

VORLESUNG 5

Vorlesung
Humboldt-Universität zu Berlin
Institut für Physik

Biologische Physik

Die Dynamik biologischer Prozesse im menschlichen Körper

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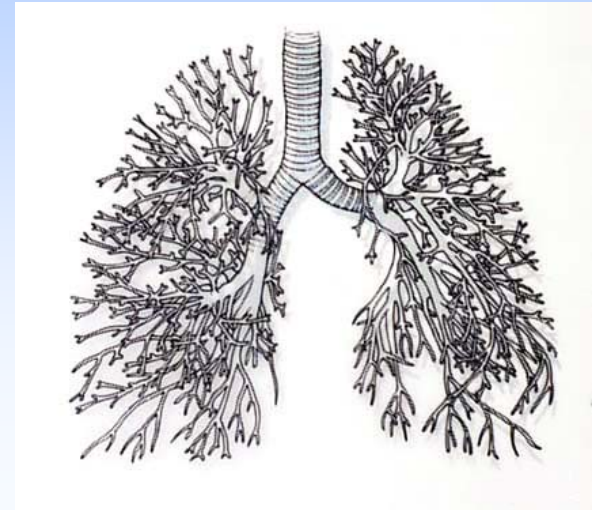
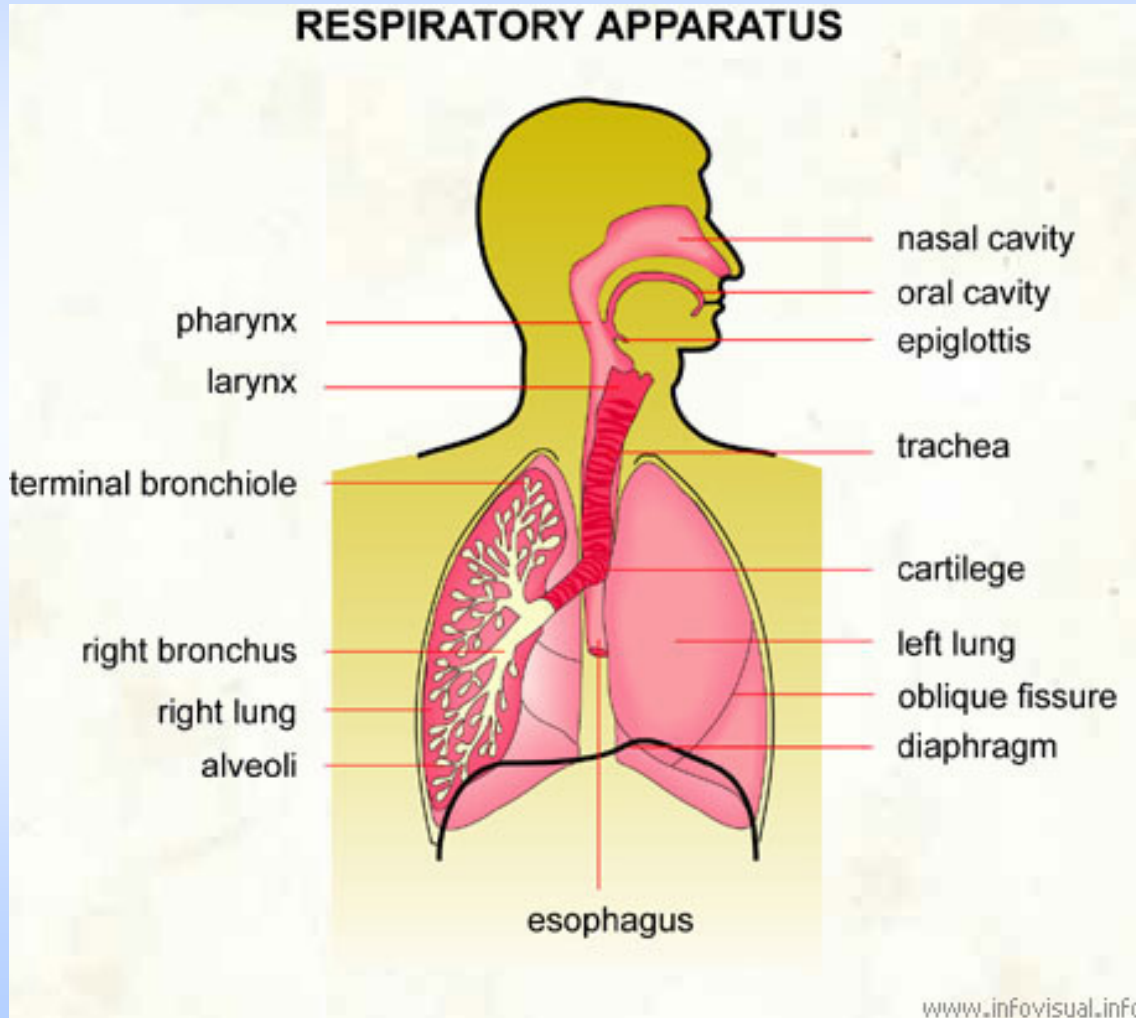


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3. Respiration

respiratory apparatus:



23 levels of bifurcation

diameter d :

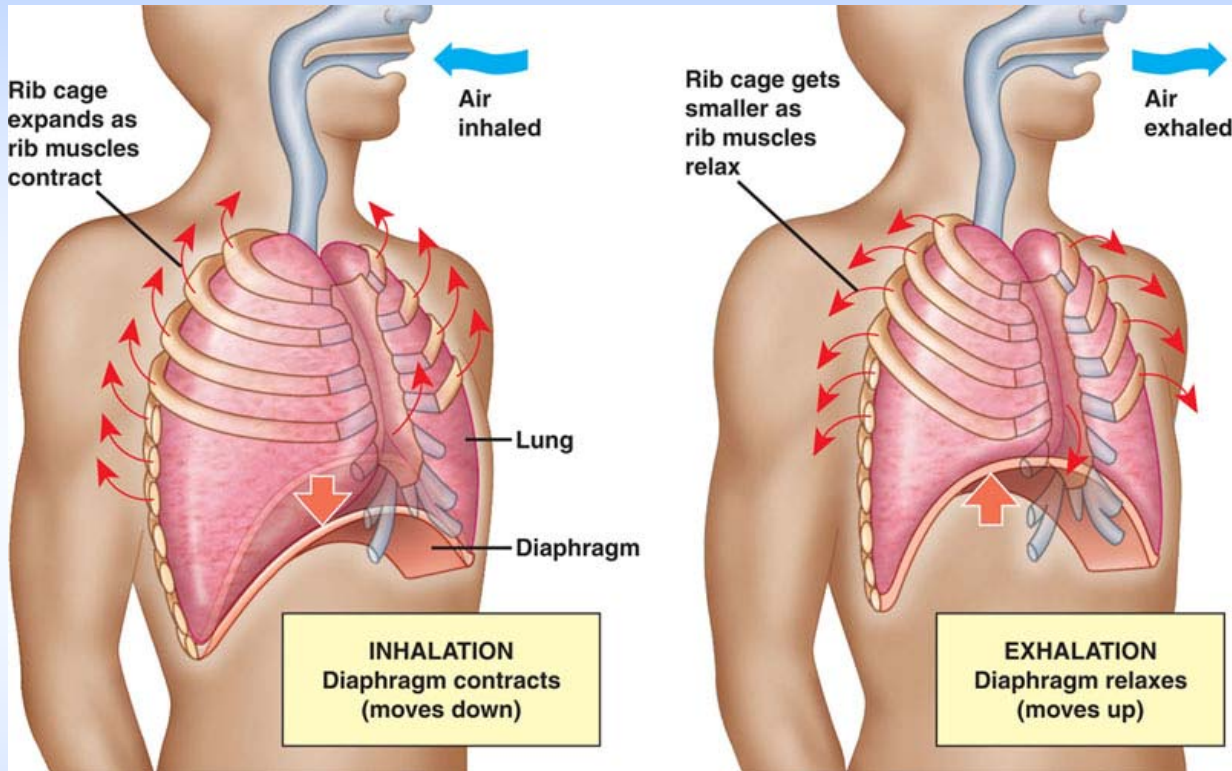
$$d(z) = d(0) 2^{-z/3}$$





3. Respiration

inhalation - exhalation:



- contraction of the diaphragm muscle
- lifting of the rib cage

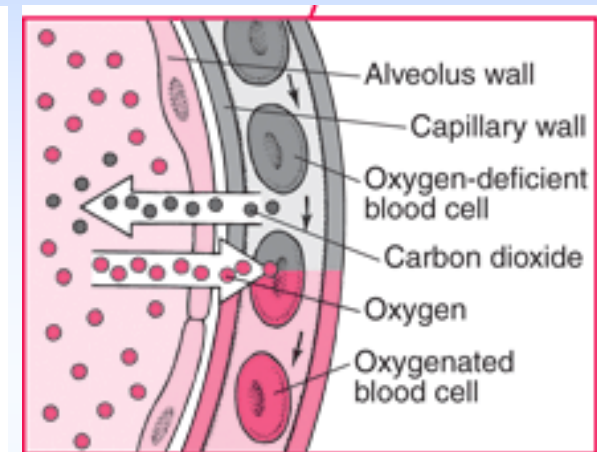
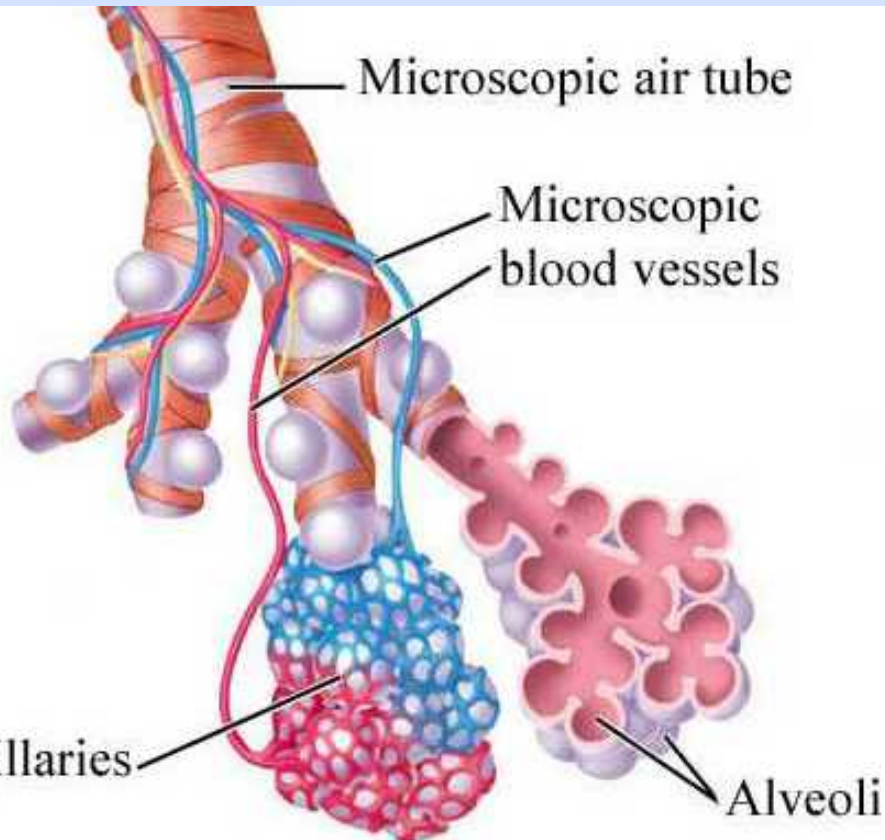
partial pressures
(in mm Hg)
of respiratory gases:

Substance	Atmospheric air	Humidified air	Alveolar air	Expired air
N ₂	597.9	563.5	569.0	566.0
O ₂	159.0	149.3	104.0	120.0
CO ₂	0.3	0.3	40.0	27.0
H ₂ O	3.7	47.0	47.0	47.0



3. Respiration

gas exchange in the alveoli:



number of alveoli:

3×10^8 alveoli

diameter of a alveolus:

~ 0.2 – 0.3 mm

total surface:

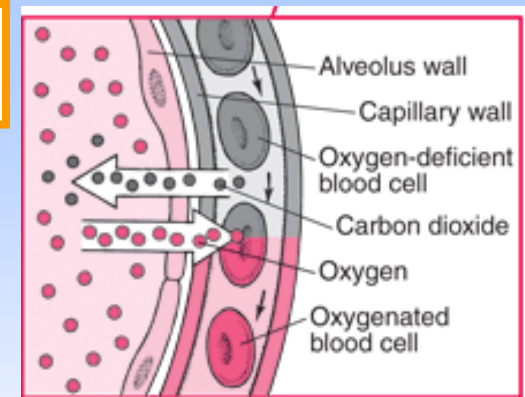
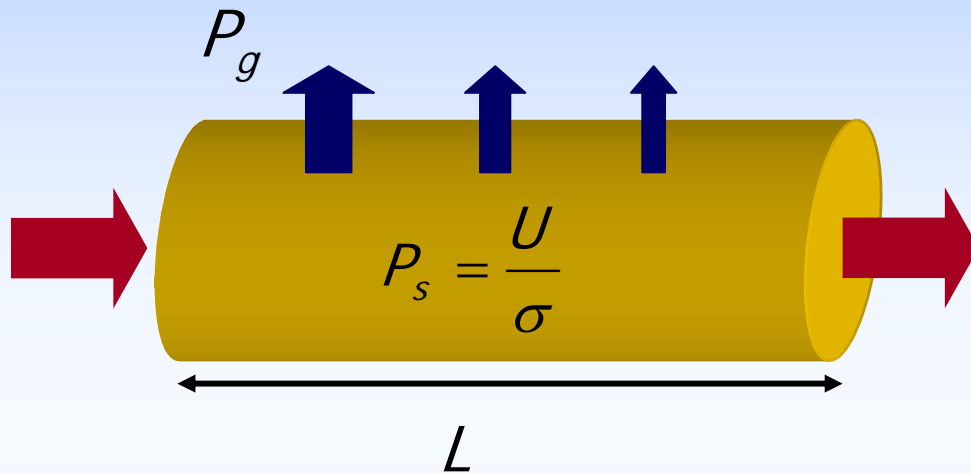
~ 80 m²





3.1 Capillary-Alveolar Transport

gas exchange in the alveoli:



surface diffusion:

$$q = D_s \left(P_g - \frac{U}{\sigma} \right)$$

steady state:

$$v \frac{dU}{dx} = D_m (\sigma P_g - U)$$

concentration profile in the capillary:

$$U(x) = \sigma P_g + (U_0 - \sigma P_g) \exp(-D_m x / v)$$

total flux of gas across the capillary wall:

$$Q = vA\sigma(P_g - P_0)(1 - \exp(-D_m L / v))$$

with

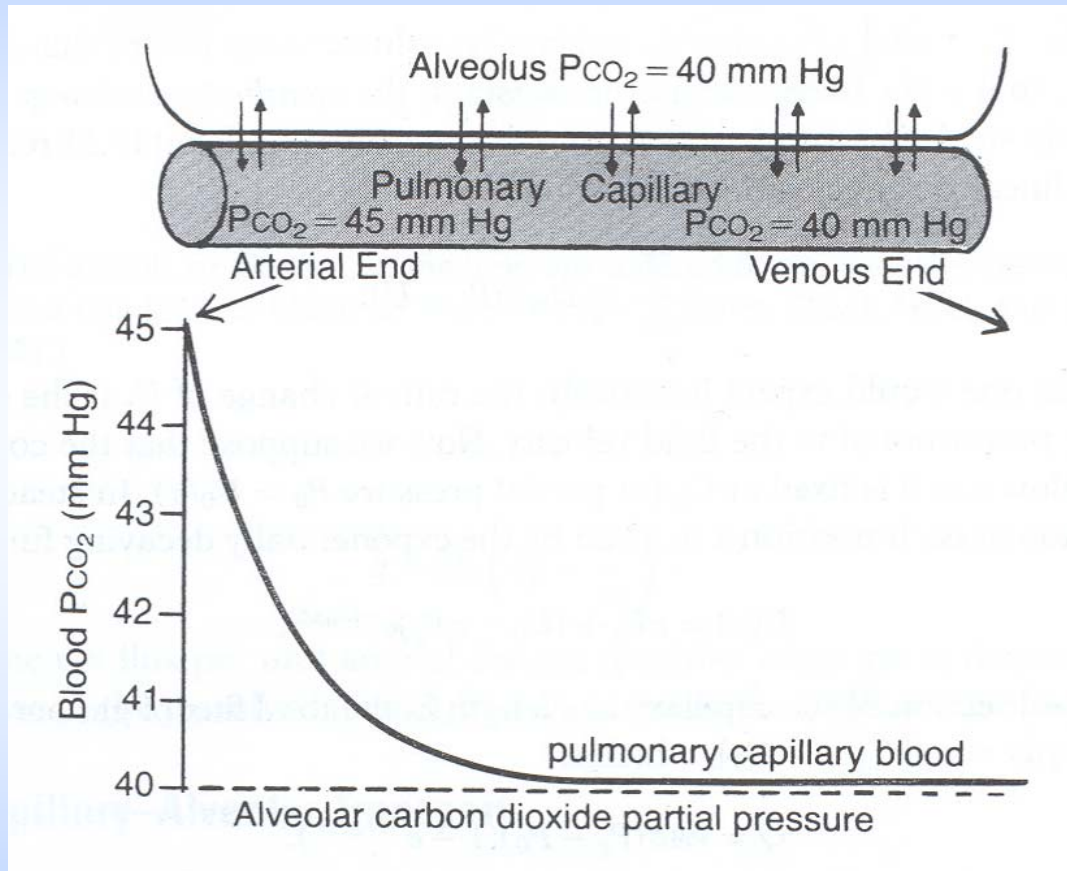
$$D_m = \frac{\rho D_s}{A \sigma}$$



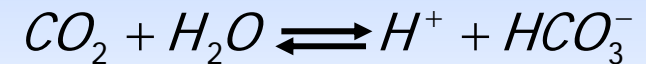


3.2 Carbon Dioxide Removal

U ... dissolved carbon dioxide in blood:



including blood chemistry:



$$[HCO_3^-] = K_c U$$

with $K_c \approx 20$

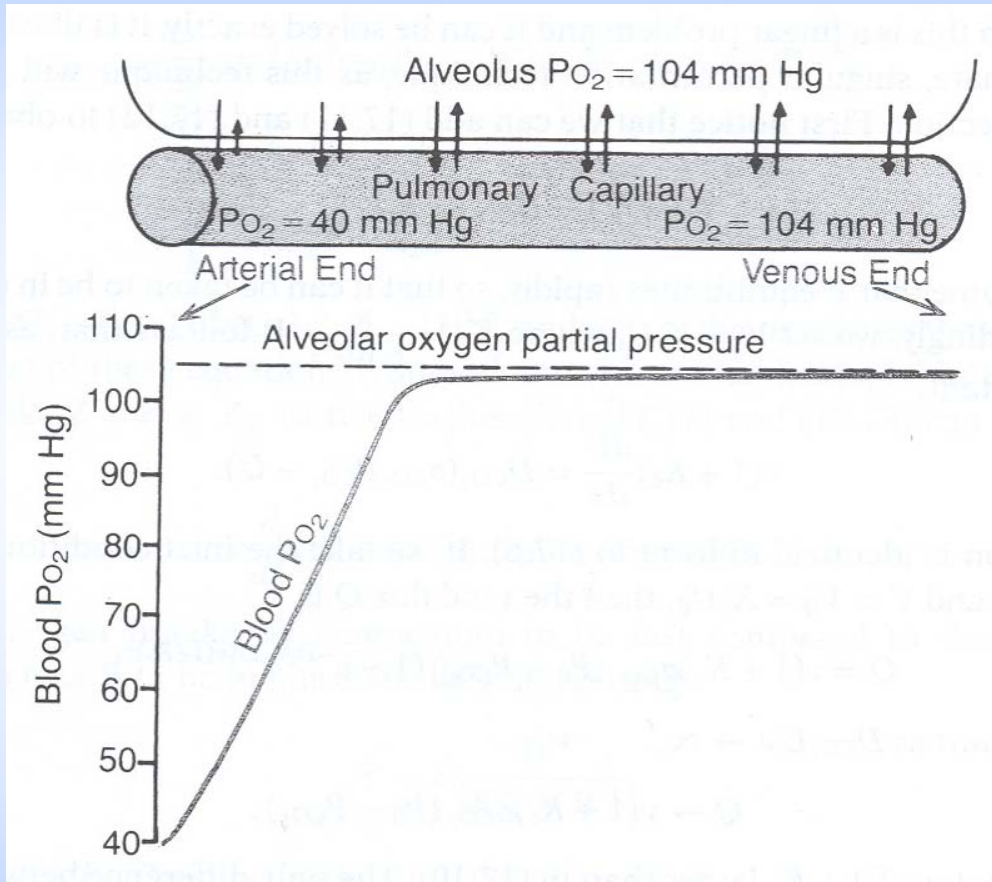
steady state:
$$v \frac{d}{dx} (U + [HCO_3^-]) = v(1 + K_c) \frac{dU}{dx} = D_{CO_2} (\sigma_{CO_2} P_{CO_2} - U)$$



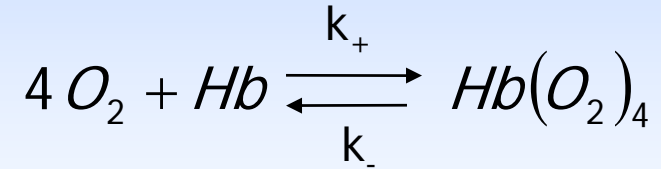


3.3 Oxygen Uptake

W ... dissolved oxygen in blood:



including blood chemistry:



$$[Hb(O_2)_4] = T_{Hb} \frac{W^4}{W^4 + K^4}$$

steady state:

$$v \frac{d}{dx} (W + 4T_{Hb} f(W)) = v \frac{d}{dx} (W + 4[Hb(O_2)_4]) = D_{O_2} (\sigma_{O_2} P_{O_2} - W)$$





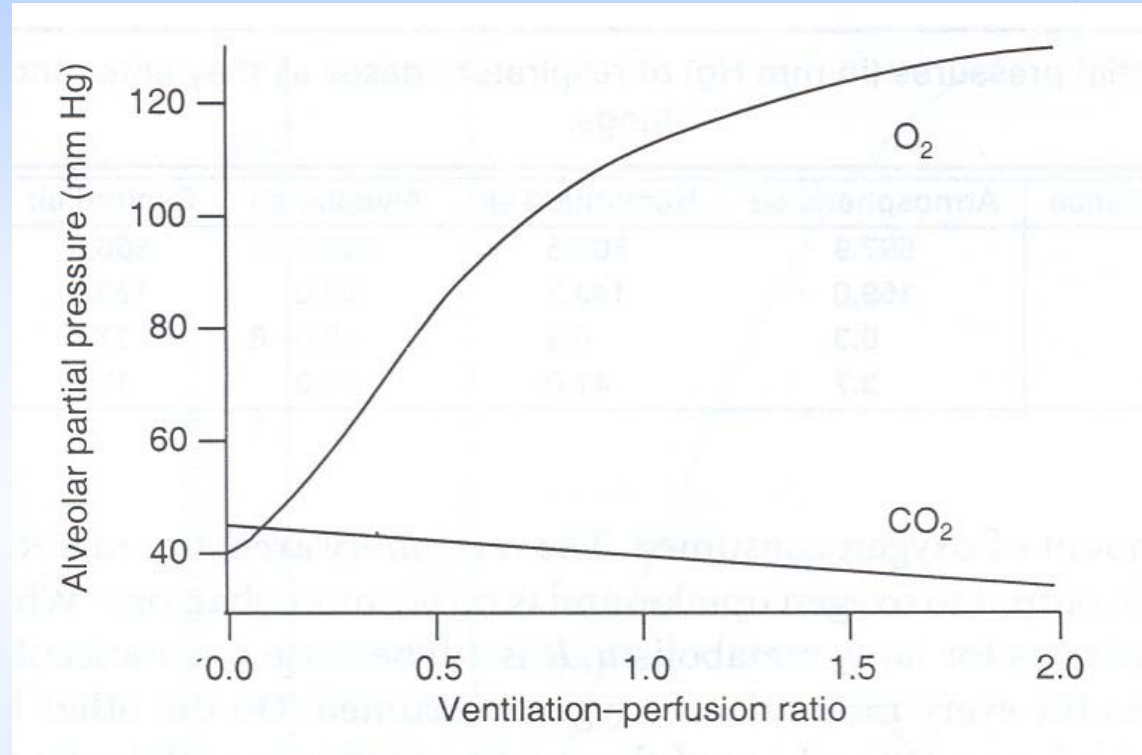
3.4 Ventilation and Perfusion

ventilation-perfusion ratio:

$$\frac{\dot{V}}{Q} \approx 1$$

hyperventilation
(→ respiratory alkalosis)
(high altitude euphoria)

hypoventilation
(→ respiratory acidosis)



regulation of ventilation (Mackey-Glass model):

x ... P_{CO_2} in blood

$$\frac{dx}{dt} = \lambda - \alpha x \dot{V}(x(t - \tau))$$

unstable for large τ
(Cheyne-Stokes breathing)

