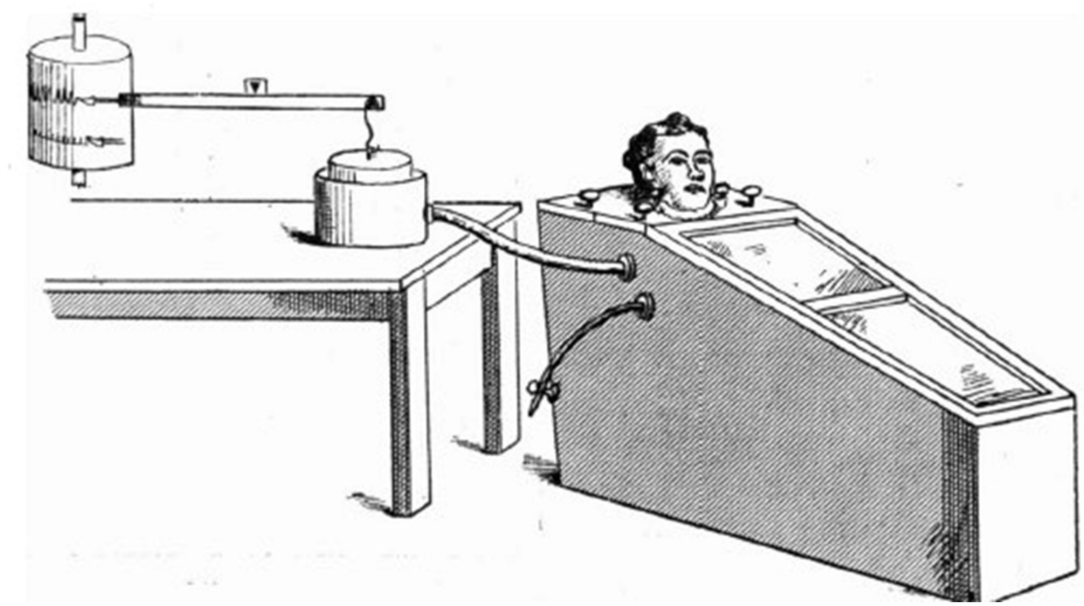
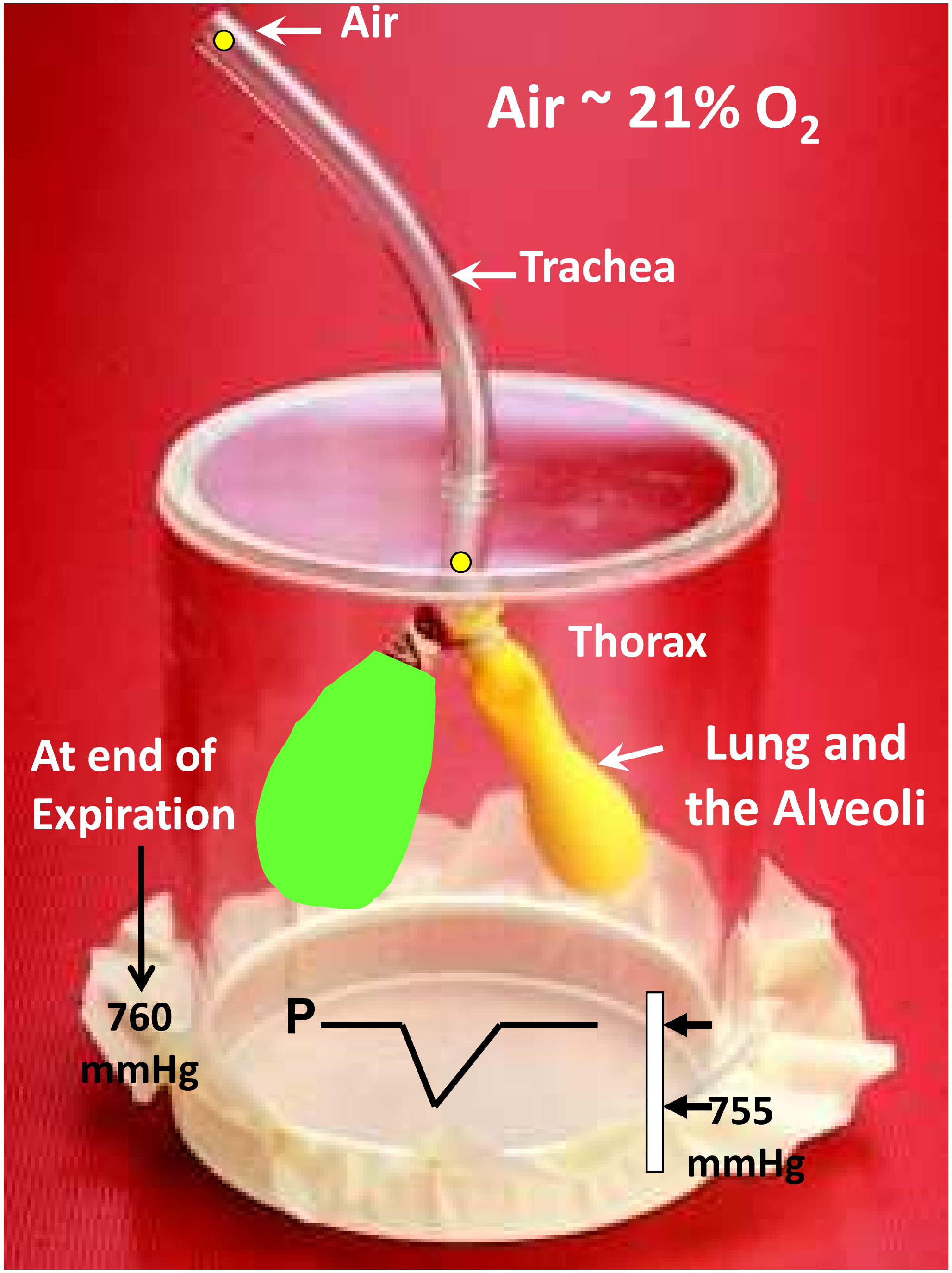
Lecture 37
Lung Volumes and Pressures



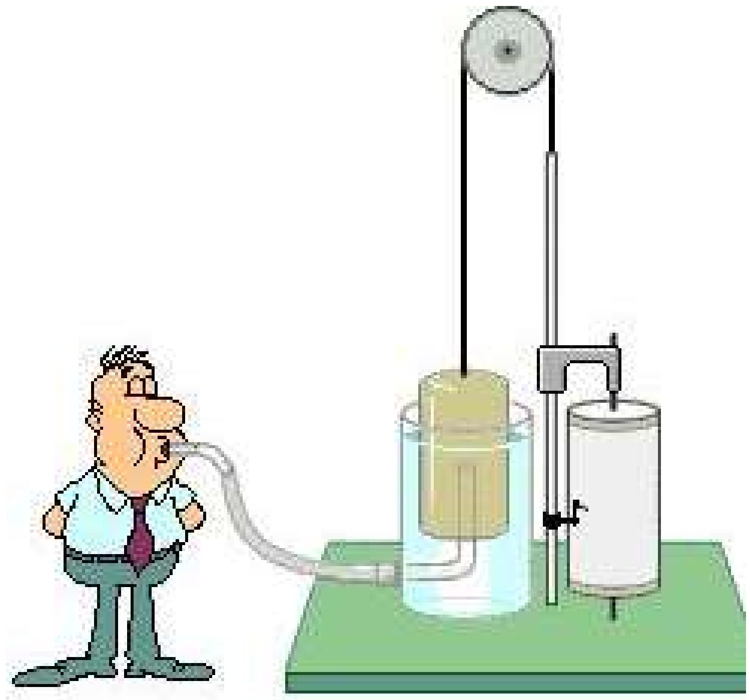
HN Mayrovitz PhD
mayrovit@nova.edu
drmayrovitz.com

Simple Breathing Model

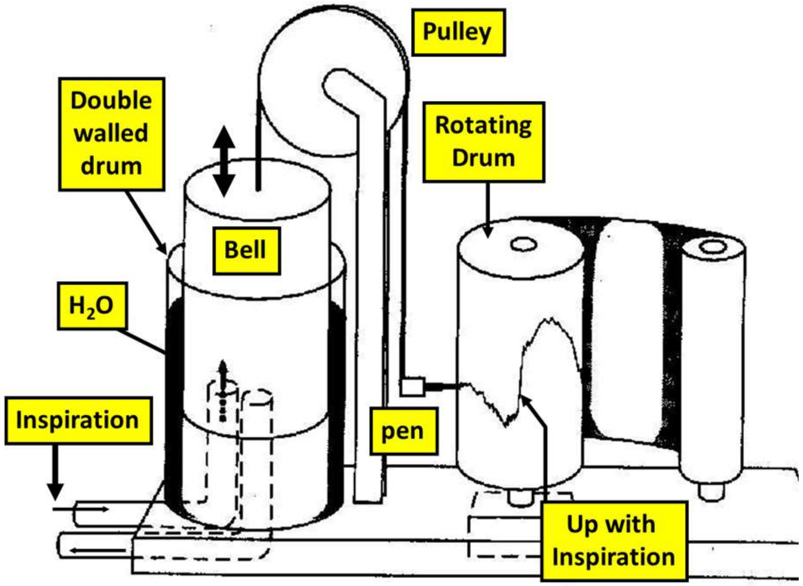


- Simple **breathing model** with the tubing representing the trachea and the two balloons representing the lungs
- The "lungs" are within the plexiglass chamber that represents the thorax
- **Air is atmospheric** at ground level with an O_2 concentration of about 21%
- **Inspiration:** air moves in as intrathoracic pressure decreases to ≈ 755 mmHg while atmospheric pressure ≈ 760 mmHg
- The 5-mmHg decrease is referenced to atmospheric so is **-5 mmHg relative**! Note that this is NOT a vacuum of -5 mmHg; just a convention used in respiratory function
- **End Inspiration**: pressure goes to prior value

Lung Volumes



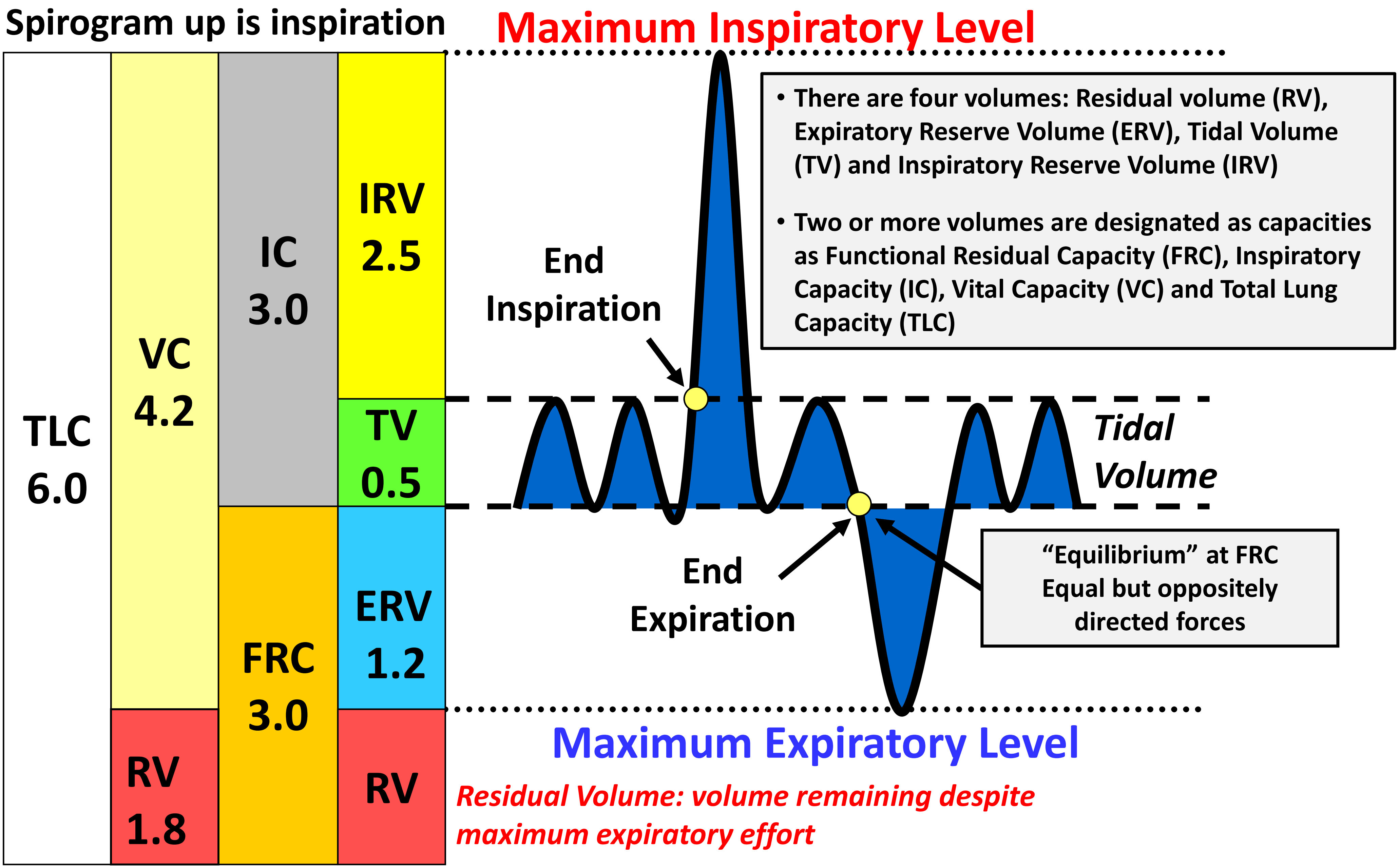
Volume Measurements - Spirometer



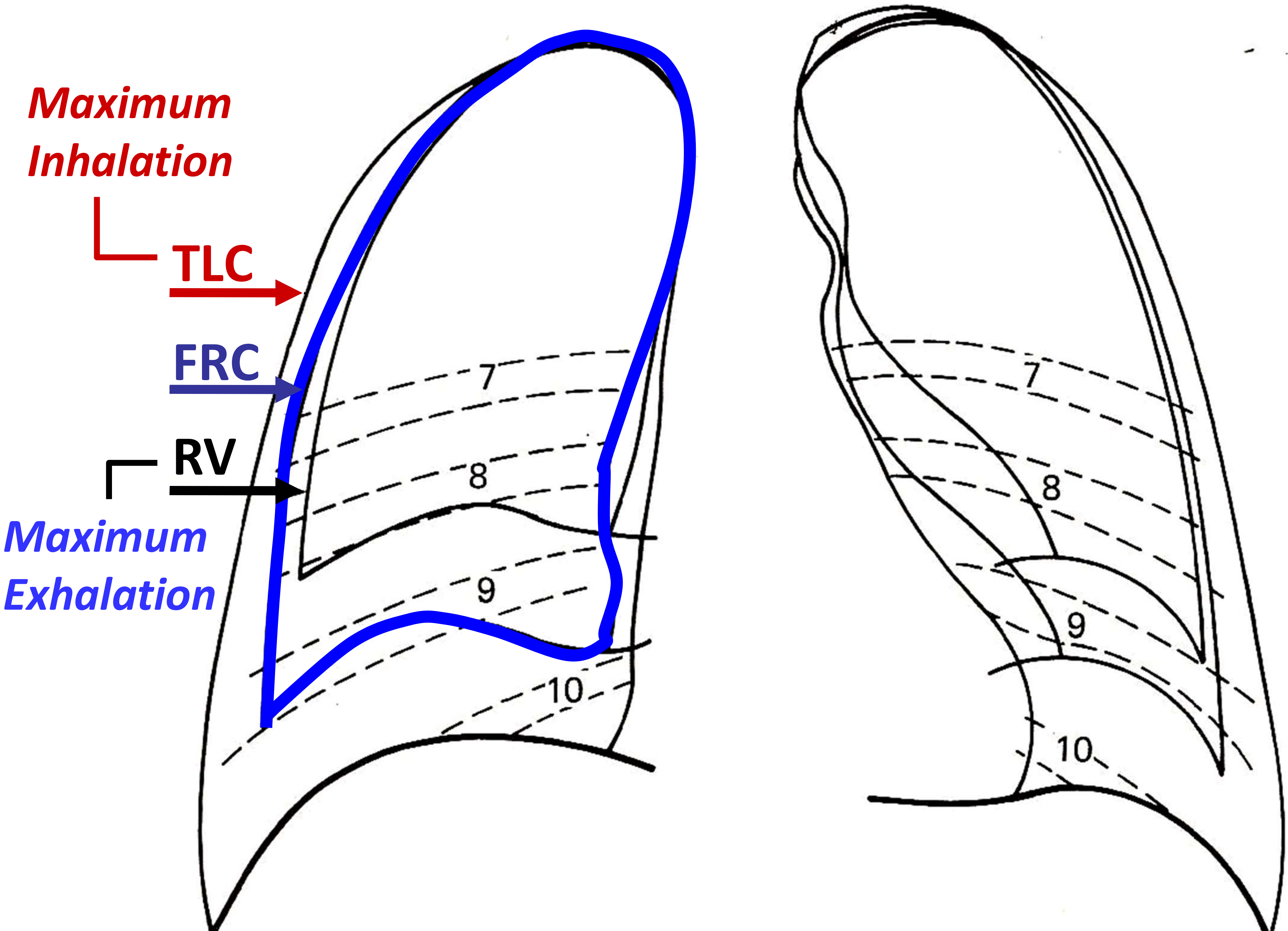
“ Classic” Water-Jacket Spirometer

- **“Classic” spirometer has a neutrally buoyant bell in water all within a double walled drum**
- **Patient inhales: bell rises and pulls pen upward**
- **Pen “writes” on rotating drum with inspiration causing upward deflection on paper**
- **Expiration (exhalation): downward deflection**
- **Record is the spirogram device is the spirograph**
- **Newer versions of spirograms are shown**

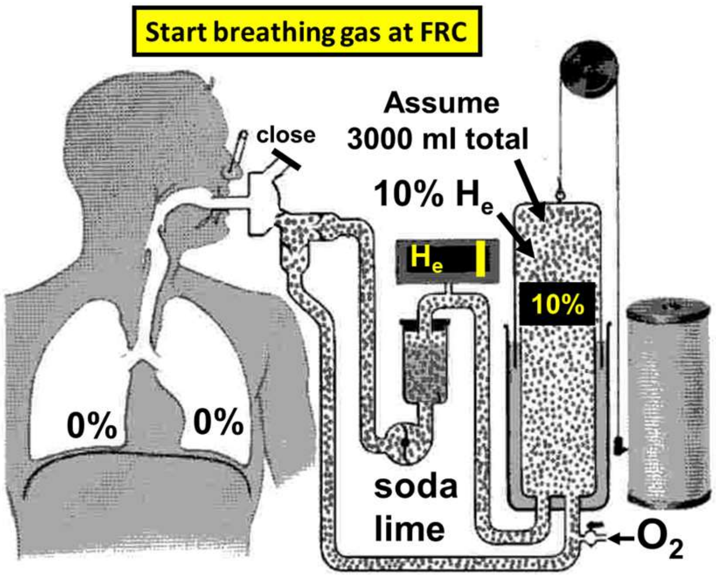
Lung Volumes and Capacities



Illustrating Lung and Ribs at Different Lung Volumes



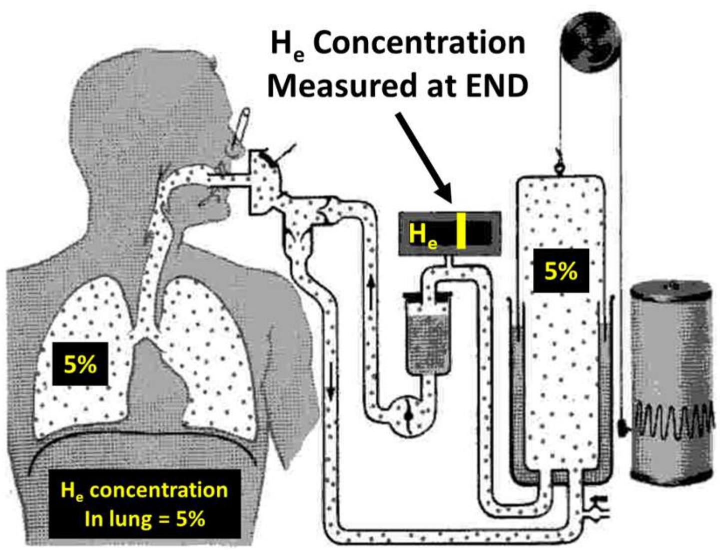
FRC and RV via Helium Dilution



Before starting test
He concentration in spirometer = 10%

START

- **Spirometer is loaded with helium (H_e) in this case 10% of total spirogram volume that in this example is 3 L.**
- **Patient hooked up but the valve remains closed so no He diffuses from the spirometer into the lungs**
- **So, at the start the lungs have 0% H_e.**
- **At FRC valve is opened and He gas enters the lung**



H_e concentration in lung & spirometer = 5%

END

- **After equilibrium (≈ 5 min) Helium concentration in the system is again measured, which for this example is 5%**
- **This is the H_e concentration in the entire volume consisting of lung volume and the spirometer volume**

Helium Dilution Calculations

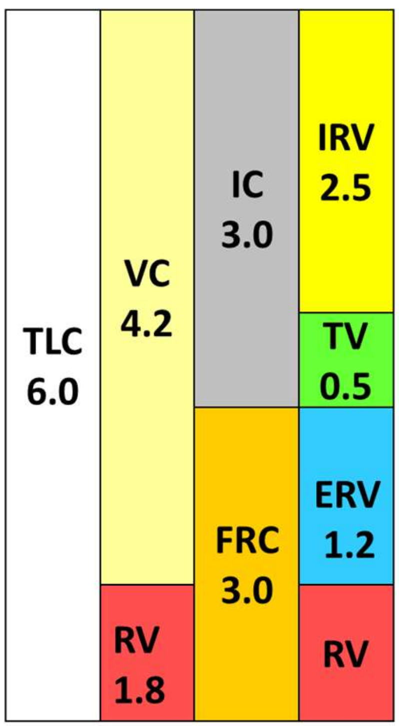
Initial H_e volume = Final H_e volume

Start		End
H_e in lungs + H_e in spiro	=	H_e in combined (lung + spiro)

$$0 + 0.10 \times 3000 = 0.05\,(FRC + 3000)$$

FRC = 3000

Calculated → RV = FRC - ERV ← Measured by Spirometry



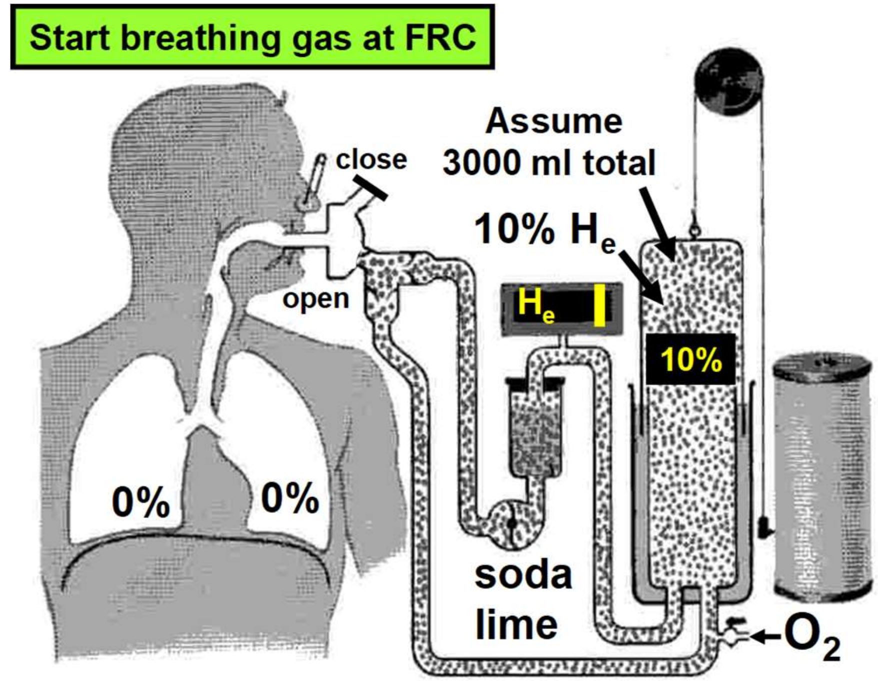
$$V_L \times F_{L\_start} + V_{sp} \times F_{sp\_start} = (V_L + V_{sp})\, F_{L\_end}$$

$$F_{L\_end} = F_{sp\_end}$$

V_L and F_L are Volume and Fractional Lung concentration
V_{sp} and F_{sp} are Volume and concentration in Spirometer

Interactive Question

Tom undergoes a helium dilution test with initial conditions as shown In the figure. The valve is opened just at the end of quiet expiration. If it is determined that under these conditions the concentration of helium in his lung at the end of the test is 3%, what is his FRC?

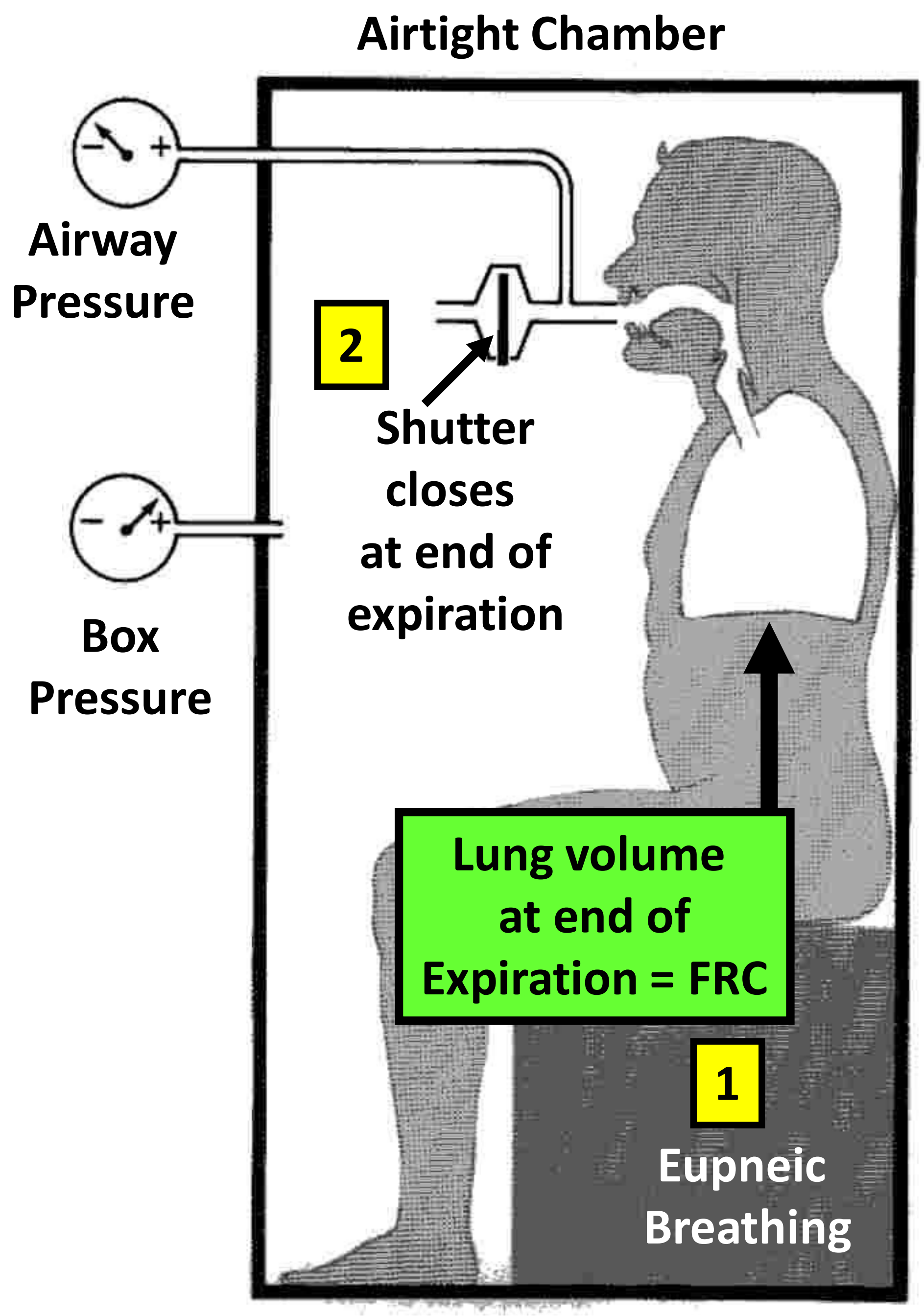


Combined Interactive Question

Mary is a 38-year-old pack-a-day smoker who of late has been experiencing shortness of breath while walking up steps. She undergoes a standard spirometer test that shows that her vital capacity is 5L. Thereafter she undergoes a helium dilution test as follows. Immediately after a forced vital capacity maneuver the test starts. Mary starts to breathe into a 12 L spirometer containing 10% helium. After some time, an equilibrium is achieved between spirometer and lung gasses. Mary then does a final forced vital capacity maneuver, and the helium concentration is measured at that time to be 8.5%. Which of the following is closest to her total lung capacity?

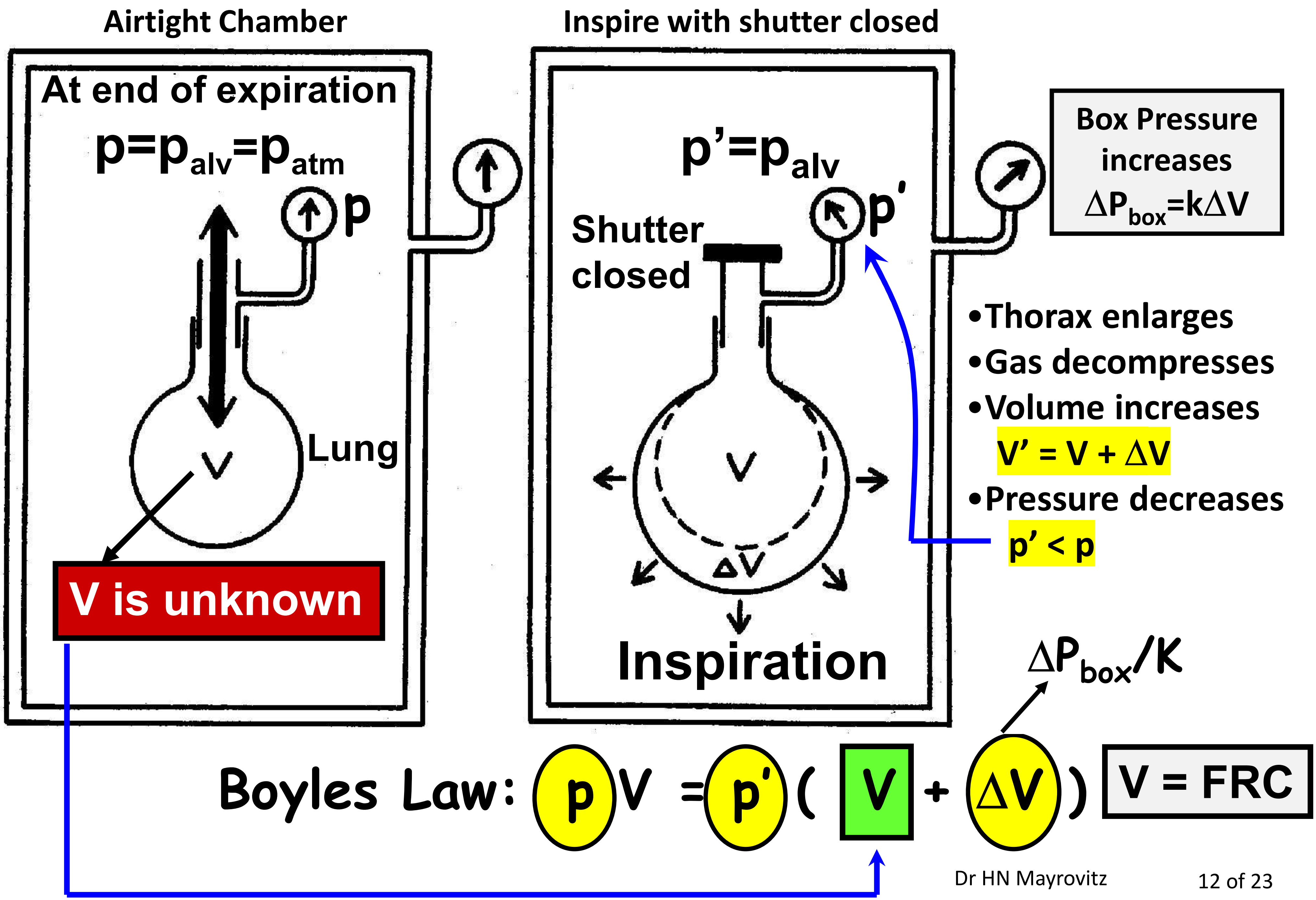
A) 3 L
B) 5 L
C) 7 L
D) 9 L
E) 11 L

FRC by Body Plethysmography: Method



- Patient sits in an airtight chamber hooked up to a breathing tube and measuring devices
- Breathes normally: at FRC the valve shutter closes
- Patient continues to breathe and changes in airway and box pressures are recorded
- Evaluation of lung volume relies on using Boyle's law; At a fixed temperature of gas, gas pressure and gas volume are related via the equation $P_1V_1=P_2V_2$

FRC by Body Plethysmography: Calculations



Method Comparisons

- H_e dilution (and N_2 washout) methods measure COMMUNICATING GAS VOLUME

Lung gas that can mix with the breathing mixture

- Body plethysmograph method measures TOTAL gas volume

Gas that is or is not in communication with alveoli

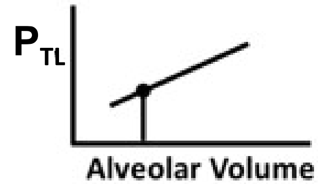
- Both methods require good patient compliance

Pressure Basics

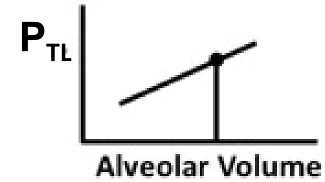
Alveolar Recoil and Translung Pressures

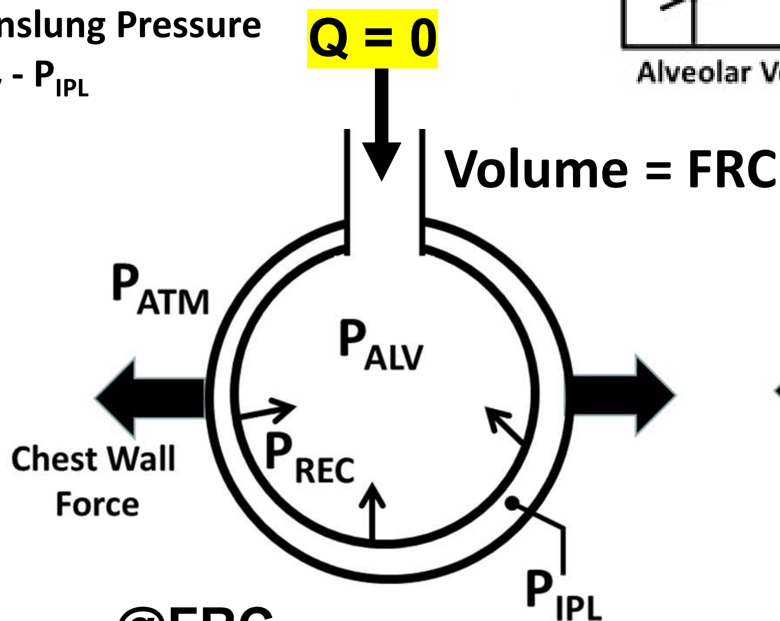
P_{ATM} = Atmospheric Pressure
P_{ALV} = Alveolar Pressure
P_{REC} = Recoil Pressure
P_{IPL} = Intrapleural Pressure
(Pressure surrounding lung)
P_{TL} = Translung Pressure
$= P_{ALV} - P_{IPL}$

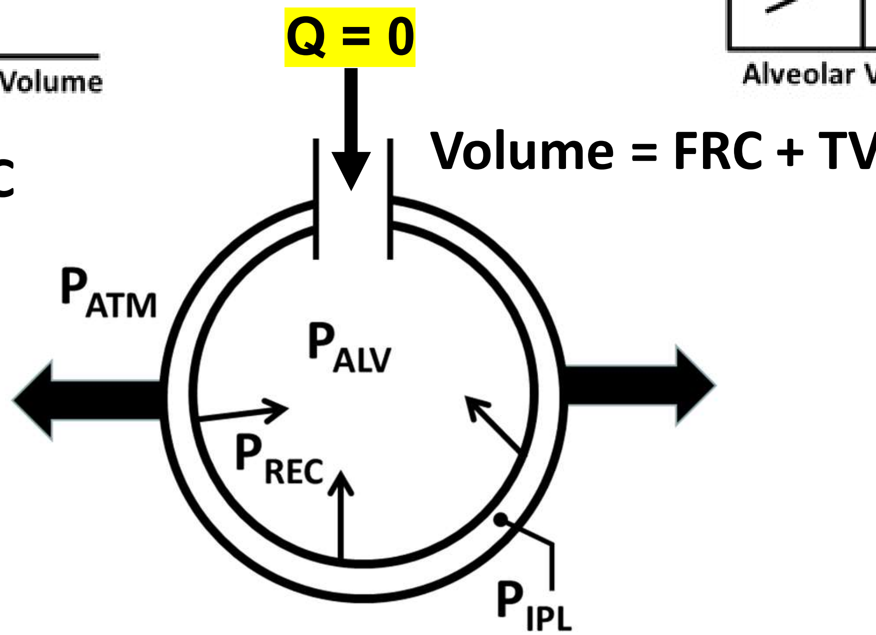
$P_{TL} = P_{ALV} - P_{IPL} = P_{REC} = +5$
$= 0 \quad - (-5) = +5$



$P_{TL} = P_{ALV} - P_{IPL} = P_{REC} = +8$







@FRC

$$P_{ALV} = P_{REC} + P_{IPL} = 0$$
$$= 5 + (-5)$$
$$= 0$$

Assume a certain alveolar volume at FRC with an associated $P_{IPL} = -5$

At any Alveolar volume

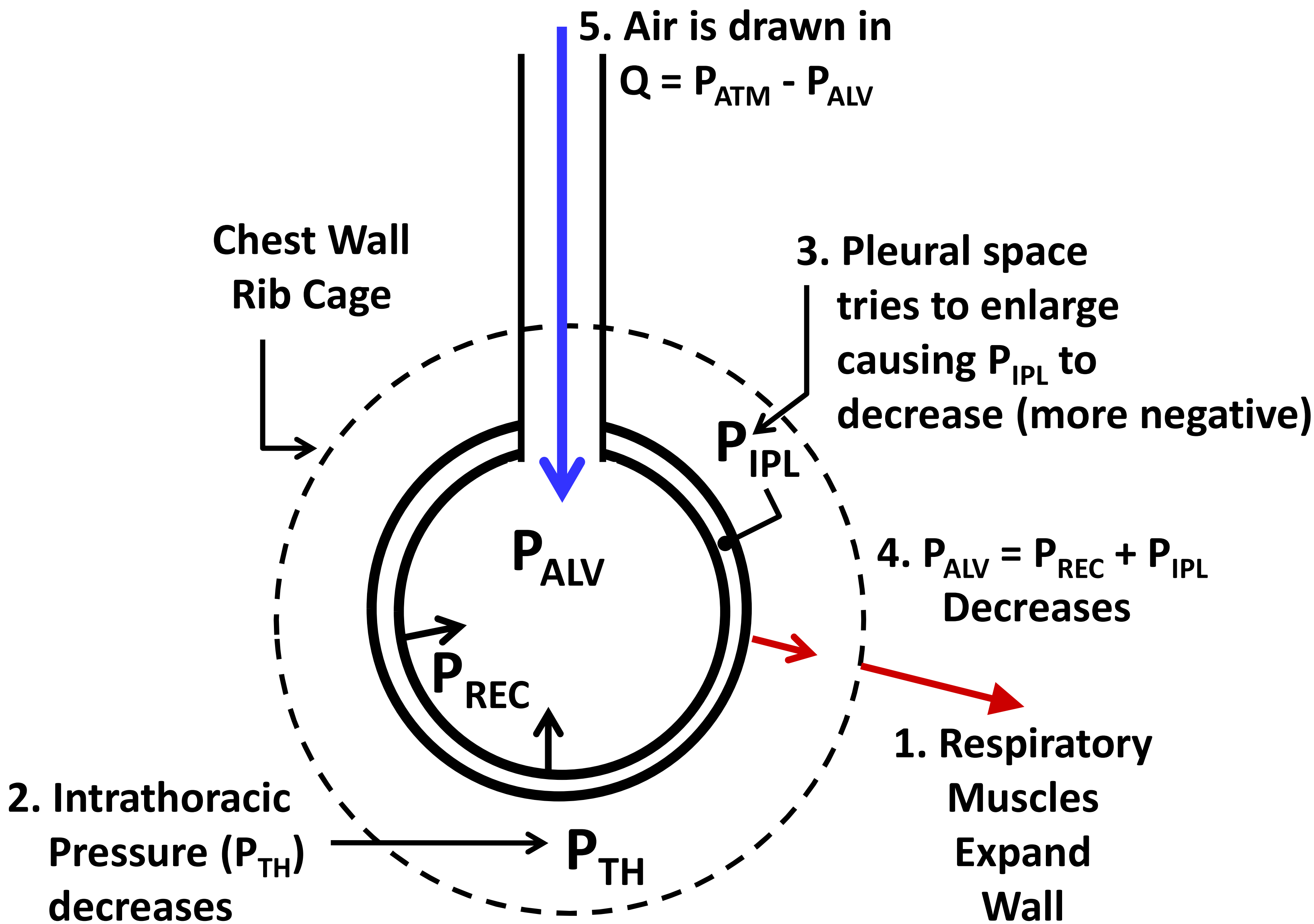
$$P_{ALV} = P_{REC} + P_{IPL}$$

- Elastic
- Surface Tension

$$P_{ALV} = P_{REC} + P_{IPL}$$
$$= 8 + (-8)$$
$$= 0$$

Alveolar volume increases with TV inspiration to an associated $P_{IPL} = -8$

Inspiration → Air Flow Process



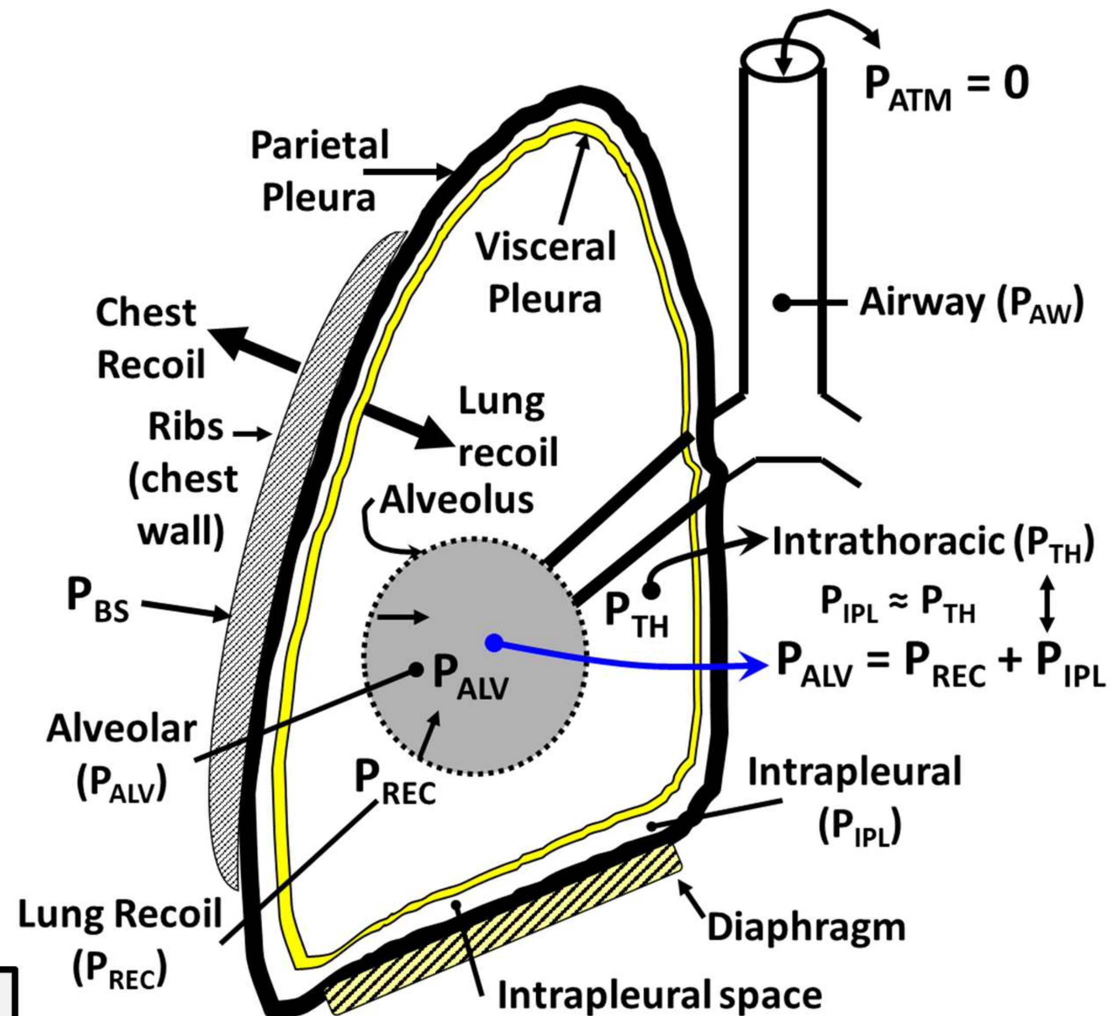
Respiratory Pressure Summary

Basic Pressures
- Alveolar $P_{ALV} = P_{IPL} + P_{REC}$
- Intrapleural P_{IPL}
- Atmospheric P_{ATM} → **can be – or +**
- Body surface P_{BS}
- Intrathoracic $P_{TH} \rightarrow P_{PL}$
- Lung recoil P_{REC}
- Wall recoil P_{RECW}

Handy Pressure Units

1 mmHg = 1 Torr
1 mmHg ≈ 1.36 cmH_2O
1 cmH_2O ≈ 0.735 mmHg
1 kPa ≈ 10 cmH_2O
1 kPa ≈ 7.5 mmHg

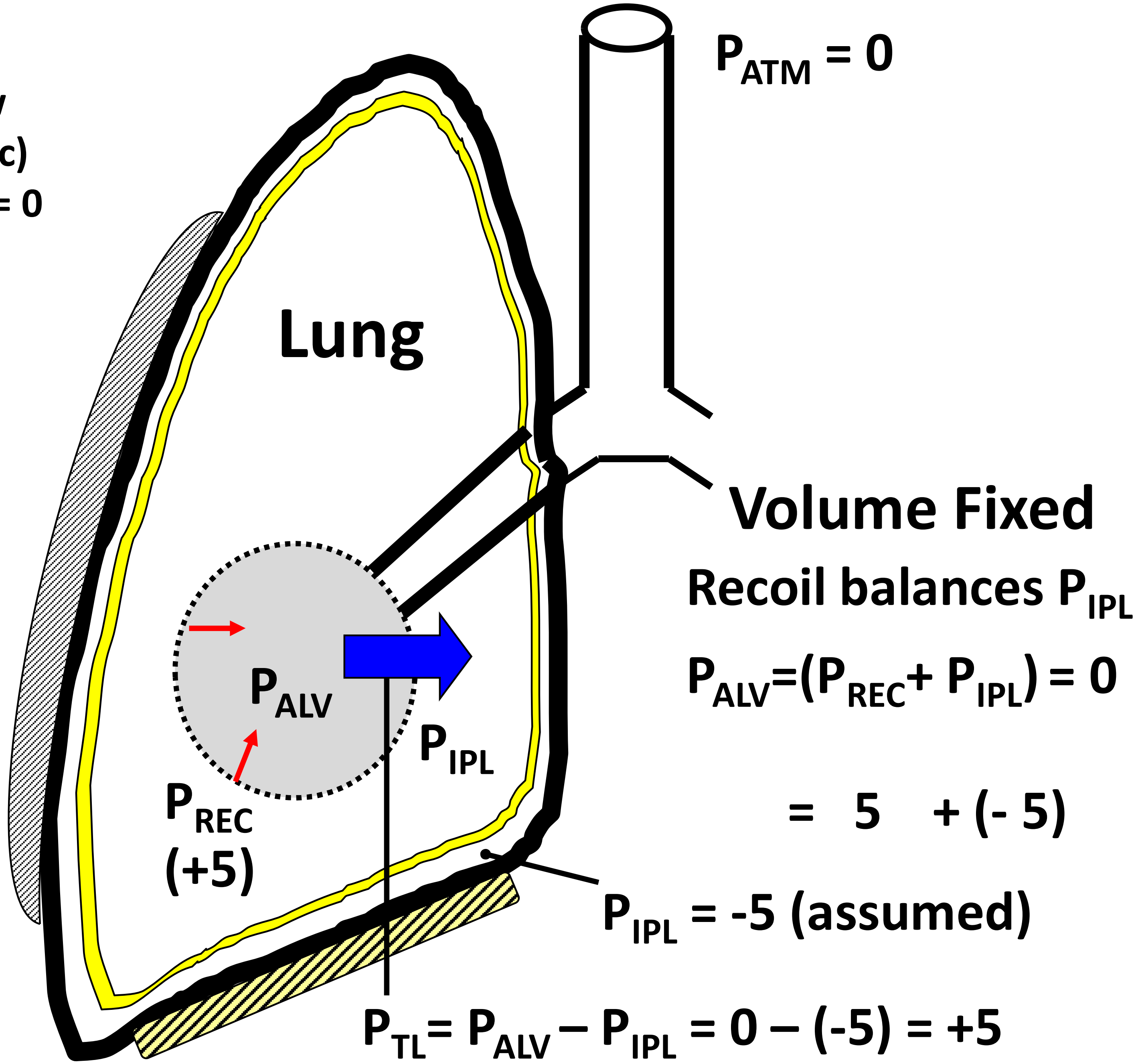
Pressure Differences (Transmural)
- Translung: $P_{TL} = P_{ALV} - P_{IPL} = P_{REC}$
- Transwall: $P_{TW} = P_{IPL} - P_{BS} = P_{IPL}$ if $P_{BS} = 0$
- Total Respiratory $P_{RS} = P_{TL} + P_{TW} = P_{ALV} - P_{BS}$



Breathing Pressures: No Airflow: *End Expiration*

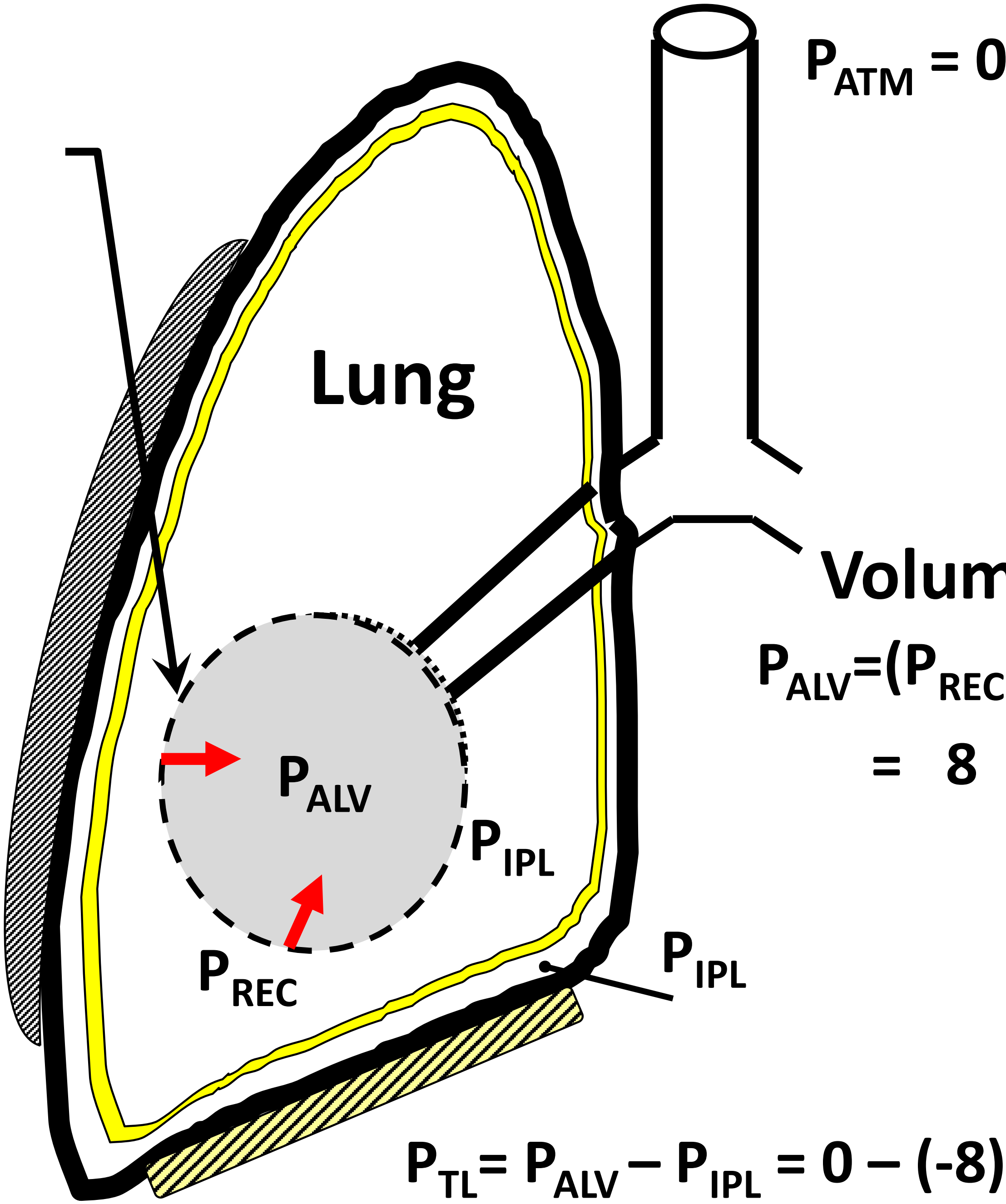
1. Under no flow conditions (Static) P_{ALV} must = P_{ATM} = 0

2. Volume is determined by P_{TL} along with lung compliance



Pressure Pressures: No Airflow: *End Inspiration*

3. To sustain the now larger volume P_{IPL} is more neg and is again balanced by the recoil pressure, P_{REC}



Volume ↑

P_{REC} ↑

Volume Fixed

$P_{ALV} = (P_{REC} + P_{IPL}) = 0$

$= 8 + (-8)$

$P_{TL} = P_{ALV} - P_{IPL} = 0 - (-8) = +8$

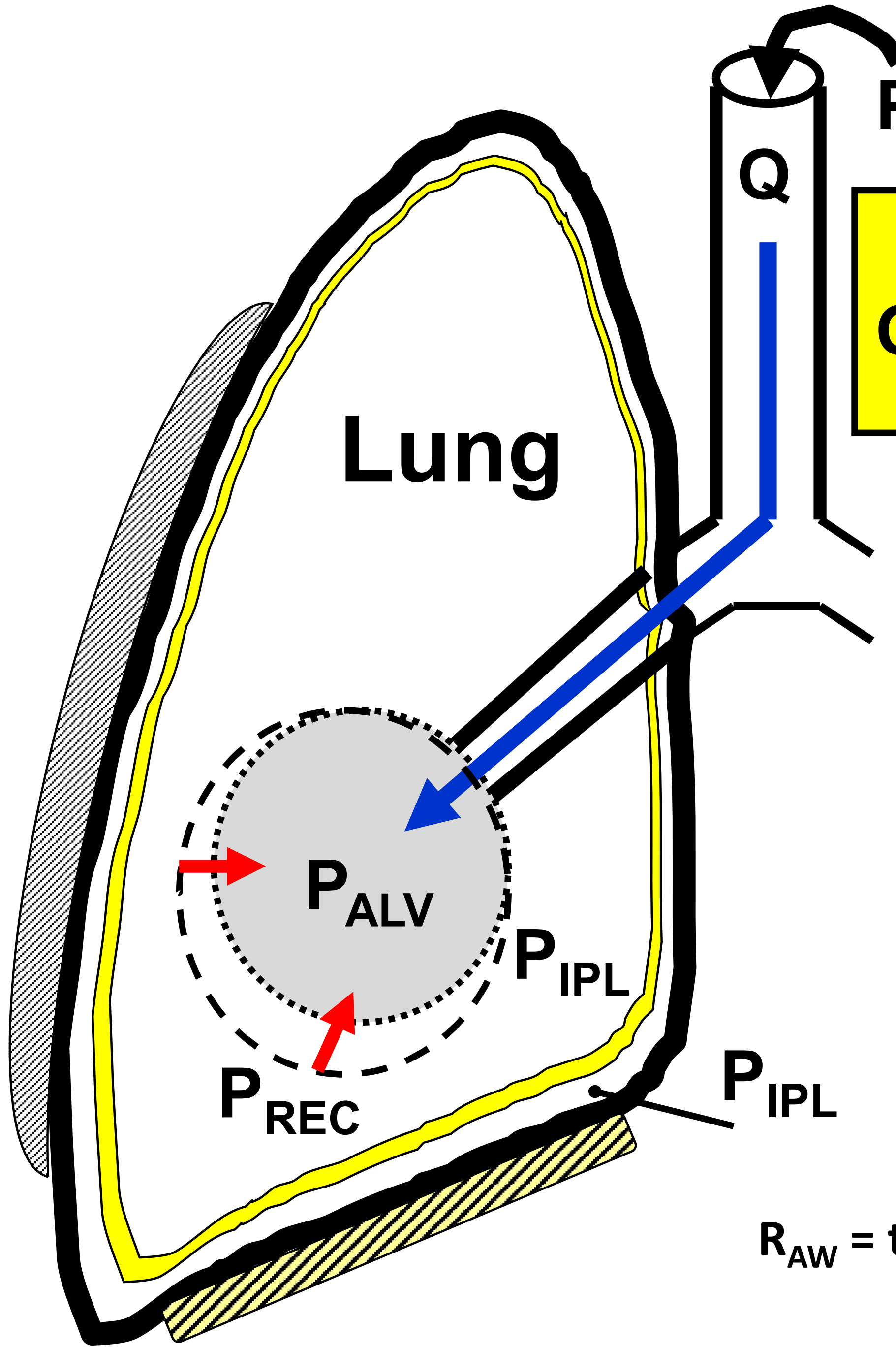
DURING Inspiration - Dynamic

1. In response to the decrease in P_{IPL} alveoli expand at initially fixed gas amount

2. P_{ALV} decreases (Boyles Law) and air flow begins

3. As more air enters alveoli, P_{ALV} becomes ***less reduced***

4. At end of inspiration P_{ALV} again = P_{ATM}



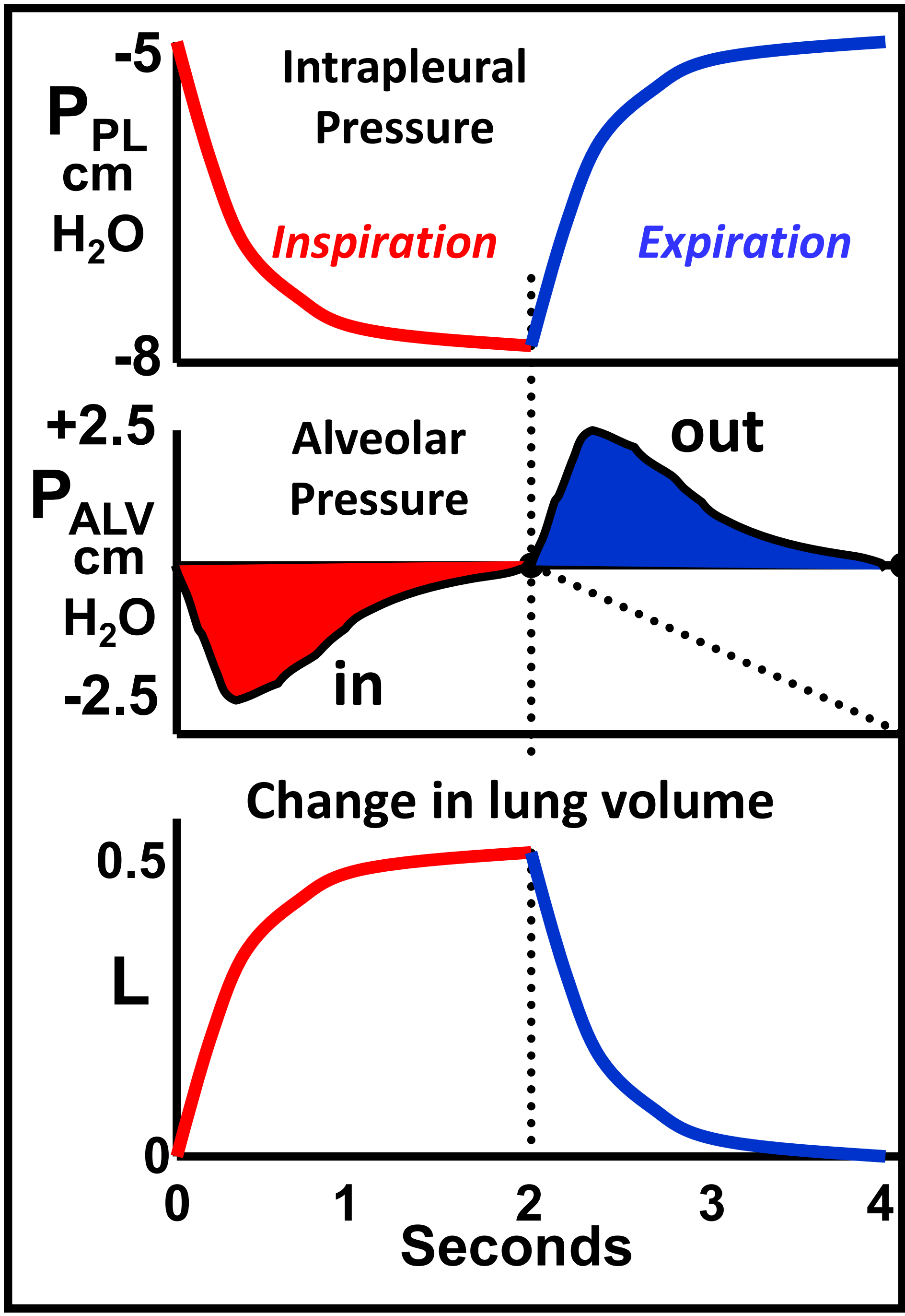
$P_{ATM} = 0$

$$Q = \frac{P_{ATM} - P_{ALV}}{R_{AW}}$$

This relationship conceptually determines amount of air inflow

R_{AW} = total airway resistance

Dynamic Pressure and Flow Changes



- Air Flow depends on difference between alveolar pressure and atmospheric pressure
- $Q \sim (P_{ATM} - P_{ALV})$
- Q (L/sec) has same form as P_{ALV}

- Air flow is zero twice during cycle When Q=0 $P_{ALV} = P_{ATM}$

Interactive Questions I

Sarah Jones is a 64-year-old retired librarian who was evaluated in Davie Florida for a respiratory issue. Her alveolar pressure is -5 cmH_2O and her intrapleural pressure is -11 cmH_2O.

What is her translung pressure in cmH_2O?

What is her transwall pressure?

What is her respiratory system pressure?

1. As you inhale does intrapleural pressure decrease or increase
2. As you inhale does translung pressure decrease or increase?
3. What is the name given to lung volume at the end of a quiet expiration?

Interactive Questions II

1. What is the name given to lung volume at the end maximum forced expiration?
2. Normal PCO2 of blood entering pulmonary capillaries is about ______?
3. Normal PO2 of blood entering pulmonary capillaries is about _______?
4. If Palv = - 5 cm H2O & intrapleural pressure is -10 cm H20

   then the value of translung pressure is __________?

1. During inspiration from FRC to TLC what happens to pulmonary vascular resistance?
2. During a normal respiratory cycle, when is the airflow zero?

End Respiratory Physiology
Lecture 37