Lecture 2: Circulation and Gas Exchange I (Chapter 42)

Keywords
- cellular respiration
- Diffusion of gases
- Speed of diffusion
- Effect of size on oxygen supply
- Gas exchange structures
- Gills, lungs
- Gastrovascular cavity
- Surface area

Themes that we'll often come across:
- Organisms have similar functional needs, but have developed diverse ways of meeting them
- Organisms must obey physical laws
- Understanding how an organism works involves biochemistry, cell biology, physiology, ecology and evolution
Cellular respiration

• A type of controlled combustion:
  • Reduced carbon (e.g., glucose) + O₂
  • ---→ CO₂ + H₂O

Organismal respiration -- a simple view

The simple view is true for animals, but there are differences

• Need to consider the problem of how gases get into and out of an animal
• Differences are observed in types of respiratory surfaces
• This will be the focus of today’s lecture
Why does size matter in respiration?

- Rate of diffusion of gases (e.g., oxygen)

How fast is diffusion of oxygen?

- 1 micron (µm) in $10^4$ seconds
  - One millionth of a meter in one tenth of a millisecond

How does diffusion work?

Consider a point source of a diffusing substance
Each molecule will travel randomly (brownian motion)

Over time particles will become separated

But particles don’t just move away from the original point source
They are travelling randomly

Thus...

- It takes a long time for molecules to diffuse over long distances

“Speed” of oxygen diffusion in liquid

- 1 µm in $10^{-4}$ seconds
- 1000 µm (1 mm) in 100 seconds
- Thus diffusion can supply oxygen only over very short distances
Examples where oxygen diffuses only short distances

- Vertebrate lung
- Very small organisms

Vertebrate Lung

Diffusion distance from alveoli to capillary is short

Picture is 500 µm across

Vertebrate Lung

Picture is 500 µm across
Very Small Organisms

Rate of oxygen entry is influenced by external concentration

How small does an organism have to be to rely on diffusion alone?

- Consider a spherical sea creature 1 mm wide
- Oxygen concentration in normal seawater is sufficient to support low rates of respiration
- Predicted that oxygen concentration only needs to be 71% of normal levels
How about a spherical sea creature 1 cm wide?

- The oxygen concentration in the water would need to be 71 times normal levels to support a low metabolic rate.

Relationship between surface area and volume changes as a function of size

- Another example of scaling

<table>
<thead>
<tr>
<th>Side (cm)</th>
<th>surface area (cm$^2$)</th>
<th>volume (cm$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>24</td>
<td>8</td>
</tr>
</tbody>
</table>

Surface area/volume is 6 vs. 3
Example of organism relying solely on surface: the Protist *Paramecium*

- *Paramecium* is a freshwater ciliate
- Other small organisms that use their surfaces only include: bacteria, microalgae, yeasts

What do you do if you want to be bigger than 1 mm?

Adaptations to enhance gas exchange:

- Circulatory systems and/or increased surface area

Example of increased surface area: Green Hydra (several mm long)
The jelly fish *Aurelia*

- Complex gastrovascular cavity that circulates fluid

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Gas exchange structures

- **Surface only** (very small organisms ≤ 1 mm)
- **Gastrovascular cavity** (hydra, jellyfish, also flatworms)
- Gills, tracheal systems, lungs
- Mixture of the above

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Gills (definition)

- Appendages around which the medium (usually water) passes.
- Often richly supplied with blood vessels
- Found in many types of invertebrates and vertebrates
Gills vs. Lungs

Fish Gill