Today, we will:

- Continue discussing The Respiratory System
- Describe spirometry, the Bohr model, and the extended Bohr model
- If time, discuss carbon monoxide (CO) and why CO is hazardous
- Do Candy Questions for Candy Friday

**SPIROMETRY** = use of instrument to measure breathing volumes & pressures

*This is for athletes*

![Figure 2.10](From Heinsohn and Cimbala, Indoor Air Quality Engineering, 2003.)

![Figure 2.11](Lung volumes and elements of spirometry. A pen records changes in the air volume on graph paper that moves to the left. The residual volume and functional residual volume cannot be measured with the spirometer (from Heinsohn & Kabel, 1999).

(From Heinsohn and Cimbala, Indoor Air Quality Engineering, 2003.)
Models of Breathing & Bohr Model

$V_d =$ anatomic dead space
$\geq 150$ mL
(air left over in bronchial tree)

Expandable Volume

$\dot{V}_a(t) =$ alveolar volume

\begin{itemize}
\item Unsteady
\item Variable volume ($\dot{V}_a(t)$)
\item Non-uniform concentration ($C_{air}, C_{CO_2}, C_{O_2}$)
\end{itemize}

Math is difficult

We want a simpler steady model

\[ \text{Extended Bohr Model} \]
Example – Review

Given: A tank contains a mixture of ideal gases – air, carbon monoxide, and benzene.
- The mol fraction of the CO is 45,000 PPM
- The mol fraction of the benzene is 5,000 PPM
- The pressure and temperature in the tank are 180 kPa and 65.0°C

To do: Calculate the partial pressure of the air in the tank. *Give your answer in units of kPa to three significant digits.*

Solution:

\[
\sum y_j = 1 \quad \text{or} \quad \sum P_{\text{PPM}} = 1,000,000
\]

\[
\begin{align*}
\text{PPM}_{\text{air}} & = 1,000,000 \text{ ppm} \\
& - 45,000 \text{ CO} \\
& - 5,000 \text{ benzene}
\end{align*}
\]

\[
\text{PPM}_{\text{air}} = 950,000 \text{ ppm}
\]

\[
y_{\text{air}} = 0.950
\]

\[
y_j = \frac{P_j}{P} \quad y_{\text{air}} = \frac{P_{\text{air}}}{P} \Rightarrow
\]

\[
P_{\text{air}} = y_{\text{air}} P = (0.950)(180 \text{ kPa}) = 171 \text{ kPa}
\]
The Extended Bohr Model:

Figure 2.24  Extended Bohr model illustrating mass transfer of a nonreacting gas through the alveolar capillary barrier.

(From Heinsohn and Cimbala, Indoor Air Quality Engineering, 2003.)

\[ k_b = \text{solubility coefficient} = \frac{\text{Volume of gas that can be absorbed into the blood}}{\text{Volume of blood}} \]

\[ k_{b, O_2} = 10.7 \, \frac{\text{mL} \, O_2}{\text{mL} \, \text{blood}} \]

\[ O_2 \text{ gets attached to hemoglobin molecules in the blood} \]
Define $Q_t = \frac{tidal \ space \ ventilation \ rate}{(volume \ flow \ rate)}$

$Q_t = \frac{V_t}{f}$

breathing

 tidal vol. \ per \ breath

$Q_t = \frac{500 \ mL}{breath} \times 12 \ breaths/min = 6000 \ mL/min \approx 6.0 \ L/min$

At rest, typ. $Q_t \approx 500 \ mL/breath \quad f = 10 \ to \ 15 \ breaths/min$

$Q_a = alveolar \ ventilation \ rate = \text{avg. vol. flow rate of fresh air that reaches the alveoli}$

Typ. resting $Q_a = \left(\frac{580 - 150}{breath}\right) \times 12 \ breaths/min = 4200 \ mL/min$

or $Q_a = \left(1 - \frac{V_d}{V_t}\right)Q_t$

358 mL of fresh air per breath
**R_{vp} = Ventilation Perfusion Ratio = \frac{Q_a}{Q_b}**

We use 4 categories or levels of exercise:

- **R** = rest
- **LE** = light exercise
- **ME** = moderate
- **HE** = heavy exercise

As exercise level ↑, \( Q_t \uparrow, Q_a \uparrow, Q_b \uparrow \)

\( Q_a \) goes ↑ much faster than \( Q_b \) goes ↑

\[ R_{vp} = \frac{Q_a}{Q_b} \text{ goes up with exercise} \]

\[ R \text{ to } HE \rightarrow R_{vp} \uparrow \text{ by } \approx 2.6 \]

**Bottom Line**: Your heart, not your lungs, limits your exercise

**Modified Ventilation Perfusion Ratio** = \( R_{vp,m} = \frac{Q_a}{Q_b \cdot K_b} \)
Table 2.4  Ventilation, blood flow, and the ventilation perfusion ratio ($R_{vp}$) during various activity levels (abstracted from Ultman, 1988 and 1989).

<table>
<thead>
<tr>
<th>parameter</th>
<th>exercise or activity level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>rest</td>
</tr>
<tr>
<td>ventilation rate, $Q_t$ (L/min)</td>
<td>11.6</td>
</tr>
<tr>
<td>frequency, min⁻¹</td>
<td>13.6</td>
</tr>
<tr>
<td>tidal volume, $V_t$ (L)</td>
<td>0.85</td>
</tr>
<tr>
<td>$V_d/V_t$</td>
<td>0.34</td>
</tr>
<tr>
<td>blood flow, $Q_b$ (L/min)</td>
<td>6.5</td>
</tr>
<tr>
<td>$Q_a = Q_d(1 - V_d/V_t)$ (L/min)</td>
<td>7.66</td>
</tr>
<tr>
<td>$R_{vp} = Q_a/Q_b$</td>
<td>1.18</td>
</tr>
</tbody>
</table>
Figure 2.26 Absorption efficiency versus modified ventilation-perfusion ratio for different values of the diffusion parameter corresponding to rest (R), light exercise (LE), moderate exercise (ME) and heavy exercise (HE) (adapted from Ultman, 1988).

<table>
<thead>
<tr>
<th>activity level</th>
<th>$N_D$</th>
<th>$R_{vpm}$</th>
<th>$\eta_u$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>rest state (R)</td>
<td>1.0</td>
<td>0.11</td>
<td>85.</td>
</tr>
<tr>
<td>light exercise state (LE)</td>
<td>0.49</td>
<td>0.18</td>
<td>69.</td>
</tr>
<tr>
<td>moderate exercise state (ME)</td>
<td>0.37</td>
<td>0.21</td>
<td>59.</td>
</tr>
<tr>
<td>heavy exercise state (HE)</td>
<td>0.31</td>
<td>0.29</td>
<td>48.</td>
</tr>
</tbody>
</table>
Carbon Monoxide:

Hemoglobin absorbs CO more readily than O₂

\[ n_{HbCO} > n_{HbO_2} \]

Figure 2.41 Response to carbon monoxide as a function of concentration (PPM) and exposure time (hr). The OSHA 8-hr PEL is 35 PPM and the EPA Primary Air Quality Standard is 9 PPM (redrawn from Seinfeld, 1986).

Bottom Line → CO is not harmful directly → But it gets absorbed into the blood more readily than oxygen.

So... you die from lack of oxygen to the brain!