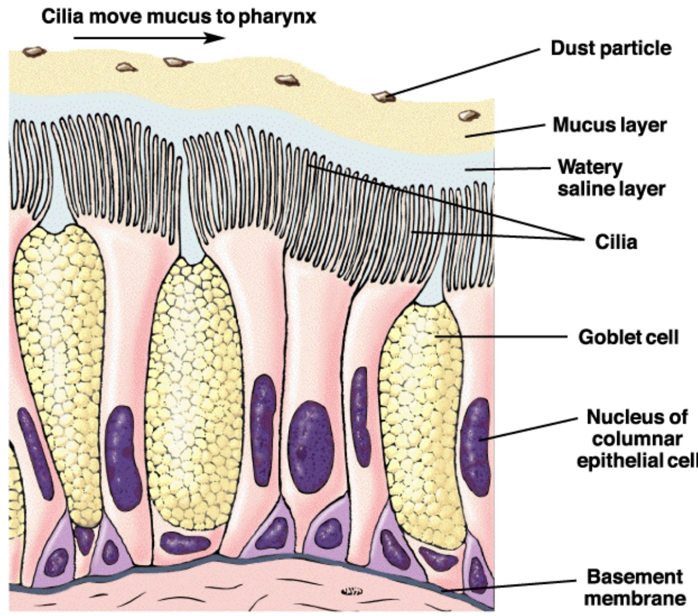
Functions of Respiratory System

- Supply O_2, remove CO_2
- Eliminate heat
- Moisten air – prevent alveoli from drying out
  - manage water loss
- Increase venous return: Pressure is negative in chest
- Maintain pH
  - Remove CO_2 at rate it is produced to prevent dangerous fluctuations in pH
- Defend against foreign matter
  - largest surface area exposed to atmosphere; 30 times that of the skin
- Olfactory sensation

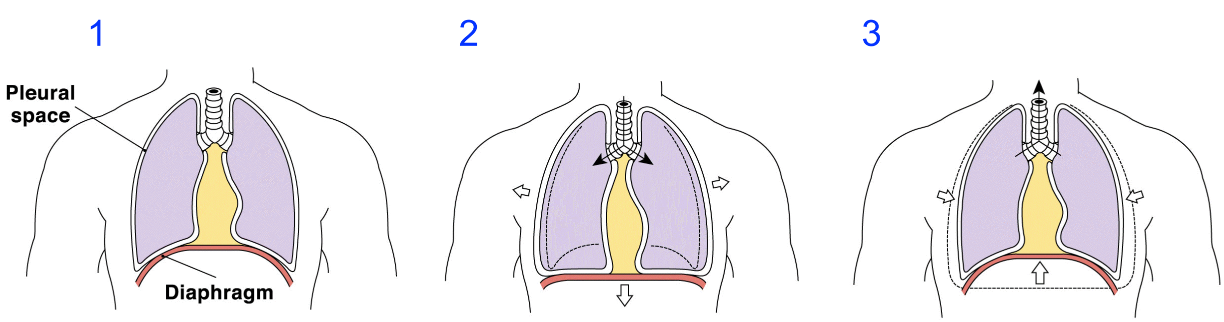


Ventilation

- Condition air to BTPS
  - Warming to 37^{o}C
  - Humidifying to 100%
  - Filter out particles
- Nose breathing allows better conditioning
- Mucus traps particles, immunoglobulins neutralize microorganisms
- Smoking paralyzes cilia

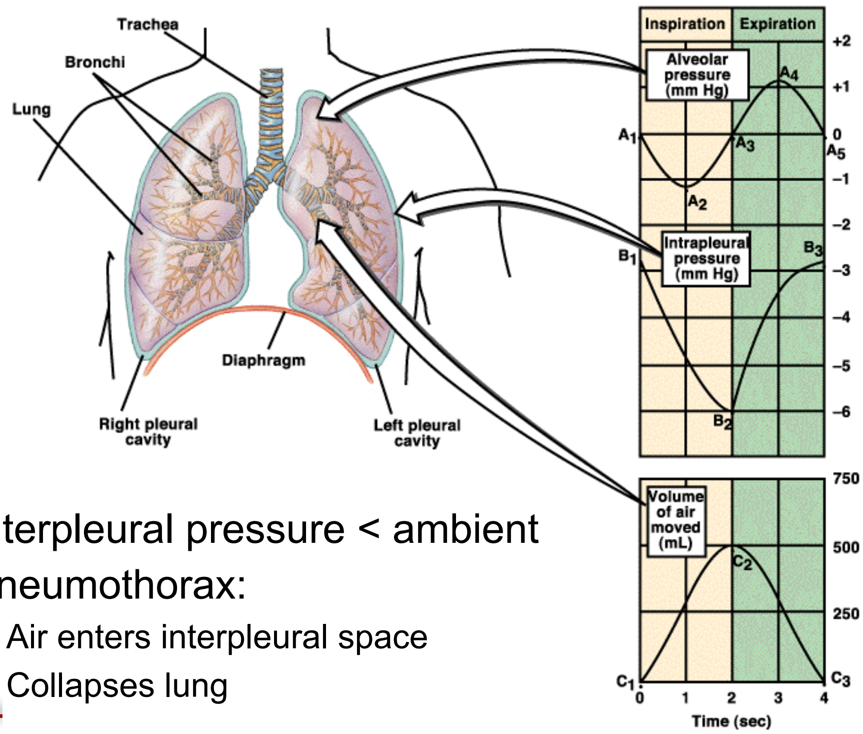


Mechanics of Ventilation



- Airflow requires pressure gradients: Flow = $\Delta P/R$
- 60-75% of inspiration at rest is from diaphragm
- Rib cage provides the remainder
- Exhalation at rest is passive
- 3-5% of body's energy required for quiet breathing.

Pressure Changes During Breathing

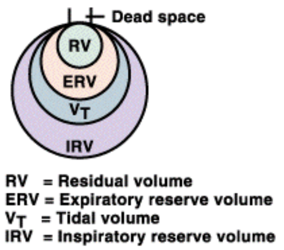


- Interpleural pressure < ambient
- Pneumothorax:
  - Air enters interpleural space
  - Collapses lung

Airway Resistance

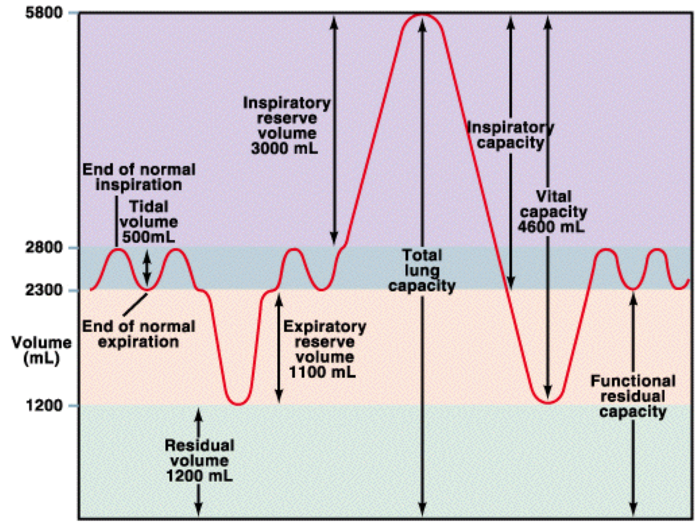
- Factors that determine resistance: $R = kL\eta/r^4$
  - Length of airway (fixed)
  - Viscosity of air (varies slightly with T and humidity)
  - Radius of airway (control mechanism)
- Radius varies and is main source of change
  - Trachea and bronchi: 90% of resistance
  - Bronchioles generally low resistance but can collapse
    - CO_2 causes bronchodilation
    - Histamine is powerful constrictor
    - Parasympath. stimulation leads to constriction
    - Epinephrine stimulates β_2 to cause dilation

Lung Volumes



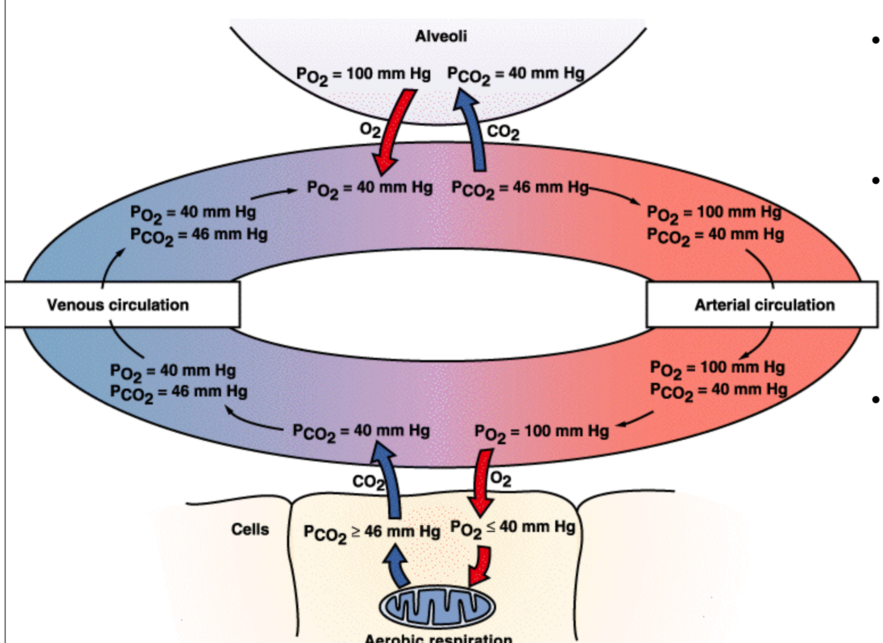
Pulmonary volumes

		Males	Females	
Vital capacity	IRV	3000	1900	Inspiratory capacity
	V_T	500	500	
	ERV	1100	700	Functional residual capacity
Residual volume		1200	1100	
		5800 mL	4200 mL	



- Dead space:
  - Anatomical and physiological (alveolar volume not involved in gas exchange)
  - Long neck increases dead space
  - Results in elevated CO_2 and reduced O_2

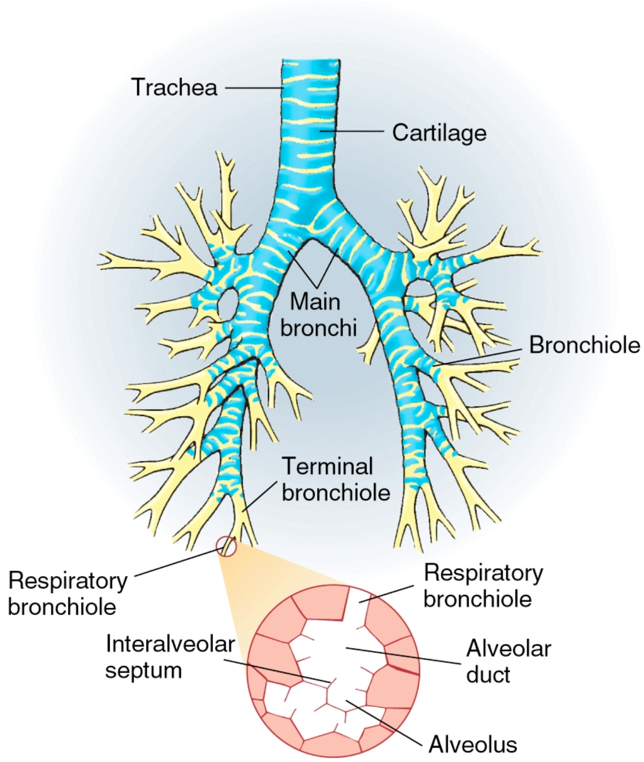
Gas Exchange



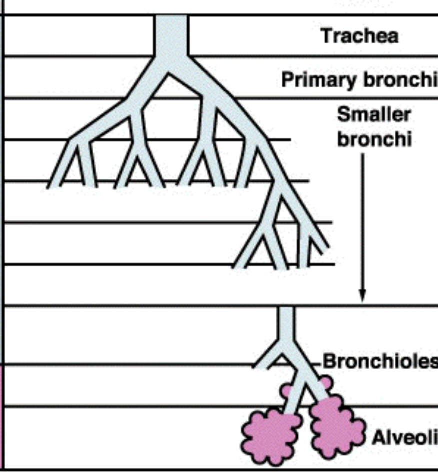
- Exchange is (normally) rapid:
  - Equilibrium in both lungs and tissues
- Pressures/concentrations drive exchange:
  - PO_2 at sea level: 100 mmHg (in lungs)
  - PO_2 at Everest: 53 mmHg
- Alveolar membrane can reduce exchange:
  - Reduction in area
  - Increase in diffusion distance:
    - e.g., edema
    - CO_2 affected less than O_2

Functional Anatomy: Mammalian Lung

- Air ducts
  - Trachea to terminal bronchioles
  - Cartilage, smooth muscle
  - Cilia move mucus along ducts for cleaning
- Respiratory portions
  - Respiratory bronchioles to alveoli
  - Alveoli interconnected by pores of Kohn (10 µm diameter)
  - Smooth muscle (point of regulation)
  - Number of terminal partitions increase (and size decreases) from amphibians to reptiles, to mammals
  - Smaller mammals have more respiratory surface (and more O_2 uptake) per weight than large ones.



Airway Branching

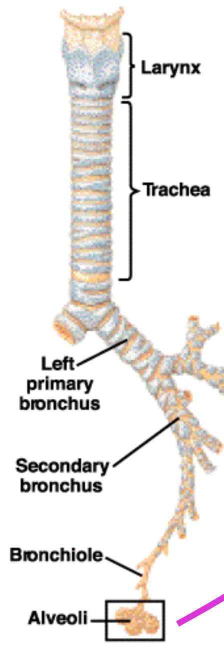


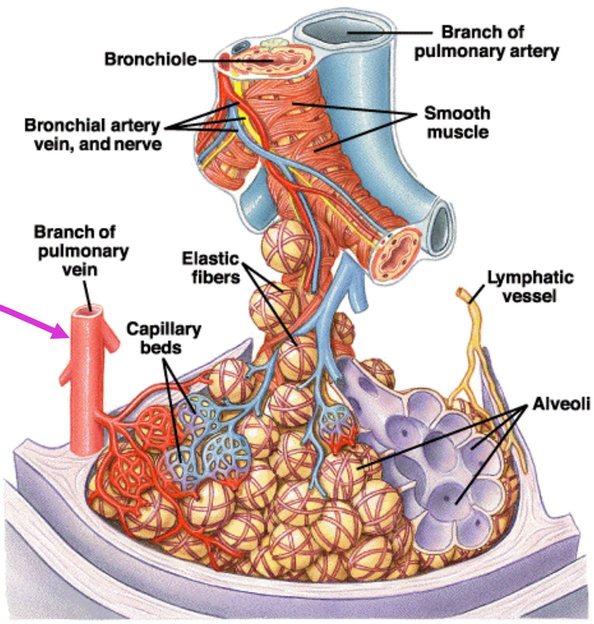
	Name	Division	Diameter (mm)	How many?	Cross-sectional area (cm)^2
Conducting system	Trachea	0	15-22	1	2.5
	Primary bronchi	1	10-15	2	↓
	Smaller bronchi ↓	2	1-10	4 ↓	
		3			
		4			
		5			
		6-11		1×10^4	
	Bronchioles	12-23	0.5-1	2×10^4 ↓ 8×10^7	100 ↓ 5×10^3
Exchange surface	Alveoli	24	0.3	$3\text{-}6 \times 10^8$	$>1 \times 10^6$

Varies from 10-24

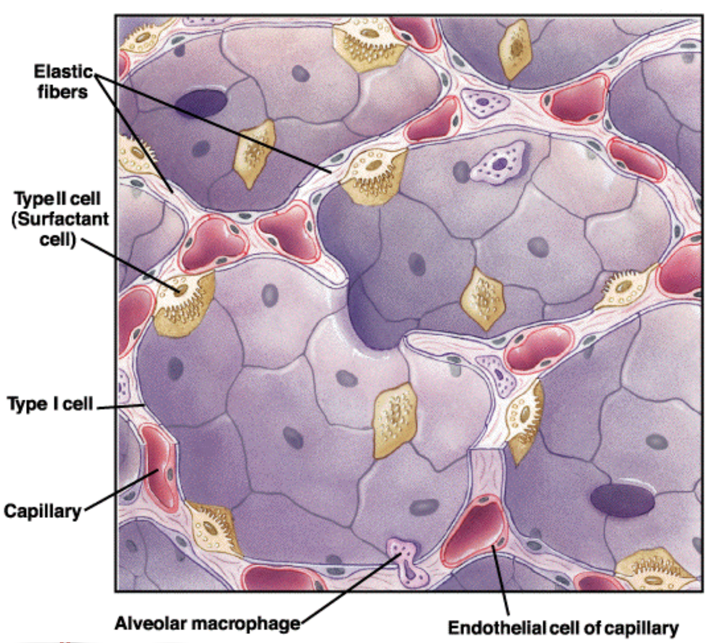
Surface area: 50-100 m^2

Ventilation System Structure





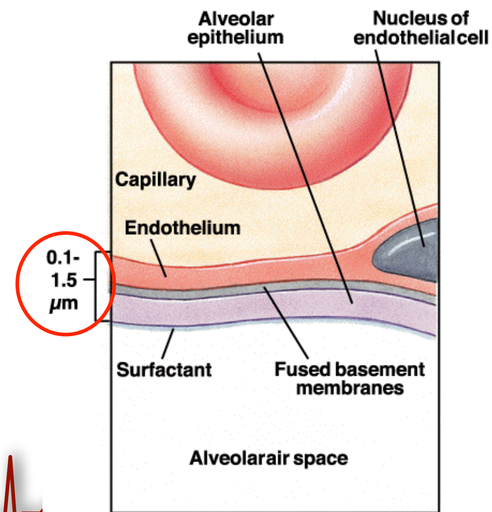
Alveolar Structure

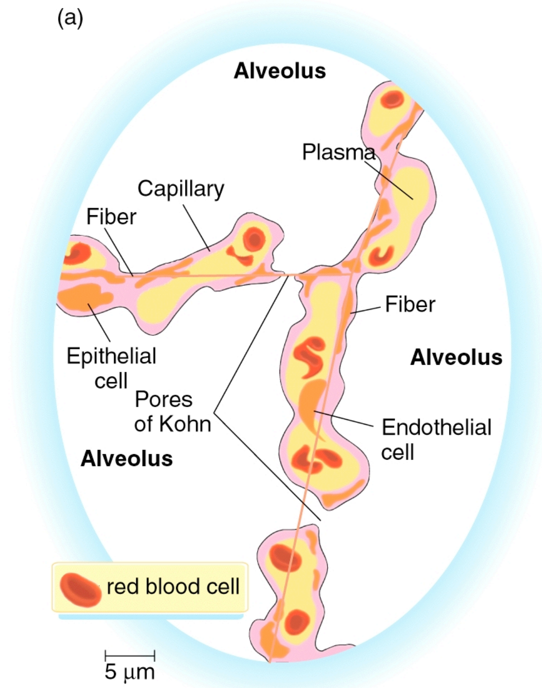


- Type I Alveoli
  - Diffusion
  - Larger with thin epithelium
  - No muscle but elastic (elastin)
  - Single cell between neighboring alveoli
- Type II Alveoli
  - Smaller, thicker cells
  - Surface villi
  - Produce surfactants
- Type III Alveoli
  - Rare, with mitochondria
  - Involved in uptake of NaCl

Diffusion Layers

- Gas exchange via diffusion
- 80-90% coverage by blood vessels
- Capillary and alveolar endothelia fuse
- Pores of Kohn connect alveoli and allow air movement



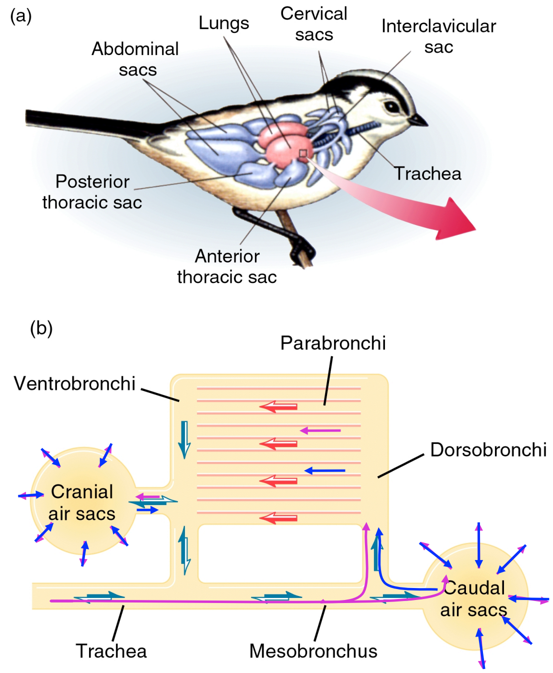


Heat and Water Loss

- In mammals, air is heated and humidified
- Nose has extensive circulation to supply water
- Conservation by:
  - Nose cools during inhalation from humidification
  - Absorbs heat from exhaled gas
  - Condensation in the nose retains water for next inhalation
- Breathing through mouth removes more heat, but also moisture
- Longer noses better at conserving water

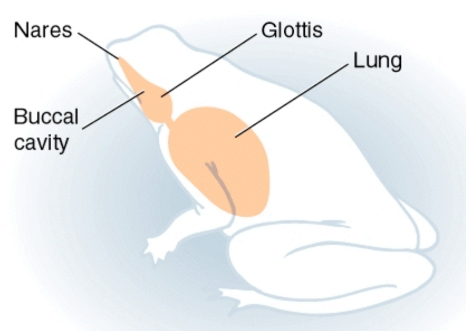
Ventilation in Birds

- Instead of alveoli, birds have air capillaries (10 µm)--the parabronchi
- Minimal breathing motion; instead, air sacs provide storage and pressure
- Achieves gas exchange in both inhalation and exhalation
- Parabronchi unidirectional flow by means of aerodynamic valving (turbulence alters resistance with direction)



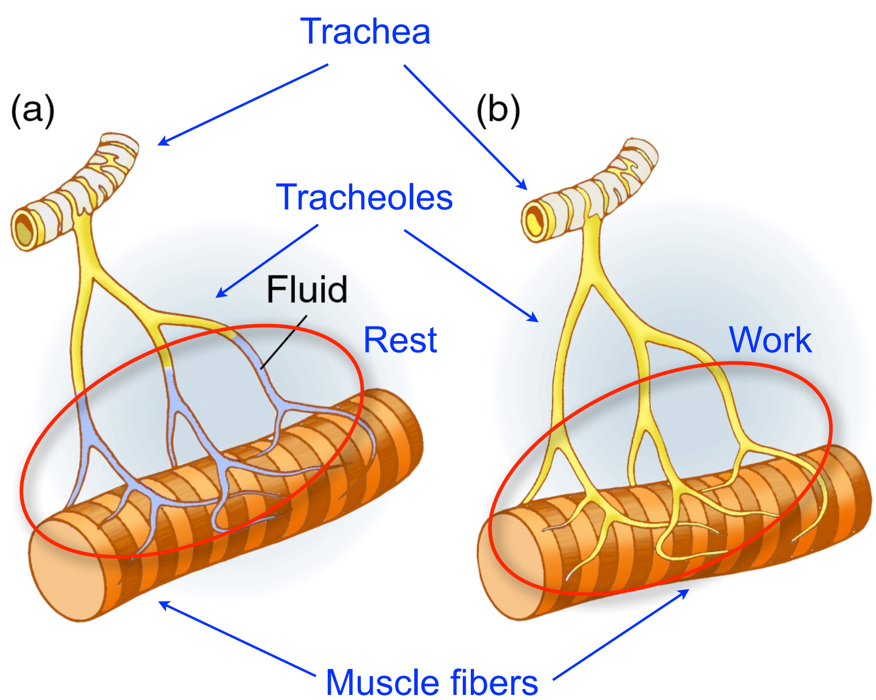
Ventilation in Frogs

- Buccal cavity and lungs separated by glottis
- Can open and close glottis and nares independently
- Inhalation (and exhalation) stepwise
- Allows mixing of pulmonary and fresh air



Tracheal Gas Exchange

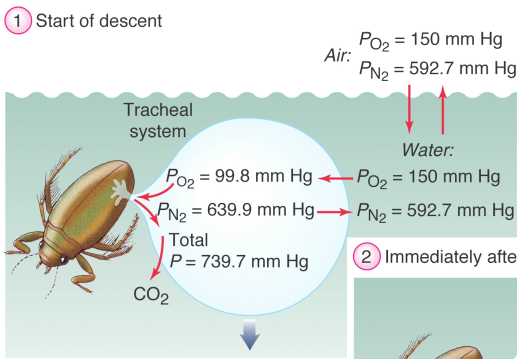
- Tracheal walls very thin (40-70 nm)
- Ends filled with fluid that regulates exchange
- Insect flight wings have highest recorded O_2 uptake of any tissue



Tracheal Systems

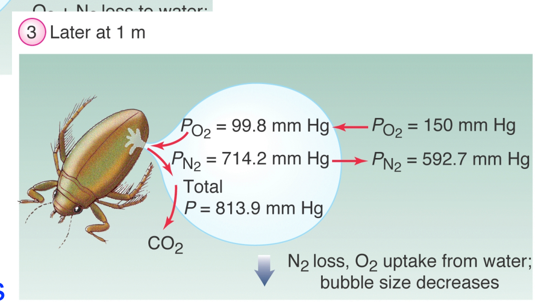
- Structure:
  - Air tubes that penetrate into the body, invaginations
  - Trachea have adjustable openings to conserve water, keep out dust
  - Trachea branch to level of individual cells, dead end into (but not inside) the cells
  - Air sacs to store gas and help insect float
- Ventilation:
  - by diffusion and convention of gases, compression of air sacs
  - Opening and closing of trachea
  - Some species use trachea only during high demand, otherwise surface is enough for diffusion

Breathing Through the Bubble



O_2 at equillibrium

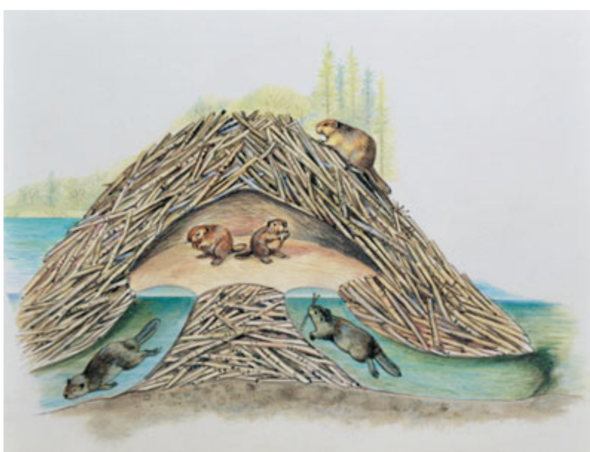
Initially O_2 loss



- 7 times the bubble volume of O_2 available through transfer from H_20

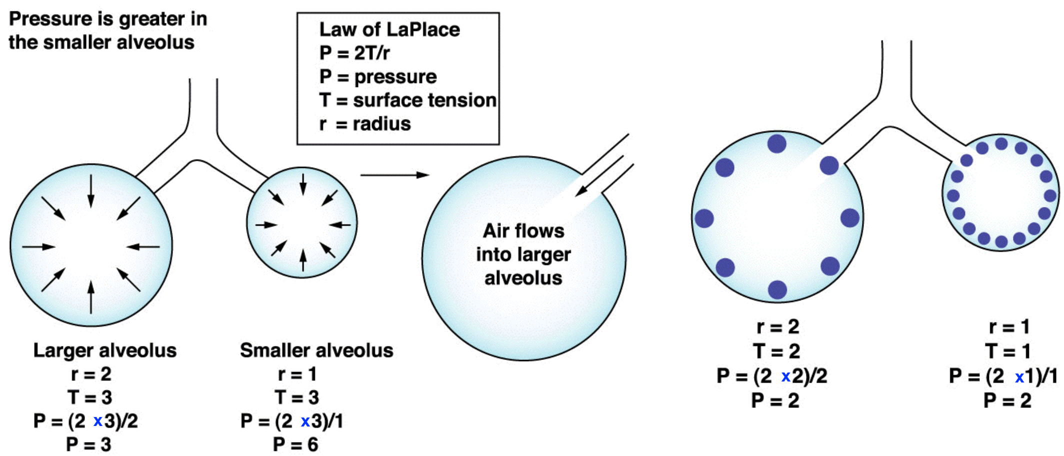
Eventually, bubble shrinks through N_2 loss

Rebreathing Bubbles



- In winter, beaver exhales under water and air is trapped under the ice
- Bubble initially has low O_2 but absorbs it over time
- Beaver rebreaths the bubbles to extract the new O_2

Surfactants



- Tension in alveoli largely result of liquid lining inner surface
- Without surfactants, air would all flow to larger alveoli and alveoli would stick together when folded
- Surfactants reduce surface tension, adhesion, allow for easy inflation
- More surfactant in smaller alveoli