

# Respiration Module

## Session 2 - Lung ventilation

# The Lungs

- are a means of getting
- air to one side
- and blood to the other side
- of a thin membrane of large surface area

# Exchange between air and blood

- occurs across the alveolar membrane
- ‘alveolar air’ has a different composition to the atmosphere
  - less Oxygen
  - more Carbon Dioxide
- exchange occurs by diffusion

# Alveolar air

- $pO_2$  normally 13.3 kPa
- $pCO_2$  normally 5.3 kPa

# Mixed venous blood

- returns to the lungs from the body
- $pO_2$  typically 6.0 kPa
- $pCO_2$  typically 6.5 kPa
- but varies with metabolism

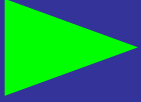
# Gradients of partial pressure

- $pO_2$  in alveolar gas  $>$   $pO_2$  in returning blood
- $pCO_2$  in alveolar gas  $<$   $pCO_2$  in returning blood
- so oxygen will diffuse into blood and carbon dioxide out

Mixed  
Venous  
Blood

Alveolar  
Gas

$pO_2 = \sim 6.0$    $pO_2 = 13.3$

$pCO_2 = \sim 6.0$    $pCO_2 = 5.3$



# Diffusion

- depends on
- area - large
- gradients - large
- diffusion resistance



# Diffusion resistance

- depends on
- nature of barrier
- nature of gas



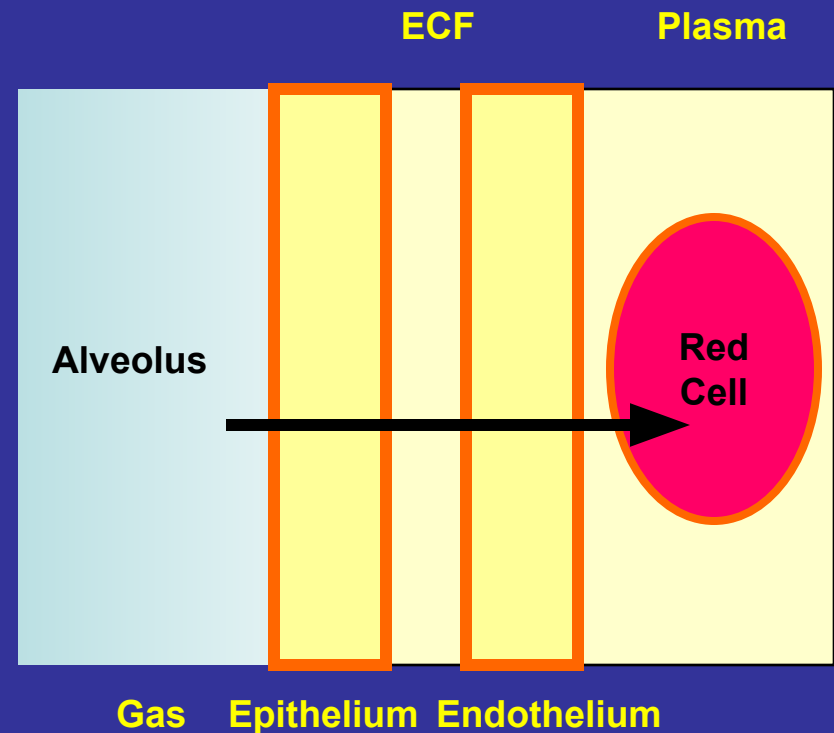


# Diffusion barrier

- diffusion through gas to alveolar wall
- epithelial cell of alveolus
- tissue fluid
- endothelial cell of capillary
- plasma
- red cell membrane

# Diffusion barrier

- gas diffusion to alveolar wall
- 5 cell membranes
- 3 layers of cytoplasm
- 2 layers of tissue fluid





# Diffusion of gases

- gases diffuse through gases
- at rate inversely proportional to molecular weight
- big molecules diffuse slower
- carbon dioxide slower than oxygen

# Diffusion of gases

- gases diffuse through liquids
- at rate proportional to solubility
- $\text{CO}_2$  much more soluble than  $\text{O}_2$
- so diffuses 21 times faster

# Diffusion barrier

- CO<sub>2</sub> diffuses much faster than O<sub>2</sub> overall
- so exchange of oxygen always limiting

# Overall diffusion resistance

- barrier  $0.6\mu$  thick
- oxygen exchange complete within 0.5 s of blood cell arriving in capillary
- blood cells spend about 1s in capillary
- so plenty of leeway
- gas diffusion not limiting on the lung

# Alveolar air

- in the normal lung
- blood leaving the alveolar capillaries
- is in equilibrium with alveolar air
- so has same  $pO_2$  and  $pCO_2$

# Alveolar ventilation

- composition of alveolar air determines
- gas composition of arterial blood
- and therefore oxygen supply to tissues



# Alveolar ventilation

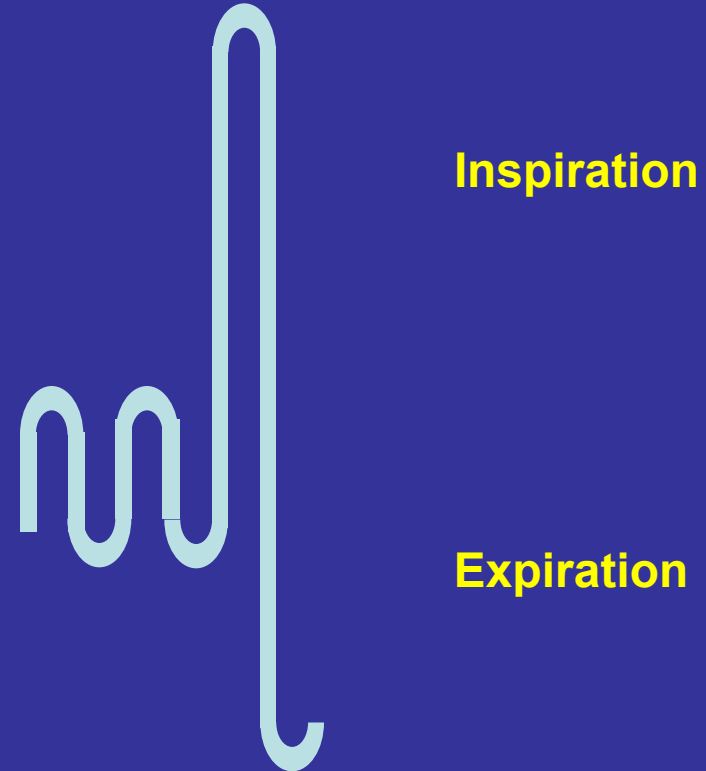
- exchange between alveolar gas
- and mixed venous blood
- will tend to lower  $pO_2$  and raise  $pCO_2$
- this is prevented by diffusion of oxygen into and carbon dioxide out of alveolar air
- from atmospheric air brought next to the alveoli by *ventilation*

# Ventilation

- expansion of lungs
- increases volume of
  - respiratory bronchioles
  - alveolar ducts
- so air flows down airways to them

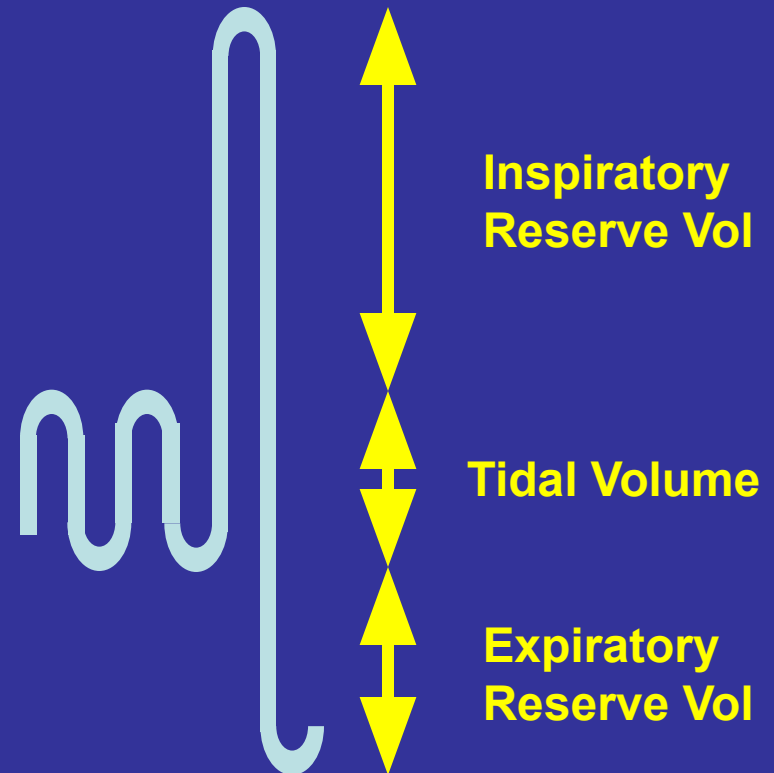
# Measurement of ventilation

- use a spirometer
- subject breathes from a closed chamber over water
- whose volume changes with ventilation



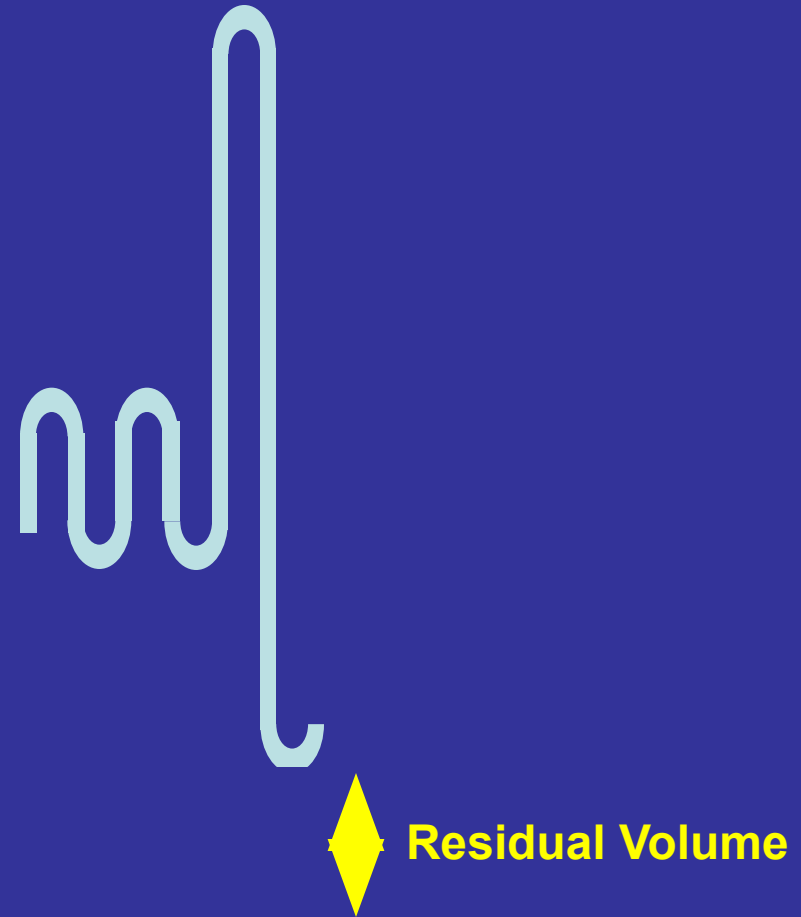
# Lung volumes

- tidal volume
  - volume in and out with each breath
- inspiratory reserve volume
  - extra volume that can be breathed in over that at rest
- expiratory reserve volume
  - extra volume that can be breathed out over that at rest



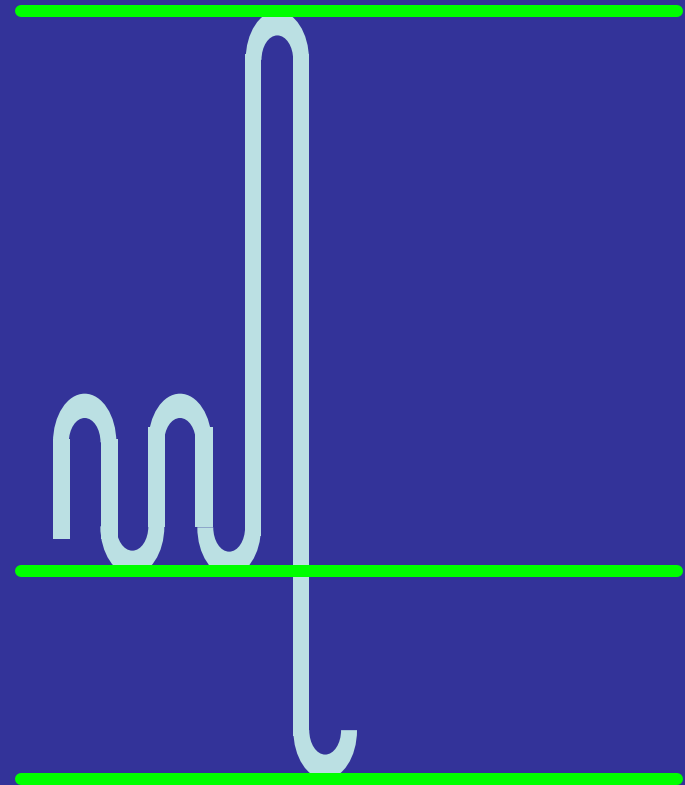
# Residual volume

- volume left in lungs at maximal expiration
- cannot be measured by spirometer
- use helium dilution



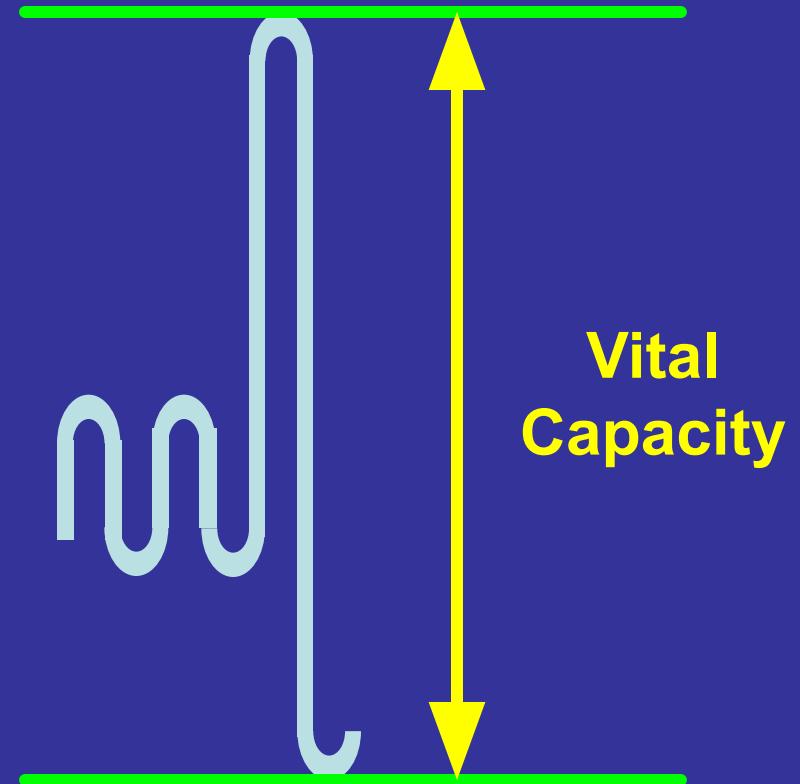
# Lung Capacities

- lung volumes change with breathing pattern
- capacities do not
- because measured from fixed points in breathing cycle



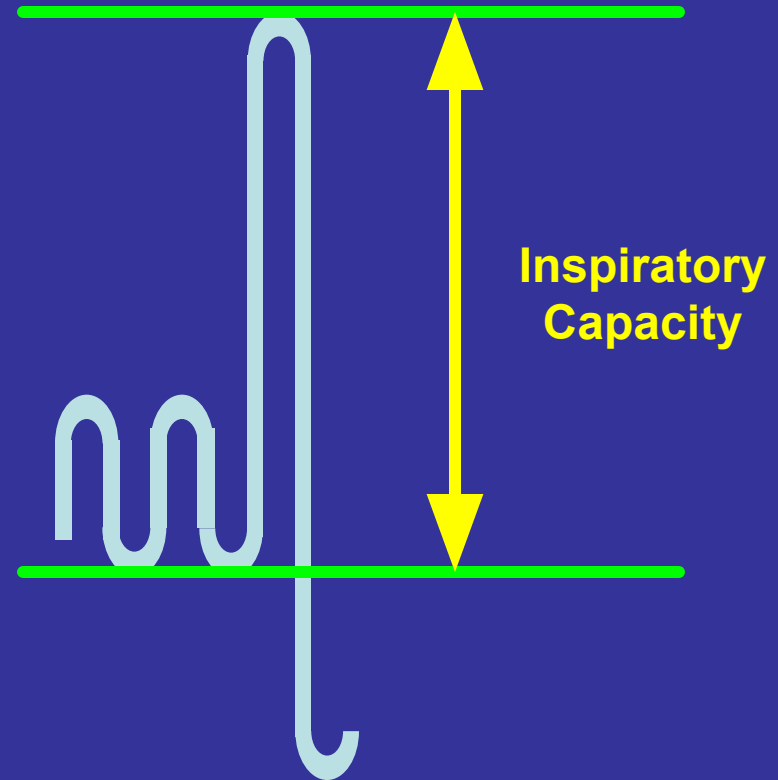
# Vital Capacity

- measured from max inspiration to max expiration
- biggest breath that can be taken
- often changes in disease
- about 5l in typical adult



# Inspiratory capacity

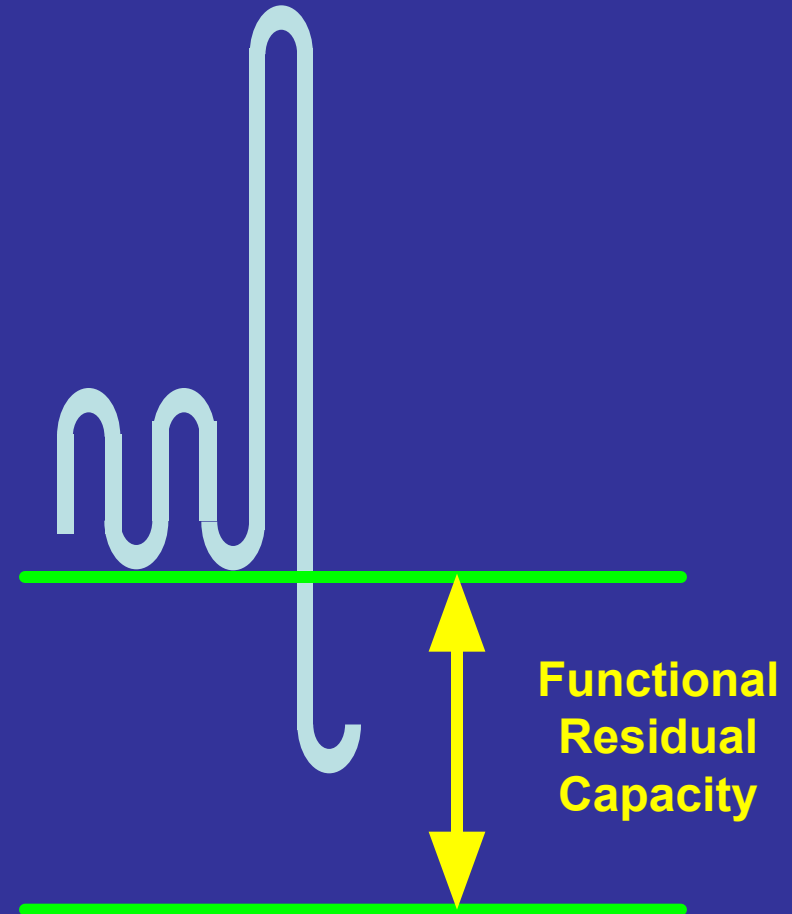
- biggest breath that can be taken
- from *resting expiratory level*
- which is lung volume at end of quiet expiration
- inspiratory capacity typically 3l





# Functional residual capacity

- volume of air in lungs
- at resting expiratory level
- typically 2l
- (expiratory reserve volume + residual volume)



# Typical values

- Tidal Volume - 0.5l
- Inspiratory reserve - 2.5l
- Expiratory reserve - 1.5l
- Residual volume - 0.8l
- Functional residual capacity - 2.3l
- Inspiratory capacity - 3.0l
- Vital Capacity - 5.0l
- Total lung capacity - 5.8l

# Ventilation rate

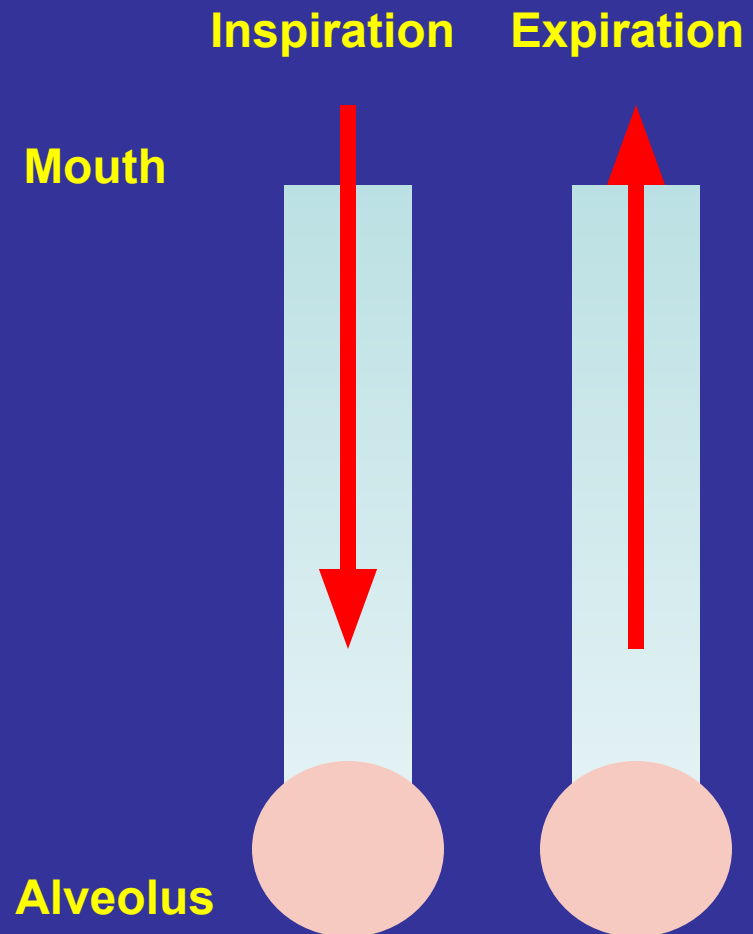
- the amount of air moved into and out of a space per minute
- product of volume moved per breath
- and respiratory rate

# Pulmonary Ventilation rate

- Tidal volume x respiratory rate
- typically  $8\text{l}\cdot\text{min}^{-1}$  at rest
- can exceed  $80\text{ l}\cdot\text{min}^{-1}$  in exercise

# Dead space

- air enters and leaves lungs by same airways
- last air in stays in airways
- and is first air out
- so it does not reach the alveoli
- and is 'wasted'



# Alveolar ventilation rate

- the amount of air that actually reaches the alveoli
- to calculate need to allow for ‘wasted’ ventilation of dead spaces

# Serial dead space

- the volume of the airways
- used to be known as ‘anatomical dead space’
- measured by nitrogen washout
  - see later lecture
- typically about 0.15l

## Distributive dead space

- some parts of the lung are not airways, but do not support gas exchange
  - dead or damaged alveoli
  - alveoli with poor perfusion
- add to serial dead space
- total is 'physiological dead space'
- typically 0.17l



# Calculation of alveolar ventilation rate

- dead space must be completely filled with air at each breath
- dead space ventilation rate therefore
- dead space vol x resp rate
- subtract this from pulmonary ventilation rate to get AVR



# Example

- $PVR = TV \times RR$ 
  - $0.5\text{l} \times 16 = 8\text{l.min}^{-1}$
- $DSVR = DSV \times RR$ 
  - $0.15\text{l} \times 16 = 2.4\text{l.min}^{-1}$
- $AVR = PVR - DSVR$ 
  - $8 - 2.4 = 5.6 \text{ l.min}^{-1}$



# Pattern of breathing

- with TV of 0.5l and RR of 16
- about one third of inspired air is 'wasted'

# Rapid shallow breathing

- if  $TV=0.25\text{l}$  &  $RR=32$
- $PVR = TV \times RR$ 
  - $0.25\text{l} \times 32 = 8\text{l}\cdot\text{min}^{-1}$
- $DSVR = DSV \times RR$ 
  - $0.15\text{l} \times 32 = 4.8\text{l}\cdot\text{min}^{-1}$
- $AVR = PVR - DSVR$ 
  - $8 - 4.8 = 3.2 \text{ l}\cdot\text{min}^{-1}$
- almost two thirds 'wasted'

# Slow deep breathing

- if  $TV=1\text{l}$  &  $RR=8$
- $PVR = TV \times RR$ 
  - $1\text{l} \times 8 = 8\text{l.min}^{-1}$
- $DSVR = DSV \times RR$ 
  - $0.15\text{l} \times 8 = 1.2\text{l.min}^{-1}$
- $AVR = PVR - DSVR$ 
  - $8 - 1.2 = 6.8\text{l.min}^{-1}$
- much less wasted



# Pattern of breathing

- slow, deep breathing gets most air to alveoli
- but is hard work
- so at rest we adopt an intermediate rate and depth