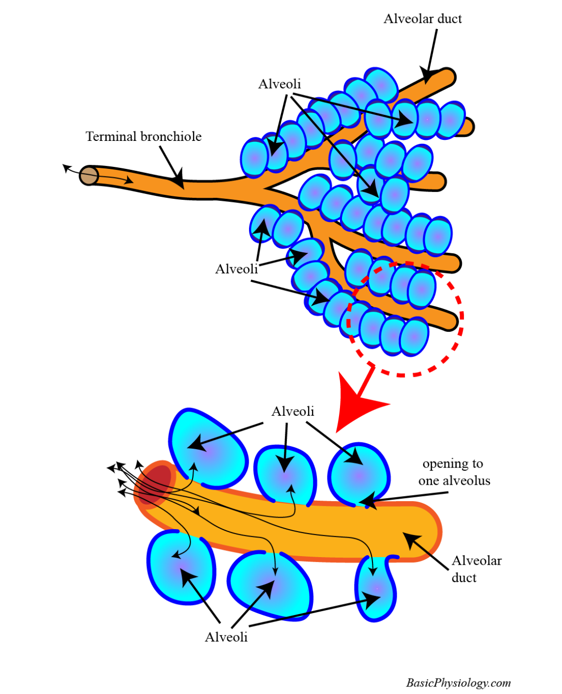
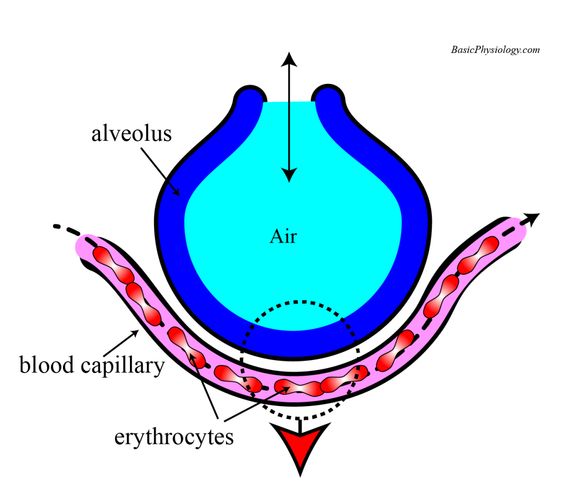
C.4.5. The Respiratory Membrane

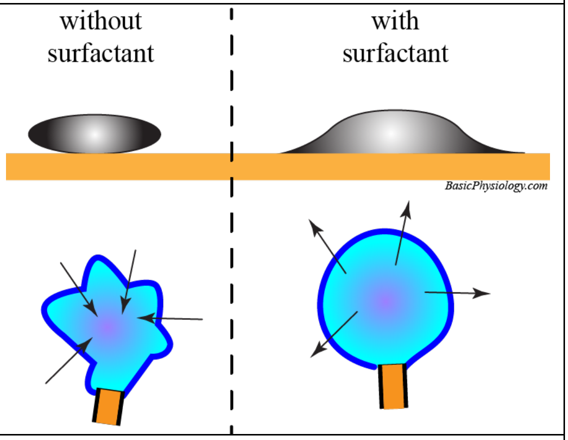
A. The terminal bronchioles and the alveoli

	1. At the end of the bronchial conduction system, the finest branches of this "tree" are the terminal bronchioles and the alveolar ducts.
	2. The alveolar ducts are dead-ends; the air cannot continue down the duct. Instead, the air flows into millions of little sacks called alveoli (singular: alveolus).
	3. These alveoli are the working 'heart' of the lungs; this is where the air is exchanged with the blood (= gas exchange).

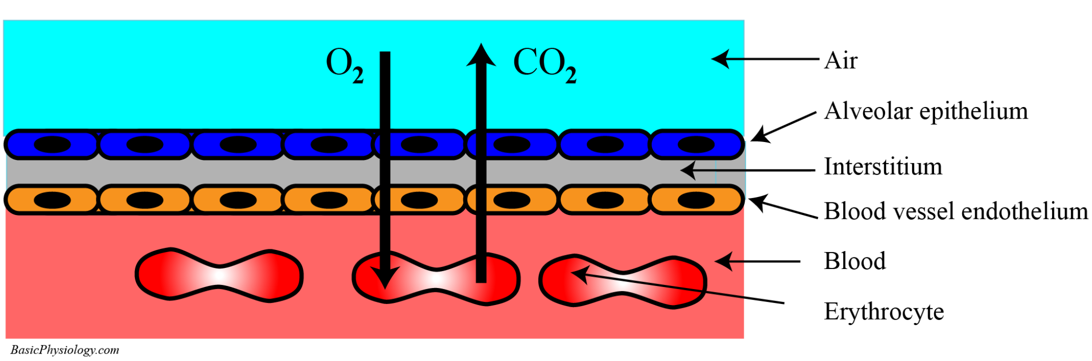
B. One Alveolus:

1. This diagram shows a single alveolus and its accompanying blood capillary.	 (see diagram Respiratory Membrane)
2. Inside the alveolus, air (light blue) flows in and out through the terminal bronchi and the bronchial tree.	
3. The inner lining of the alveolus consists of a thin layer of fluid which contains **surfactant** (*see next panel)*.	
4. Just outside the alveoli lies the blood capillary. Inside the capillary, blood flows from one end to the other end, and, with it, the erythrocytes (= red blood cells).	5. You may know/remember that it is the red blood cells that transport oxygen through our body!

C. The role of Surfactant:

1. Surfactant is a compound that decreases the surface tension of water in the alveoli. Why is that important??	2. Well, did you ever notice, in the rain, or in the kitchen or the bathroom, how water has the tendency to shape itself in drops?
3. This is because water molecules attract each other, due to their electrical polarity ($H_2^{++}O^{--}$).	
4. This also occurs in the thin layer of water fluid lining the inner membrane of the alveolus. But that is actually a problem!	5. This surface tension would actually make the alveoli smaller! (*left in diagram*) That is not good.
6. Therefore, it is necessary to decrease the surface tension of the water and this is the purpose of **surfactant** (=Surface Active Agent).	7. You can see the importance of surfactant very well in premature babies. Sometimes, especially if they are born prematurely, there is not enough surfactant in the alveoli, their alveoli therefore collapse, and they have great difficulty in breathing! This is called Respiratory Distress Syndrome (=RDS)!

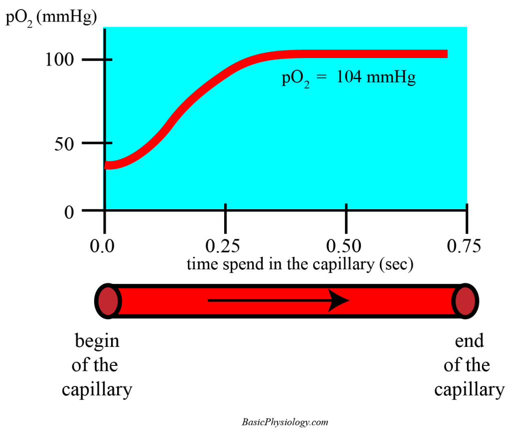
D. The respiratory membrane



1. To explain how an alveolus works, I have reduced the figure in the previous section into its basics as shown in this diagram.	2. In this diagram, I have sketched two cell layers: a. the alveolar epithelium b. the endothelium of the blood vessel. I also indicated the air (in the alveolus) and the erythrocytes (in the capillary).
3. Between these two layers, there is a very thin **interstitium**. This interstitial layer, together with the two cell layers, forms the **respiratory membrane**. This is the frontier where all our respiratory gasses are exchanged!	4. The transport of the blood gasses is performed by simple diffusion. If the **concentration of oxygen** in the blood is lower than in the alveolus (which is usually the case), then oxygen will **diffuse** from the alveolar air to the blood.
5. The same thing is also true for the major **exhaust** gas of our body; **carbon dioxide**. We make plenty of carbon dioxide in the metabolism of our body and therefore its concentration in blood is high.	6. Note that both the O_2 and the CO_2 molecules must pass through several structures: a. the alveolar epithelium b. the interstitium between the alveolar wall and the blood vessel wall. c. The endothelium of the capillary
7. As you may remember from a previous webpage (*link*), diffusion is inversely proportional to the distance of diffusion; the shorter the distance, the faster the diffusion. Fortunately, in the healthy lungs, the respiratory membrane is extremely thin; about 0.5 to 1.0 micron!	8. Note that both O_2 and CO_2 have to pass several membrane layers before reaching their goal. In fact, they have to pass **five plasma membranes**: 1. two from the alveolar epithelium 2. two from the blood vessel endothelium 3. one through the erythrocyte.

Link: A.2.3. Passive Transport Systems

E. How fast is this gas exchange?

<table>
<tr><td>1.
Very fast!</td><td>2.
From the previous section, it would seem that it takes a long time for the gas concentration to equalize across both sides of the respiratory membrane.</td></tr>
<tr><td>3.
This is not the case. In the diagram (right), the horizontal-axis plots the time that blood flows through the capillary. On the vertical-axis, the pO_2 concentration is plotted.</td><td rowspan="3">
</td></tr>
<tr><td>4.
From the curve, you can see that the pO_2 increases from about 40 mmHg (at the beginning of the capillary) to 104 mmHg (= the maximum) in about 0.25 seconds!</td></tr>
<tr><td>5.
One reason for this fast equilibration is the thinness of the respiratory membrane (0.5 – 1.0 micron) and the shorter the distance, the faster the diffusion.</td></tr>
<tr><td>6.
But another even more important reason is the total surface area of the membrane. Link</td><td>7.
If you put all the millions of alveoli together from both lungs, you get an enormous surface area of about 50-100 m^2 (depending on body size and gender).</td></tr>
<tr><td>8.
Imagine! Your respiratory membrane is probably bigger than the size of your sitting room; about 5-10 x 5 meters (15-30 x 15 feet)!</td><td>9.
And the larger the diffusion area, the faster is the diffusion. This is how we breathe fresh air. Through a membrane the size of your room!</td></tr>
</table>

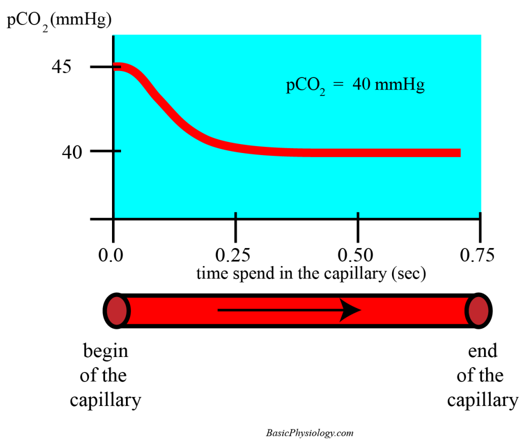
F. How much gas?

1. How much of which gasses is there actually in blood and how much is exchanged?	2. Well, that depends of course on how much is used in the body.

3.
As you know, oxygen-poor blood streams from the body to the right heart and is then pumped in the pulmonary artery by the right ventricle. This blood has, on average, a pO_2 of 40 mmHg and a pCO_2 of 45 mmHg.

4.
The CO_2 also has to diffuse into the alveoli, just like oxygen has to diffuse into the blood.

5.
The CO_2 diffusion is as fast as that of oxygen, but obviously, in the opposite direction.



6.
Note that the gradient is smaller for CO_2 (45-40 = 5) than for oxygen (104-40 = 64) but that is not a problem for CO_2 as the solubility for CO_2 is 20x higher than for oxygen.

7.
In the pulmonary veins, after passage through the lungs, the pO_2 in the blood has increased to 104 mmHg and the pCO_2 decreased to 40 mmHg (see table).

8.
This is exactly the same as the pO_2 and the pCO_2 in the alveolar air! (but they had ample time to equilibrate of course!).

Table:	Outside air	Humidified air	Alveolar air	Expired air
pN_2	599	563	569	566
pO_2	**161**	**150**	**104**	**120**
pH_2O	3.8	47	47	47
pCO_2	0.3	0.3	40	27
Total	*760*	*760*	*760*	*760*

(All values in mmHg)

G. Venous blood and expired air.

1.
The table above is a continuation of the table we discussed in a previous page ("*Partial Pressures*").

2.
There, we had discussed the effect of water ("humidification") on the other gas pressures in the inspired air.

3.
Now, in the alveolar air, we can see that the oxygen pressure has further decreased as oxygen has now left the alveoli and diffused into the capillaries (from 149 to 104 mmHg).

4.
At the same time, the pCO_2 has increased (from 0.3 to 40 mmHg) as CO_2 diffused from the blood into the alveoli.

5.
Since the pressures in the alveoli have had more than enough time to equilibrate with that in the blood (see the two diagrams above), the partial pressures in the venous blood will be exactly the same as that in the alveoli.

	Arterial blood	Venous blood
pO_2	40	104
pCO_2	47	40

(Values in mmHg)

6.
It is also interesting to see the changes in the pressures from the arterial blood to the venous blood.

7.
One final point. Look at the partial pressures in the table column “Expired air”. See anything strange?

8.
It would seem that the expired air has more oxygen than the alveolar air (and less CO_2). Is that really, correct?

9.
Yes, it is. This is because the expired air is a **mixture** of air coming from the alveoli and that of air from the dead space (which is equal to the “humidified air”).

10.
The air in the dead space has not been exchanged with blood and therefore its oxygen concentration is still high (about 149 mmHg). When this is mixed with the air coming from the alveoli (which is approximately 104 mmHg), the mixture will be somewhere between these two values.

11.
In fact, if you understand the above material, then you can now think, when you **exhale**, which part of the air you exhale will have a **high** oxygen concentration and which part will have a **low** oxygen concentration!!
*(**Hint**: you exhale air from the dead space first while the alveolar air will be exhaled the last).*