Respiration

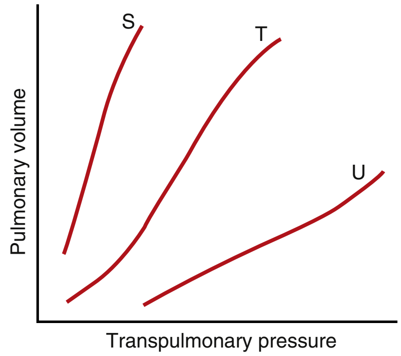
1. What tends to decrease airway resistance?
   A) Asthma
   B) Stimulation by sympathetic fibers
   C) Treatment with acetylcholine
   D) Exhalation to residual volume

2. The pleural pressure of a normal 56-year-old woman is approximately −5 cm H_2O during resting conditions immediately before inspiration (i.e., at functional residual capacity [FRC]). What is the pleural pressure (in cm H_2O) during inspiration?
   A) +1
   B) +4
   C) 0
   D) −3
   E) −7

3. A healthy, 25-year-old medical student participates in a 10-kilometer charity run for the American Heart Association. Which muscles does the student use (contract) during expiration?
   A) Diaphragm and external intercostals
   B) Diaphragm and internal intercostals
   C) Diaphragm only
   D) Internal intercostals and abdominal recti
   E) Scaleni
   F) Sternocleidomastoid muscles

4. Which of the following would be expected to increase the measured airway resistance?
   A) Stimulation of parasympathetic nerves to the lungs
   B) Low lung volumes
   C) Release of histamine by mast cells
   D) Forced expirations
   E) All of the above

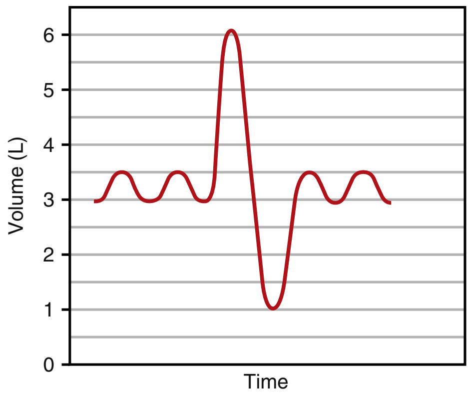
5. Several students are trying to see who can generate the highest expiratory flow. Which muscle is most effective at producing a maximal effort?
   A) Diaphragm
   B) Internal intercostals
   C) External intercostals
   D) Rectus abdominis
   E) Sternocleidomastoid



6. The above figure shows three different compliance curves (S, T, and U) for isolated lungs subjected to various transpulmonary pressures. Which of the following best describes the relative compliances for the three curves?
   A) S < T < U
   B) S < T > U
   C) S – T – U
   D) S > T < U
   E) S > T > U

Questions 7 and 8

Use the figure below to answer Questions 7 and 8.



7. Assuming a respiratory rate of 12 breaths/min, calculate the minute ventilation.
   A) 1 L/min
   B) 2 L/min
   C) 4 L/min
   D) 5 L/min
   E) 6 L/min

8. A 22-year-old woman inhales as much air as possible and exhales as much air as she can, producing the spirogram shown in the figure. A residual volume of 1.0 liter was determined using the helium dilution technique. What is her FRC (in liters)?

A) 2.0
B) 2.5
C) 3.0
D) 3.5
E) 4.0
F) 5.0

9. With a slow decrease in left heart function, which of the following will minimize the formation of pulmonary edema?

A) An increase in plasma protein concentration due to fluid loss
B) Increase in the negative interstitial hydrostatic pressure
C) Increased pumping of lymphatics
D) Increase in the concentration of interstitial proteins

10. A 22-year-old woman has a pulmonary compliance of 0.2 L/cm H_2O and a pleural pressure of −4 cm H_2O. What is the pleural pressure (in cm H_2O) when the woman inhales 1.0 liter of air?

A) −6
B) −7
C) −8
D) −9
E) −10

11. A preterm infant has a surfactant deficiency. Without surfactant, many of the alveoli collapse at the end of each expiration, which in turn leads to pulmonary failure. Which set of changes is present in the preterm infant compared with a normal infant?

	Alveolar Surface Tension	Pulmonary Compliance
A)	Decreased	Decreased
B)	Decreased	Increased
C)	Decreased	No change
D)	Increased	Decreased
E)	Increased	Increased
F)	Increased	No change
G)	No change	No change

12. A patient has a dead space of 150 milliliters, FRC of 3 liters, tidal volume (VT) of 650 milliliters, expiratory reserve volume (ERV) of 1.5 liters, total lung capacity (TLC) of 8 liters, and respiratory rate of 15 breaths/min. What is the residual volume (RV)?

A) 500 milliliters
B) 1000 milliliters
C) 1500 milliliters
D) 2500 milliliters
E) 6500 milliliters

13. A patient has a dead space of 150 milliliters, FRC of 3 liters, VT of 650 milliliters, ERV of 1.5 liters, TLC of 8 liters, and respiratory rate of 15 breaths/min. What is the alveolar ventilation (VA)?

A) 5 L/min
B) 7.5 L/min
C) 6.0 L/min
D) 9.0 L/min

14. The various lung volumes and capacities include the total lung capacity (TLC), vital capacity (VC), inspiratory capacity (IC), tidal volume (VT), expiratory capacity (EC), expiratory reserve volume (ERV), inspiratory reserve volume (IRV), functional residual capacity (FRC), and residual volume (RV). Which of the following lung volumes and capacities can be measured using direct spirometry without additional methods?

	TLC	VC	IC	VT	EC	ERV	IRV	FRC	RV
A)	No	No	Yes	No	Yes	No	Yes	No	No
B)	No	Yes	Yes	Yes	Yes	Yes	Yes	No	No
C)	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
D)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
E)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

15. What happens during exercise?

A) Blood flow is uniform throughout the lung
B) Lung-diffusing capacity increases because blood flow is continuous in all pulmonary capillaries
C) Pulmonary blood volume decreases
D) The transit time of blood in the pulmonary capillaries does not change from rest

16. A 34-year-old man sustains a bullet wound to the chest that causes a pneumothorax. What best describes the changes in lung volume and thoracic volume in this man compared with normal?

	Lung Volume	Thoracic Volume
A)	Decreased	Decreased
B)	Decreased	Increased
C)	Decreased	No change
D)	Increased	Decreased
E)	Increased	Increased
F)	No change	Decreased

17. A healthy 10-year-old boy breathes quietly under resting conditions. His tidal volume is 400 milliliters and his ventilation frequency is 12/min. Which of the following best describes the ventilation of the upper, middle, and lower lung zones in this boy?

	Upper Zone	Middle Zone	Lower Zone
A)	Highest	Lowest	Intermediate
B)	Highest	Intermediate	Lowest
C)	Intermediate	Lowest	Highest
D)	Lowest	Intermediate	Highest
E)	Same	Same	Same

18. An experiment is conducted in two persons (subjects T and V) with identical VTs (1000 milliliters), dead space volumes (200 milliliters), and ventilation frequencies (20 breaths per minute). Subject T doubles his VT and reduces his ventilation frequency by 50%. Subject V doubles his ventilation frequency and reduces his VT by 50%. What best describes the total ventilation (also called minute ventilation) and VA of subjects T and V?

	Total Ventilation	VA
A)	T < V	T – V
B)	T < V	T > V
C)	T – V	T < V
D)	T – V	T – V
E)	T – V	T > V
F)	T > V	T < V
G)	T > V	T – V

19. A person with normal lungs has an oxygen (O_2) consumption of 750 ml O_2/min. The hemoglobin (Hb) concentration is 15 g/dl. The mixed venous saturation is 25%. What is the cardiac output?

A) 2500 ml/min
B) 5000 ml/min
C) 7500 ml/min
D) 10,000 ml/min
E) 20,000 ml/min

20. A cardiac catheterization is performed in a healthy adult. The blood sample withdrawn from the catheter shows 60% O_2 saturation, and the pressure recording shows oscillations from a maximum of 27 mm Hg to a minimum of 12 mm Hg. Where was the catheter tip located?

A) Ductus arteriosus
B) Foramen ovale
C) Left atrium
D) Pulmonary artery
E) Right atrium

21. If alveolar surface area is decreased 50% and pulmonary edema leads to a doubling of diffusion distance, how does diffusion of O_2 compare with normal?

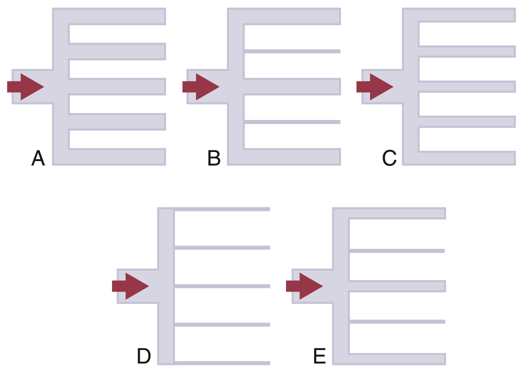
A) 25% increase
B) 50% increase
C) 25% decrease
D) 50% decrease
E) 75% decrease

22. Which of the following sets of differences best describes the hemodynamics of the pulmonary circulation when compared with the system circulation?

	Flow	Resistance	Arterial Pressure
A)	Higher	Higher	Higher
B)	Higher	Lower	Lower
C)	Lower	Higher	Lower
D)	Lower	Lower	Lower
E)	Same	Higher	Lower
F)	Same	Lower	Lower

23. A 67-year-old man is admitted emergently to the hospital because of severe chest pain. A Swan-Ganz catheter is floated into the pulmonary artery, the balloon is inflated, and the pulmonary wedge pressure is measured. The pulmonary wedge pressure is used clinically to monitor which pressure?

A) Left atrial pressure
B) Left ventricular pressure
C) Pulmonary artery diastolic pressure
D) Pulmonary artery systolic pressure
E) Pulmonary capillary pressure



24. Which diagram in the above figure best illustrates the pulmonary vasculature when the cardiac output has increased to a maximum extent?

A) A
B) B
C) C
D) D
E) E

25. A 19-year-old man sustains a full-thickness burn over 60% of his body surface area. A systemic *Pseudomonas aeruginosa* infection occurs, and severe pulmonary edema follows 7 days later. The following data are collected from the patient: plasma colloid osmotic pressure, 19 mm Hg; pulmonary capillary hydrostatic pressure, 7 mm Hg; and interstitial fluid hydrostatic pressure, 1 mm Hg. Which set of changes has occurred in the lungs of this patient as a result of the burn and subsequent infection?

	Lymph Flow	Plasma Colloid Osmotic Pressure	Pulmonary Capillary Permeability
A)	Decrease	Decrease	Decrease
B)	Increase	Decrease	Decrease
C)	Increase	Decrease	Increase
D)	Increase	Increase	Decrease
E)	Increase	Increase	Increase

26. A human experiment is being performed in which forearm blood flow is being measured under a variety of conditions. The forearm is infused with a vasodilator, resulting in an increase in blood flow. Which of the following occurs?
    A) Tissue interstitial partial pressure of oxygen (PO_2) will increase
    B) Tissue interstitial partial pressure of carbon dioxide (PCO_2) will increase
    C) Tissue pH will decrease

27. Blood gas measurements are obtained in a resting patient who is breathing room air. The patient has an arterial content of 19 ml O_2/min with a PO_2 of 95. The mixed venous O_2 content is 4 ml O_2/100 ml blood. Which condition does the patient have?
    A) An increase in physiological dead space
    B) Pulmonary edema
    C) A low Hb concentration
    D) A low cardiac output

28. A normal male subject has the following initial conditions (in the steady state):

    Arterial PO_2 = 92 mm Hg
    Arterial O_2 saturation = 97%
    Venous O_2 saturation = 20%
    Venous PO_2 = 30 mm Hg
    Cardiac output = 5600 ml/min
    O_2 consumption = 256 ml/min
    Hb concentration = 12 gm/dl

    If you ignore the contribution of dissolved O_2 to the O_2 content, what is the venous O_2 content?
    A) 2.2 ml O_2/100 ml blood
    B) 3.2 ml O_2/100 ml blood
    C) 4 ml O_2/100 ml blood
    D) 4.6 ml O_2/100 ml blood
    E) 6.2 ml O_2/100 ml blood
    F) 10.8 ml O_2/100 ml blood
    G) 16 ml O_2/100 ml blood

29. A man fell asleep in his running car. He was unconscious when he was brought into the emergency department. With carbon monoxide (CO) poisoning, you would expect his alveolar O_2 partial pressure (PaO_2) would be _______, while his arterial O_2 content (CaO_2) would be ______.
    A) Normal, decreased
    B) Decreased, decreased
    C) Increased, normal
    D) Increased, normal

30. A 30-year-old woman performs a Valsalva maneuver about 30 minutes after eating lunch. Which option best describes the changes in pulmonary and systemic blood volumes that occur in this woman?

	Pulmonary Volume	Systemic Volume
A)	Decreases	Decreases
B)	Decreases	Increases
C)	Decreases	No change
D)	Increases	Decreases
E)	Increases	Increases
F)	Increases	No change
G)	No change	Decreases
H)	No change	Increases
I)	No change	No change

31. A child who is eating round candies approximately 1 and 1.5 cm in diameter inhales one down his airway, blocking his left bronchiole. Which of the following describes the changes that occur?

	Left Lung Alveolar PCO_2	Left Lung Alveolar PO_2	Systemic Arterial PO_2
A)	↑	↑	↔
B)	↑	↔	↑
C)	↓	↓	↓
D)	↑	↑	↑
E)	↑	↓	↓

32. A person with normal lungs at sea level (760 mm Hg) is breathing 50% O_2. What is the approximate alveolar PO_2?
    A) 100
    B) 159
    C) 306
    D) 330
    E) 380

33. The forces governing the diffusion of a gas through a biological membrane include the pressure difference across the membrane (ΔP), the cross-sectional area of the membrane (A), the solubility of the gas (S), the distance of diffusion (d), and the molecular weight of the gas (MW). Which changes increase the diffusion of a gas through a biological membrane?

	ΔP	A	S	d	MW
A)	Increase	Increase	Increase	Increase	Increase
B)	Increase	Increase	Increase	Increase	Decrease
C)	Increase	Decrease	Increase	Decrease	Decrease
D)	Increase	Increase	Increase	Decrease	Increase
E)	Increase	Increase	Increase	Decrease	Decrease

34. A person's normal VT is 400 milliliters with a dead space of 100 milliliters. The respiratory rate is 12 breaths/min. The person undergoes ventilation during surgery, and the VT is 700 with a rate of 12. What is the approximate alveolar PCO_2 for this person?

A) 10
B) 20
C) 30
D) 40
E) 45

35. Arterial PO_2 is 100 mm Hg and arterial PCO_2 is 40 mm Hg. Total blood flow to a muscle is 700 ml/min. There is a sympathetic activation resulting in a decrease in blood flow of this muscle to 350 ml/min. There is no neuromuscular activation, and thus no contraction of the muscle. Which of the following will occur?

	Venous PO_2	Venous PCO_2
A)	↑	↓
B)	↓	↑
C)	↓	↔
D)	↔	↑
E)	↑	↑
F)	↓	↓
G)	↔	↔

36. A 45-year-old man at sea level has an inspired O_2 tension of 149 mm Hg, nitrogen tension of 563 mm Hg, and water vapor pressure of 47 mm Hg. A small tumor pushes against a pulmonary blood vessel, completely blocking the blood flow to a small group of alveoli. What are the O_2 and carbon dioxide (CO_2) tensions of the alveoli that are not perfused (in mm Hg)?

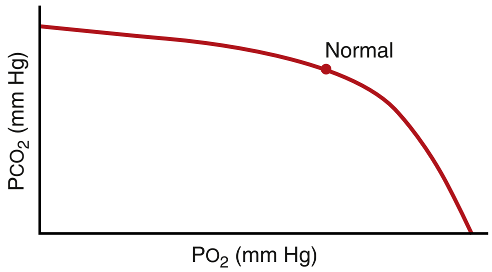
	CO_2	O_2
A)	0	0
B)	0	149
C)	40	104
D)	47	149
E)	45	149

37. In which conditions is alveolar PO_2 increased and alveolar PCO_2 decreased?

A) Increased VA and unchanged metabolism
B) Decreased VA and unchanged metabolism
C) Increased metabolism and unchanged VA
D) Proportional increase in metabolism and VA

38. The diffusing capacity of a gas is the volume of gas that will diffuse through a membrane each minute for a pressure difference of 1 mm Hg. Which gas is often used to estimate the O_2-diffusing capacity of the lungs?

A) CO_2
B) CO
C) Cyanide gas
D) Nitrogen
E) O_2



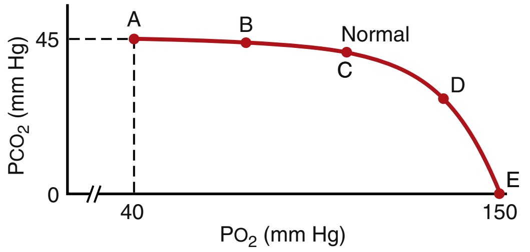
39. The O_2-CO_2 diagram above shows a ventilation-perfusion (V/Q) ratio line for the normal lung. Which of the following best describes the effect of decreasing V/Q ratio on the alveolar PO_2 and PCO_2?

	CO_2 Tension	O_2 Tension
A)	Decrease	Decrease
B)	Decrease	Increase
C)	Decrease	No change
D)	Increase	Decrease
E)	Increase	Increase

40. A 23-year-old medical student has mixed venous O_2 and CO_2 tensions of 40 mm Hg and 45 mm Hg, respectively. A group of alveoli are not ventilated in this student because mucus blocks a local airway. What are the alveolar O_2 and CO_2 tensions distal to the mucus block (in mm Hg)?

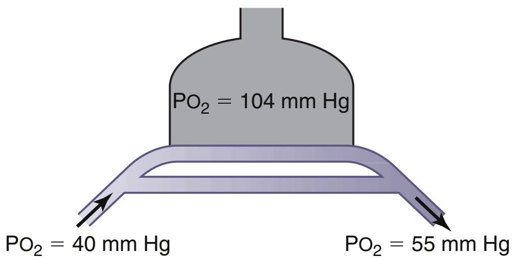
	CO_2	O_2
A)	40	100
B)	40	40
C)	45	40
D)	50	50
E)	90	40

Questions 41 and 42

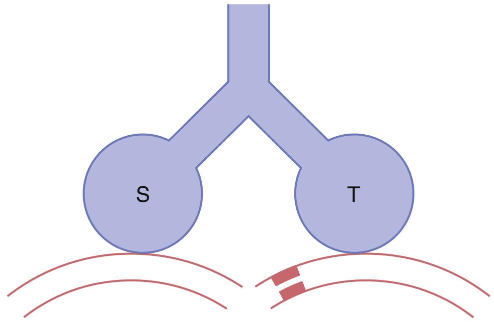


41. A 67-year-old man has a solid tumor that pushes against an airway, partially obstructing air flow to the distal alveoli. Which point on the V/Q line of the O_2-CO_2 diagram above corresponds to the alveolar gas of these distal alveoli?
    - A) A
    - B) B
    - C) C
    - D) D
    - E) E

42. A 55-year-old man has a pulmonary embolism that completely blocks the blood flow to his right lung. Which point on the V/Q line of the O_2-CO_2 diagram above corresponds to the alveolar gas of his right lung?
    - A) A
    - B) B
    - C) C
    - D) D
    - E) E

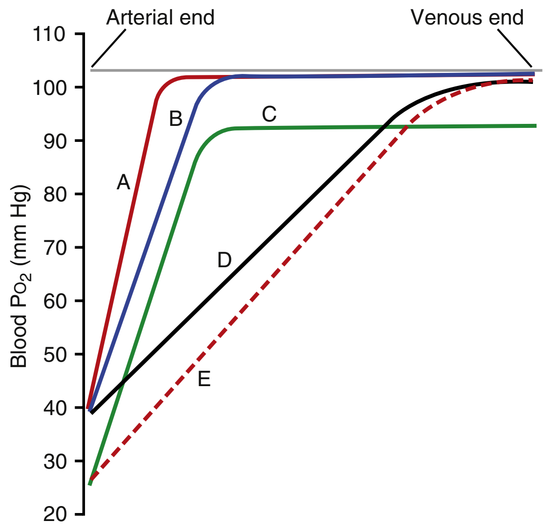


43. The figure above shows a lung with a large shunt in which mixed venous blood bypasses the O_2 exchange areas of the lung. Breathing room air produces the O_2 partial pressures shown on the diagram. What is the O_2 tension of the arterial blood (in mm Hg) when the person breathes 100% O_2 and the inspired O_2 tension is greater than 600 mm Hg?
    - A) 40
    - B) 55
    - C) 60
    - D) 175
    - E) 200
    - F) 400
    - G) 600

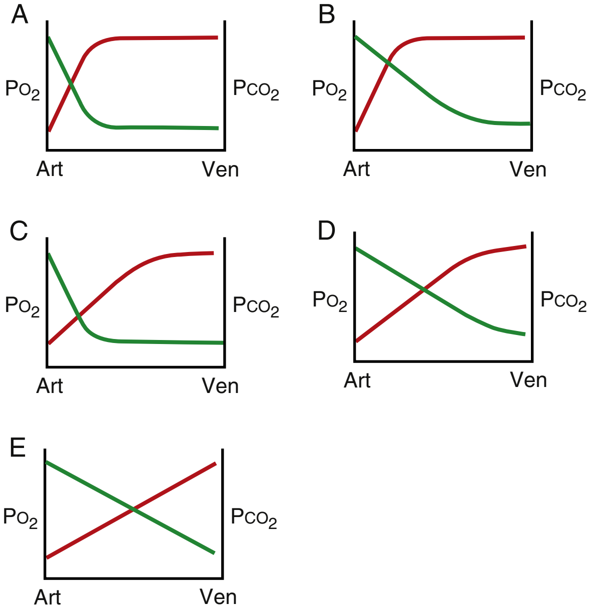


44. The figure above shows two lung units (S and T) with their blood supplies. Lung unit S has an ideal relationship between blood flow and ventilation. Lung unit T has a compromised blood flow. What is the relationship between alveolar dead space (D_{ALV}), physiologic dead space (D_{PHY}) and anatomic dead space (D_{ANAT}) for these lung units?

	Lung Unit S	Lung Unit T
A)	$D_{PHY} < D_{ANAT}$	$D_{PHY} = D_{ANAT}$
B)	$D_{PHY} = D_{ALV}$	$D_{PHY} > D_{ALV}$
C)	$D_{PHY} = D_{ANAT}$	$D_{PHY} < D_{ANAT}$
D)	$D_{PHY} = D_{ANAT}$	$D_{PHY} > D_{ANAT}$
E)	$D_{PHY} > D_{ANAT}$	$D_{PHY} < D_{ANAT}$



45. A 32-year-old medical student has a fourfold increase in cardiac output during strenuous exercise. Which curve on the above figure most likely represents the changes in O_2 tension that occur as blood flows from the arterial end to the venous end of the pulmonary capillaries in this student?
    - A) A
    - B) B
    - C) C
    - D) D
    - E) E

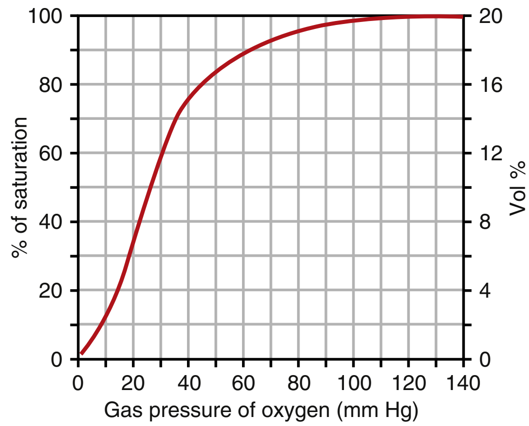


46. The above figure shows changes in the partial pressures of O_2 and CO_2 as blood flows from the arterial (Art) end to the venous (Ven) end of the pulmonary capillaries. Which diagram best depicts the normal relationship between Po_2 (red line) and Pco_2 (green line) during resting conditions?

A) A
B) B
C) C
D) D
E) E

47. Which of the following would be true if the blood lacked red blood cells and just had plasma and the lungs were functioning normally?

A) The arterial Po_2 would be normal
B) The O_2 content of arterial blood would be normal
C) Both A and B
D) Neither A nor B

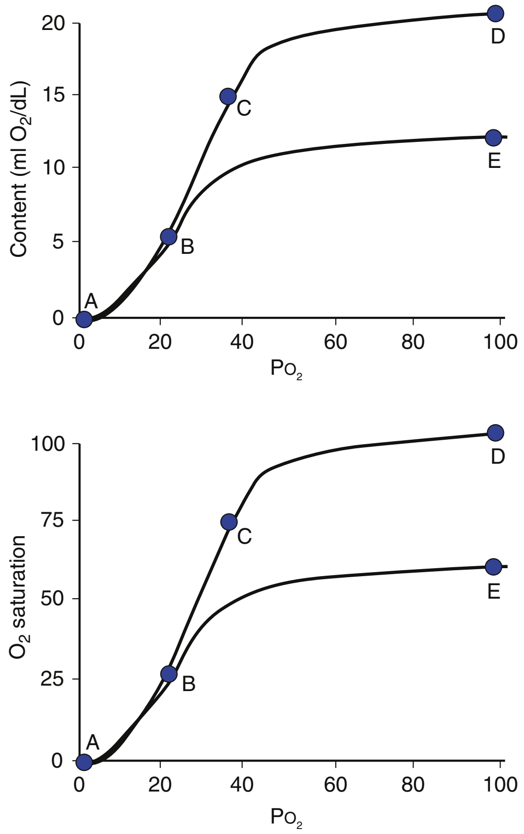


48. The above figure shows a normal O_2-Hb dissociation curve. What are the approximate values of Hb saturation (% Hb-O_2), Po_2, and O_2 content for oxygenated blood leaving the lungs and reduced blood returning to the lungs from the tissues?

	Oxygenated Blood			Reduced Blood		
	% Hb-O_2	Po_2	O_2 Content	% Hb-O_2	Po_2	O_2 Content
A)	100	104	15	80	42	16
B)	100	104	20	30	20	6
C)	100	104	20	75	40	15
D)	90	100	16	60	30	12
E)	98	140	20	75	40	15

49. A person with anemia has an Hb concentration of 12 g/dl. He starts exercising and uses 12 ml O_2/dl. What is the mixed venous Po_2?

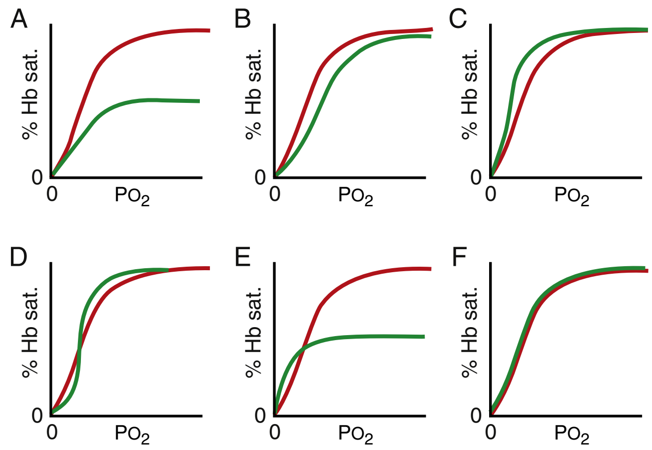
A) 0 mm Hg
B) 10 mm Hg
C) 20 mm Hg
D) 40 mm Hg
E) 100 mm Hg



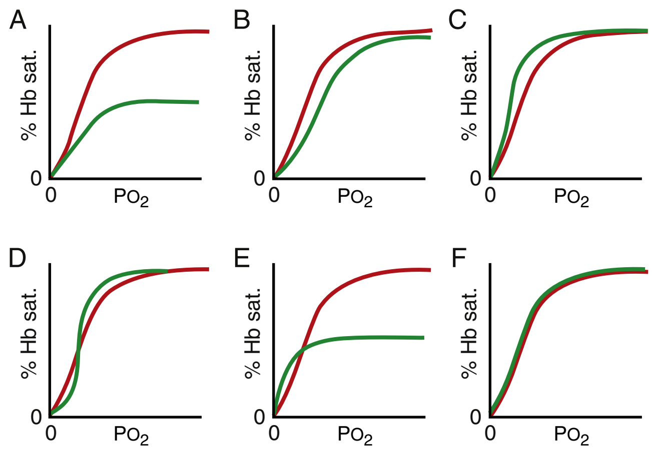
50. Which points on the above figure represent arterial blood in a severely anemic person?

	Top Graph	Bottom Graph
A)	D	D
B)	E	E
C)	D	E
D)	E	D

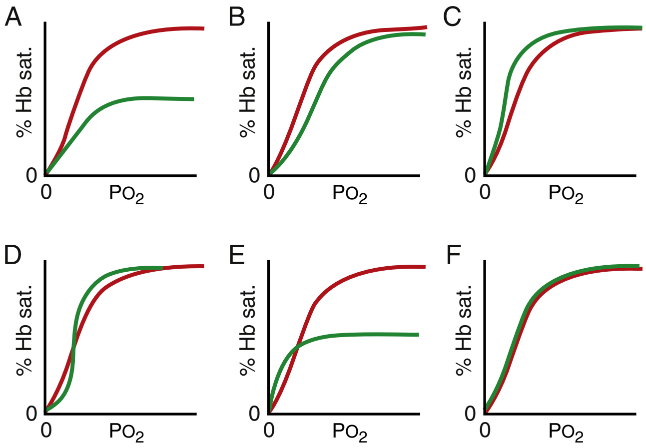
51. A stroke that destroys the respiratory area of the medulla would be expected to lead to which of the following?
   A) Immediate cessation of breathing
   B) Apneustic breathing
   C) Ataxic breathing
   D) Rapid breathing (hyperpnea)
   E) None of the above (breathing would remain normal)



52. Which of the above O_2-Hb dissociation curves corresponds to normal blood (red line) and blood containing CO (green line)?
   A) A
   B) B
   C) C
   D) D
   E) E
   F) F



53. Which of the above O_2-Hb dissociation curves corresponds to blood during resting conditions (red line) and blood during exercise (green line)?
   A) A
   B) B
   C) C
   D) D
   E) E
   F) F



54. Which of the above O_2-Hb dissociation curves corresponds to blood from an adult (red line) and blood from a fetus (green line)?
   A) A
   B) B
   C) C
   D) D
   E) E
   F) F

55. Arterial Po_2 is 100 mm Hg and arterial Pco_2 is 40 mm Hg. Total blood flow to all muscle is 700 ml/min. There is a sympathetic activation resulting in a decrease in blood flow to 350 ml/min. What will occur?

	Venous Po_2	Venous Pco_2
A)	↑	↓
B)	↓	↑
C)	↓	↔
D)	↔	↑
E)	↑	↑
F)	↓	↓
G)	↔	↔

56. What is the *most important* pathway for the respiratory response to systemic arterial CO_2 (Pco_2)?
   A) CO_2 activation of the carotid bodies
   B) Hydrogen ion (H^+) activation of the carotid bodies
   C) CO_2 activation of the chemosensitive area of the medulla
   D) H^+ activation of the chemosensitive area of the medulla
   E) CO_2 activation of receptors in the lungs

57. The basic rhythm of respiration is generated by neurons located in the medulla. What limits the duration of inspiration and increases respiratory rate?
   A) Apneustic center
   B) Dorsal respiratory group
   C) Nucleus of the tractus solitarius
   D) Pneumotaxic center
   E) Ventral respiratory group

58. When the respiratory drive for increased pulmonary ventilation becomes greater than normal, a special set of respiratory neurons that are inactive during normal quiet breathing then becomes active, contributing to the respiratory drive. These neurons are located in which structure?
   A) Apneustic center
   B) Dorsal respiratory group
   C) Nucleus of the tractus solitarius
   D) Pneumotaxic center
   E) Ventral respiratory group

59. A 26-year-old medical student on a normal diet has a respiratory exchange ratio of 0.8. How much O_2 and CO_2 are transported between the lungs and tissues of this student (in ml gas/100 ml blood)?

	O_2	CO_2
A)	4	4
B)	5	3
C)	5	4
D)	5	5
E)	6	3
F)	6	4

60. CO_2 is transported from the tissues to the lungs predominantly in the form of bicarbonate ion. Compared with arterial red blood cells, which of the following options best describes venous red blood cells?

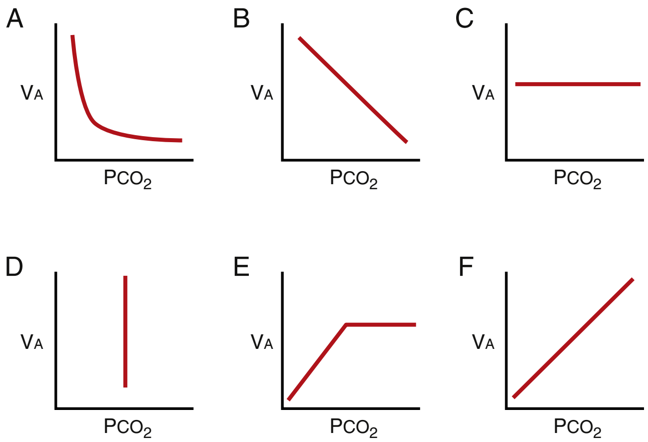
	Intracellular Chloride Concentration	Cell Volume
A)	Decreased	Decreased
B)	Decreased	Increased
C)	Decreased	No change
D)	Increased	Decreased
E)	Increased	No change
F)	Increased	Increased
G)	No change	Decreased
H)	No change	Increased
I)	No change	No change

61. The afferent (sensory) endings for the Hering-Breuer reflex are mechanoreceptors located in the
   A) Carotid arteries
   B) Alveoli
   C) External intercostals
   D) Bronchi and bronchioles
   E) Diaphragm

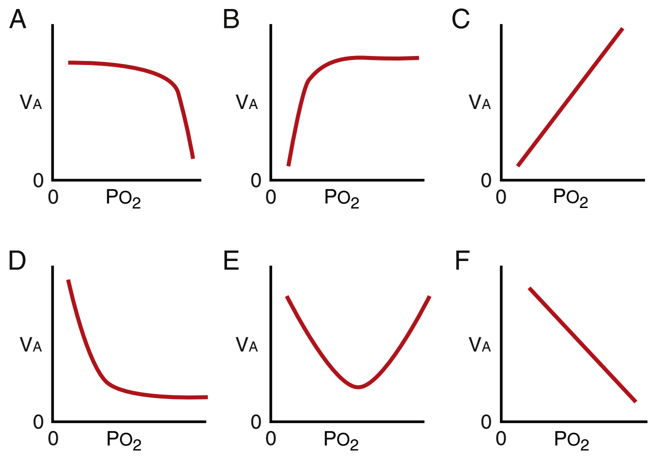
62. An anesthetized man is breathing with no assistance. He then undergoes artificial ventilation for 10 minutes at his normal VT but at twice his normal frequency. He undergoes ventilation with a gas mixture of 60% O_2 and 40% nitrogen. The artificial ventilation is stopped and he fails to breathe for several minutes. This apneic episode is due to which of the following?
    - A) High arterial Po_2 suppressing the activity of the peripheral chemoreceptors
    - B) Decrease in arterial pH suppressing the activity of the peripheral chemoreceptors
    - C) Low arterial Pco_2 suppressing the activity of the medullary chemoreceptors
    - D) High arterial Pco_2 suppressing the activity of the medullary chemoreceptors
    - E) Low arterial Pco_2 suppressing the activity of the peripheral chemoreceptors

63. Which of the following describes a patient with constricted lungs compared with a normal patient?

	TLC	RV	Maximum Expiratory Flow
A)	Normal	Normal	Normal
B)	Normal	Normal	Reduced
C)	Normal	Reduced	Reduced
D)	Reduced	Normal	Normal
E)	Reduced	Reduced	Normal
F)	Reduced	Reduced	Reduced



64. Which diagram in the above figure best describes the relationship between VA and arterial CO_2 tension (Pco_2) when the Pco_2 is changed acutely over a range of 35 to 75 mm Hg?
    - A) A
    - B) B
    - C) C
    - D) D
    - E) E
    - F) F



65. Which diagram in the above figure best describes the relationship between VA and arterial O_2 tension (Po_2) when the Po_2 is changed acutely over a range of 0 to 160 mm Hg and the arterial Pco_2 and H^+ concentration remain normal?
    - A) A
    - B) B
    - C) C
    - D) D
    - E) E
    - F) F

66. At a fraternity party a 17-year-old male places a paper bag over his mouth and breathes in and out of the bag. As he continues to breathe into this bag, his rate of breathing continues to increase. Which of the following is responsible for the increased ventilation?
    - A) Increased alveolar Po_2
    - B) Increased alveolar Pco_2
    - C) Decreased arterial Pco_2
    - D) Increased pH

67. VA increases severalfold during strenuous exercise. Which factor is most likely to stimulate ventilation during strenuous exercise?
    - A) Collateral impulses from higher brain centers
    - B) Decreased mean arterial pH
    - C) Decreased mean arterial Po_2
    - D) Decreased mean venous Po_2
    - E) Increased mean arterial Pco_2

68. During strenuous exercise, O_2 consumption and CO_2 formation can increase as much as 20-fold. VA increases almost exactly in step with the increase in O_2 consumption. Which option best describes what happens to the mean arterial O_2 tension (Po_2), CO_2 tension (Pco_2), and pH in a healthy athlete during strenuous exercise?

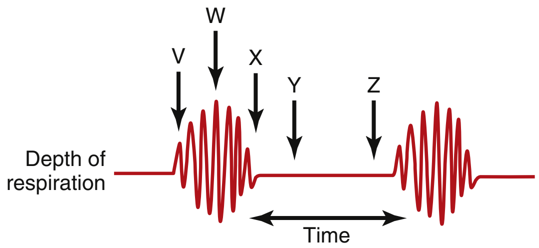
	Arterial Po_2	Arterial Pco_2	Arterial pH
A)	Decreases	Decreases	Decreases
B)	Decreases	Increases	Decreases
C)	Increases	Decreases	Increases
D)	Increases	Increases	Increases
E)	No change	No change	No change

69. A 54-year-old woman with advanced emphysema due to long-term cigarette smoking is admitted to the hospital for shortness of breath. She is diagnosed with pulmonary hypertension. Her arterial blood gases are

    Po_2 = 75 mm Hg
    Pco_2 = 45 mm Hg
    pH = 7.35

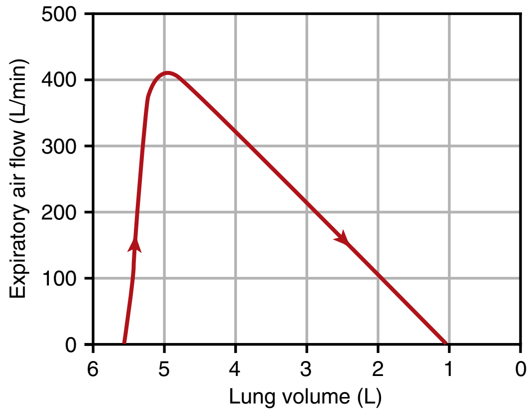
    What is the cause of the pulmonary hypertension in this woman?

    A) Increased alveolar Pco_2
    B) Increased sympathetic tone
    C) Decreased alveolar Po_2
    D) Decreased pulmonary capillary number



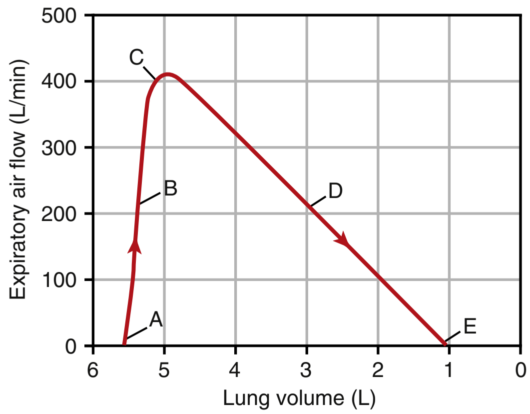
70. Cheyne-Stokes breathing is an abnormal breathing pattern characterized by a gradual increase in the depth of breathing, followed by a progressive decrease in the depth of breathing that occurs again and again approximately every minute. Which time points on the above figure (V-Z) are associated with the highest Pco_2 of lung blood and highest Pco_2 of the neurons in the respiratory center?

	Lung Blood	Respiratory Center
A)	V	V
B)	V	W
C)	W	W
D)	X	Z
E)	Y	Z



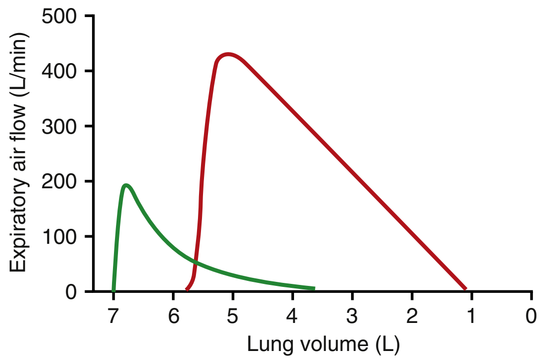
71. A 45-year-old man inhaled as much air as possible and then expired with a maximum effort until no more air could be expired. This action produced the maximum expiratory flow-volume (MEFV) curve shown in the above figure. What is the forced vital capacity (FVC) of this man (in liters)?

    A) 1.5
    B) 2.5
    C) 3.5
    D) 4.5
    E) 5.5
    F) 6.5



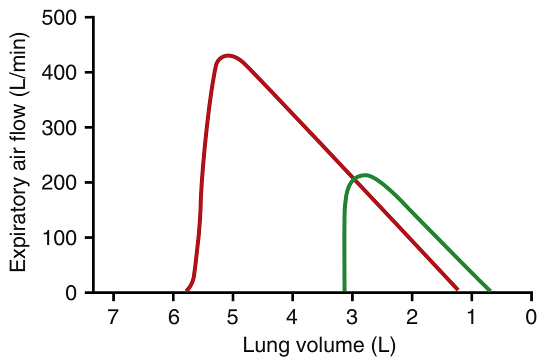
72. The MEFV curve shown in the above figure is used as a diagnostic tool for identifying obstructive and restrictive lung diseases. At which point on the curve does airway collapse limit maximum expiratory air flow?

    A) A
    B) B
    C) C
    D) D
    E) E



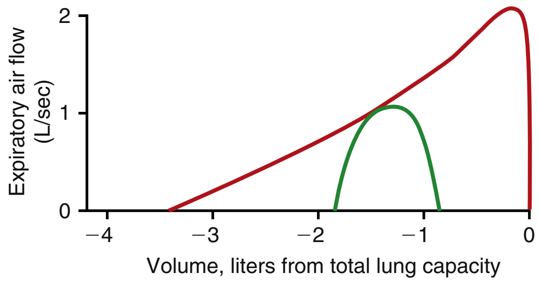
73. The MEFV curves shown in the above figure were obtained from a healthy person (red curve) and a 57-year-old man with shortness of breath (green curve). The man with shortness of breath likely has which disorder?

A) Asbestosis
B) Emphysema
C) Kyphosis
D) Scoliosis
E) Silicosis
F) Tuberculosis



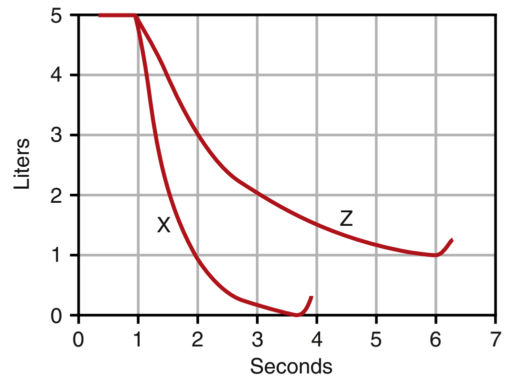
74. A 62-year-old man reports difficulty breathing. The above figure shows an MEFV curve from the patient (green line) and from a typical healthy individual (red curve). Which of the following best explains the MEFV curve of the patient?

A) Asbestosis
B) Asthma
C) Bronchospasm
D) Emphysema
E) Old age



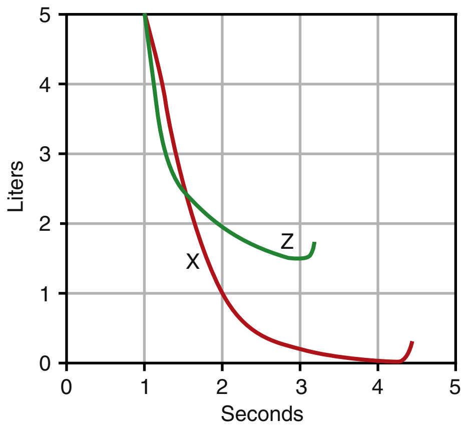
75. The MEFV curve shown in the above figure (red line) was obtained from a 75-year-old man who smoked 40 cigarettes per day for 60 years. The green flow-volume curve was obtained from the man during resting conditions. Which set of changes is most likely to apply to this man?

	Exercise Tolerance	TLC	RV
A)	Decreased	Decreased	Decreased
B)	Decreased	Increased	Increased
C)	Decreased	Normal	Normal
D)	Increased	Increased	Increased
E)	Normal	Decreased	Decreased



76. The above figure shows a forced expiration for a healthy person (curve X) and a person with a pulmonary disease (curve Z). What is the forced expiratory volume in the first second of expiration (FEV_{1})/FVC ratio (as a percent) in these persons?

	Person X	Person Z
A)	80	50
B)	80	40
C)	100	80
D)	100	60
E)	90	50
F)	90	60

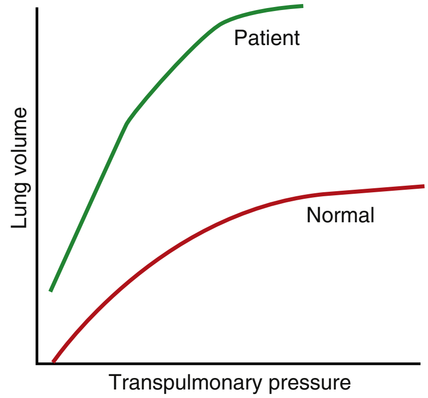


77. The above figure shows forced expirations from a person with healthy lungs (curve X) and from a patient (curve Z). The patient most likely has which condition?
    A) Asthma
    B) Bronchospasm
    C) Emphysema
    D) Old age
    E) Silicosis

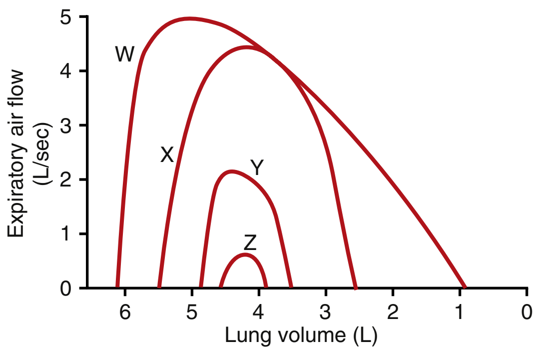
78. Which of the following describes blood gases during consolidated pneumonia?

	Arterial Po_2	Arterial O_2 Content	Arterial Pco_2
A)	Normal	Normal	Normal
B)	Normal	Normal	Increased
C)	Decreased	Normal	Normal
D)	Decreased	Decreased	Increased
E)	Decreased	Decreased	Decreased
F)	Decreased	Decreased	Normal

79. Which of the following occurs during atelectasis of one lung?
    A) Increase in arterial Pco_2
    B) A 40% decrease in Po_2
    C) Normal blood flow in the lung with atelectasis
    D) Slight decrease in arterial content



80. The volume–pressure curves in the above figure were obtained from a normal subject and a patient with a pulmonary disease. Which abnormality is most likely present in the patient?
    A) Asbestosis
    B) Emphysema
    C) Mitral obstruction
    D) Rheumatic heart disease
    E) Silicosis
    F) Tuberculosis



81. A 34-year-old medical student generates the flow-volume curves shown in the above figure. Curve W is a normal MEFV curve generated when the student was healthy. Which of the following best explains curve X?
    A) Asthma attack
    B) Aspiration of meat into the trachea
    C) Heavy exercise
    D) Light exercise
    E) Normal breathing at rest
    F) Pneumonia
    G) Tuberculosis

82. Which of the following best describes comparison of the lung compliance and surfactant levels in a premature infant with respiratory distress syndrome versus a normal full-term infant?

	Lung Compliance (Premature vs. Full Term Infant)	Surfactant Levels (Premature vs. Full Term Infant)
A)	↑	↓
B)	↑	↑
C)	↓	↓
D)	↓	↑
E)	↔	↑
F)	↔	↓

83. Compared with a normal healthy person, how do TLC and maximum expiratory flow (MEF) change with restrictive lung disease?

	TLC	MEF
A)	↑	↓
B)	↓	↓
C)	↑	↑
D)	↓	↑

84. A 78-year-old man who smoked 60 cigarettes per day for 55 years reports shortness of breath. The patient is diagnosed with chronic pulmonary emphysema. Which set of changes is present in this man compared with a healthy nonsmoker?

	Pulmonary Compliance	Lung Elastic Recoil	TLC
A)	Decreased	Decreased	Decreased
B)	Decreased	Decreased	Increased
C)	Decreased	Increased	Increased
D)	Increased	Decreased	Decreased
E)	Increased	Decreased	Increased
F)	Increased	Increased	Increased

85. While breathing room air, a patient with chronic obstructive pulmonary disease, has a systemic arterial P_{CO_2} of 65 mm Hg and a P_{O_2} of 40 mm Hg. Supplemental oxygen is administered at a 40% fractional concentration of oxygen in inspired gas (F_{IO_2}), which resulted in an increase of P_{O_2} to 55 mm Hg and P_{CO_2} to 70 mm Hg. Which of the following describes the supplemental O_2?

A) Restored arterial dissolved O_2 to normal
B) Did not change breathing
C) Reduced the hypoxic stimulation of breathing
D) Increased the pulmonary excretion of CO_2

86. Which of the following describes diffusing capacity of O_2 in the lung?

A) Does not change during exercise
B) Is greater than diffusing capacity for CO_2
C) Is greater in residents at sea level than in residents at 3000 meters altitude
D) Is directly related to alveolar capillary surface area

87. When he was in his early 40s, a 75-year-old man worked for 5 years in a factory where asbestos was used as an insulator. The man is diagnosed with asbestosis. Which set of changes is present in this man compared with a person with healthy lungs?

	Pulmonary Compliance	Lung Elastic Recoil	TLC
A)	Decreased	Decreased	Decreased
B)	Decreased	Increased	Increased
C)	Decreased	Increased	Decreased
D)	Increased	Decreased	Decreased
E)	Increased	Decreased	Increased
F)	Increased	Increased	Increased

ANSWERS

1. B) A decrease in airway resistance is due to an increase in the diameter of the airway. Asthma causes bronchoconstriction, which is prevented by β-agonists. Sympathetic stimulation of the airways results in a relaxation of airways, decreasing resistance. Acetylcholine is a bronchoconstrictor, increasing resistance. With low lung volumes there is a collapse of the airways, leading to decreased diameter and increased resistance.

TMP13 p. 505

2. E) The pleural pressure (sometimes called the intrapleural pressure) is the pressure of the fluid in the narrow space between the visceral pleura of the lungs and parietal pleura of the chest wall. The pleural pressure is normally about −5 cm H_2O immediately before inspiration (i.e., at FRC) when all of the respiratory muscles are relaxed. During inspiration, the volume of the chest cavity increases and the pleural pressure becomes more negative. The pleural pressure averages about −7.5 cm H_2O immediately before expiration when the lungs are fully expanded. The pleural pressure then returns to its resting value of −5 cm H_2O as the diaphragm relaxes and lung volume returns to FRC. Therefore, the intrapleural pressure is always subatmospheric under normal conditions, varying between −5 and −7.5 cm H_2O during quiet breathing.

TMP13 pp. 498-499

3. D) Contraction of the internal intercostals and abdominal recti pull the rib cage downward during expiration. The abdominal recti and other abdominal muscles compress the abdominal contents upward toward the diaphragm, which also helps to eliminate air from the lungs. The diaphragm relaxes during expiration. The external intercostals, sternocleidomastoid muscles, and scaleni increase the diameter of the chest cavity during exercise and thus assist with inspiration, but only the diaphragm is necessary for inspiration during quiet breathing.

TMP13 pp. 497-498

4. E) Stimulation of parasympathetic nerves results in a bronchoconstriction. With low lung volumes a collapse of the airways occurs, leading to decreased diameter and increased resistance. Histamine is a bronchoconstrictor. Forced exhalations will increase pleural pressure, decreasing airway diameter, and thus increasing resistance. All the responses are correct.

TMP13 pp. 504, 505, 550

5. E) The diaphragm and external intercostals are used for inhalation. The sternocleidomastoid is a muscle in the neck and is not used for inhalation or exhalation. The rectus abdominis and internal intercostals are used for exhalation. The majority of the force for exhalation is generated by the rectus abdominis.

TMP13 p. 497

6. E) Compliance (C) is the change in lung volume (ΔV) that occurs for a given change in the transpulmonary pressure (ΔP): that is, $C = \Delta V/\Delta P$. (The transpulmonary pressure is the difference between the alveolar pressure and pleural pressure.) Because compliance is equal to the slope of the volume–pressure relationship, it should be clear that curve S represents the highest compliance and that curve U represents the lowest compliance.

TMP13 p. 499

7. E) Minute ventilation is VT × respiratory rate. VT from the graph is 500 milliliters. Therefore, minute ventilation = 500 × 12 = 6 L/min.

TMP13 p. 503

8. C) A slow increase in left heart function will lead to a gradual increase in pulmonary capillary pressure, and thus greater fluid filtration. Over time there will be an increase in lymphatics and lymphatic pumping to remove the fluid from the interstitial space. With heart failure there is an increase in fluid retention, and thus no decrease in plasma protein concentration. An increase in interstitial hydrostatic pressure will result in an increase in edema (see Chapter 25, pp. 316-320). An increase in interstitial proteins will cause an increase in interstitial osmotic pressure, leading to an increase in net filtration pressure and increased filtration.

TMP13 pp. 513-514

9. C) The FRC equals the ERV (2 liters) plus the RV (1.0 liter). This is the amount of air that remains in the lungs at the end of a normal expiration. FRC is considered to be the resting volume of the lungs because none of the respiratory muscles is contracted at FRC. This problem illustrates an important point: a spirogram can measure changes in lung volume but not absolute lung volumes. Thus, a spirogram alone cannot be used to determine RV, FRC, or TLC.

TMP13 pp. 501-503

10. D) Because the compliance is 0.2 L/cm H_2O, it should be clear that a 1.0-liter increase in volume will cause a 5 cm H_2O decrease in pleural pressure (1.0 L/0.2 L/cm H_2O = 5.0 cm H_2O), and because the initial pleural pressure was −4 cm H_2O before inhalation,

the pressure is reduced by 5 cm H_2O (to −9 cm H_2O) when 1.0 liter of air is inhaled.
TMP13 pp. 498-499

11. D) Surfactant is formed relatively late in fetal life. Premature babies born without adequate amounts of surfactant can develop pulmonary failure and die. Surfactant is a surface active agent that greatly reduces the surface tension of the water lining the alveoli. Water is normally attracted to itself, which is why raindrops are round. By reducing the surface tension of the water lining the alveoli (and thus reducing the tendency of water molecules to coalesce), the surfactant reduces the work of breathing—that is, less transpulmonary pressure is required to inhale a given volume of air. Because compliance is equal to the change in lung volume for a given change in transpulmonary pressure, it should be clear that pulmonary compliance is decreased in the absence of surfactant.
TMP13 pp. 499-500

12. C) Residual volume = FRC − ERV = 3 L − 1.5 L = 1.5 L
TMP13 pp. 501-503

13. B) VA = Frequency × (V_T − V_D) = 15/min × (650 − 150) = 7.5 L/min
TMP13 p. 504

14. B) A spirometer can be used to measure changes in lung volume, but it cannot determine absolute volume. It consists of a drum filled with air inverted over a chamber of water. When the person breathes in and out, the drum moves up and down, recording the changes in lung volume. The spirometer cannot be used to measure RV because the RV of air in the lungs cannot be exhaled into the spirometer. The FRC is the amount of air left in the lungs after a normal expiration. FRC cannot be measured using a spirometer because it contains the RV. The TLC is the total amount of air that the lungs can hold after a maximum inspiration. Because the TLC includes the RV, it cannot be measured using a spirometer. TLC, FRC, and RV can be determined using the helium dilution method or a body plethysmograph.
TMP13 pp. 501-503

15. B) Blood flow during exercise is still higher at the base of the lung compared with the apex due to gravity. During exercise there is an opening of more blood vessels in the lung, and thus better perfusion. With the opening of more blood vessels an increase in diffusing capacity occurs, allowing equilibration of the blood with O_2 in spite of the increase in flow. Due to the opening of unperfused vessels and vasodilation of existing vessels, there would be no decrease in lung blood volume. With an increase in cardiac output there will be a decrease in transit time; however, the blood is still equilibrated.
TMP13 pp. 511-513, 524-525

16. B) Both the lung and thoracic cage are elastic. Under normal conditions, the elastic tendency of the lungs to collapse is exactly balanced by the elastic tendency of the thoracic cage to expand. When air is introduced into the pleural space, the pleural pressure becomes equal to atmospheric pressure—the chest wall springs outward and the lungs collapse.
TMP13 pp. 498-499

17. D) The lower zones of the lung ventilate better than the upper zones, and the middle zones have intermediate ventilation. These differences in regional ventilation can be explained by regional differences in pleural pressure. The pleural pressure is typically about −10 cm H_2O in the upper regions and about −2.5 cm H_2O in the lower regions. A less negative pleural pressure in the lower regions of the chest cavity causes less expansion of the lower zones of the lung during resting conditions. Therefore, the bottom of the lung is relatively compressed during rest but expands better during inspiration compared with the apex.
TMP13 pp. 525-526

18. E) Total ventilation is equal to the tidal volume (V_T) times the ventilation frequency. VA = (V_T − V_D) × Frequency, where V_D is the dead space volume. Both persons have the same total ventilation: subject T, 1000 × 10 = 10 L/min; subject V, 500 × 20 = 10 L/min. However, subject T has a VA of 18 liters (i.e., (2000 − 200) × 10), whereas subject V has a VA of only 12 liters (i.e., (500 − 200) × 40). This problem further illustrates that the most effective means of increasing VA is to increase the V_T, not the respiratory frequency.
TMP13 p. 504

19. B) Arterial content = 15 g/dl × 1.34 ml O_2/gm Hb = 20 ml O_2/dl (1 dl = 100 ml)
Venous saturation is 25%, so venous content is 20 ml O_2/dl × 0.25 = 5 ml O_2/dl
Fick's principal is O_2 consumption = cardiac output (arterial content − venous content)
750 ml O_2/min = cardiac output × (20 ml O_2/dl − 5 ml O_2/dl)
Cardiac output = (750 ml O_2/min)/(15 ml O_2/dl) = 5000 ml/min
TMP13 pp. 257, 530-531

20. D) Ductus arteriosus is present in a fetus, not a healthy adult, in the segment that connects the pulmonary artery to the aorta. Either this is not present in an adult or the pressures would be higher than measured because this is connected to the aorta. The foramen ovale is a cardiac shunt in the fetal heart from right atrium to left atrium, so pressures would be very low. The left atrial pressure should be between 1 and 5 mm Hg. The pulmonary artery pressure ranges from 25 systolic to ~12 to 14 mm Hg diastolic. The right atrial pressure is ~0 to 2 mm Hg.
TMP13 p. 510

21. E) Fick's law of diffusion states that
Diffusion = (Pressure gradient × Surface area × Solubility)/(Distance × $MW^{½}$). To simplify, make everything have a value of 1 so diffusion = 1. Now decrease surface area to 0.5 (50% decrease) and double distance to 2. Then diffusion = (1 × 0.5 × 1)/(2 × 1) = 0.25. Thus, the answer is 0.25, which is a 75% decrease from normal.
TMP13 p. 517

22. F) The pulmonary and systemic circulations both receive about the same amount of blood flow because the lungs receive the entire cardiac output. (However, the output of the left ventricle is actually 1% to 2% higher than that of the right ventricle because the bronchial arterial blood originates from the left ventricle and the bronchial venous blood empties into the pulmonary veins.) The pulmonary blood vessels have a relatively low resistance, allowing the entire cardiac output to pass through them without increasing the pressure to a great extent. The pulmonary artery pressure averages about 15 mm Hg, which is much lower than the systemic arterial pressure of about 100 mm Hg.
TMP13 pp. 509-511

23. A) It is usually not feasible to measure the left atrial pressure directly in a normal human being because it is difficult to pass a catheter through the heart chambers into the left atrium. The balloon-tipped, flow-directed catheter (Swan-Ganz catheter) was developed nearly 30 years ago to estimate left atrial pressure for the management of acute myocardial infarction. When the balloon is inflated on a Swan-Ganz catheter, the pressure measured through the catheter, called the wedge pressure, approximates the left atrial pressure for the following reason: blood flow distal to the catheter tip has been stopped all the way to the left atrium, which allows left atrial pressure to be estimated. The wedge pressure is actually a few mm Hg higher than the left atrial pressure, depending on where the catheter is wedged, but this still allows changes in left atrial pressure to be monitored in patients with left ventricular failure.
TMP13 p. 510

24. A) The pulmonary blood flow can increase severalfold without causing an excessive increase in pulmonary artery pressure for the following two reasons: previously closed vessels open up (recruitment), and the vessels enlarge (distension). Recruitment and distension of the pulmonary blood vessels both serve to lower the pulmonary vascular resistance (and thus to maintain low pulmonary blood pressures) when the cardiac output has increased.
TMP13 p. 512

25. C) A *P. aeruginosa* infection can increase the capillary permeability in the lungs and elsewhere in the body, which leads to excess loss of plasma proteins into the interstitial spaces. This leakage of plasma proteins from the vasculature caused the plasma colloid osmotic pressure to decrease from a normal value of about 28 mm Hg to 19 mm Hg. The capillary hydrostatic pressure remained at a normal value of 7 mm Hg, but it can sometimes increase to higher levels, exacerbating the formation of edema. The interstitial fluid hydrostatic pressure has increased from a normal value of about −5 mm Hg to 1 mm Hg, which tends to decrease fluid loss from the capillaries. Excess fluid in the interstitial spaces (edema) causes lymph flow to increase.
TMP13 pp. 513-515

26. A) With an increase in blood flow to a tissue, with no change in metabolism, there will be an increase in tissue Po_2 due to the increased delivery of O_2 with no change in metabolism. This increase in tissue Po_2 leads to a decreased Pco_2 due to increased washout of CO_2 and an increase in pH, due to the fall in Pco_2.
TMP13 pp. 528-529

27. D) With a Po_2 of 95 and a content of 19 ml O_2/dl on room air, the patient has no issues with V/Q ratio or pulmonary edema. An arterial content of 19 ml O_2/dl and a Po_2 of 95 suggest a normal Hb concentration. A low cardiac output would require a greater extraction of O_2 from the blood to supply O_2 to the tissue, resulting in a decreased mixed venous content.
TMP13 pp. 522-523, 528

28. B) Arterial content = 12 g Hb/dl × 1.34 ml O_2/dl = 16 ml O_2/dl
Venous saturation = 20%, so venous content = 16 ml O_2/dl × 0.2 = 3.2 ml O_2/dl
TMP13 pp. 530-531

29. A) CO binds to the Hb, displacing the O_2 bound to Hb, leading to a decrease in content. The normal particle pressure of CO is a couple of mm Hg. However, arterial Po_2 is a measure of dissolved Po_2; therefore, the Po_2 will be normal.
TMP13 pp. 528, 534

30. B) When a person performs the Valsalva maneuver (forcing air against a closed glottis), high pressure builds up in the lungs that can force as much as 250 milliliters of blood from the pulmonary circulation into the systemic circulation. The lungs have an important blood reservoir function, automatically shifting blood to the systemic circulation as a compensatory response to hemorrhage and other conditions in which the systemic blood volume is too low.
TMP13 p. 510

31. E) When an airway is blocked, no movement of fresh air occurs. Therefore, the air in the alveoli reaches an equilibration with pulmonary arterial blood. Therefore, Po_2 will decrease from 100 to 40, Pco_2 will increase

from 40 to 45, and systemic Po_2 will decrease because there is a decrease in O_2 uptake from the alveoli and thus decreased O_2 diffusion from the alveoli.
TMP13 pp. 524-525

32. C) To calculate inspired Po_2, one must remember that the air is humidified when it enters the body. Therefore, the humidified air has an effective total pressure of atmospheric pressure (760) – water vapor pressure (47), which yields a pressure of (760 – 47) = 713 mm Hg. The O_2 is 50% of the total gas, so the Po_2 is 713 × 0.5 = 356 mm Hg. To correct for the CO_2 in the alveoli, one then must subtract the Pco_2 divided by the respiratory quotient (normally 0.8). Therefore, the alveolar $Po_2 = PIo_2 - (Pco_2/R) - 356 - (40/0.8) = 356 - 50 = 306$ mm Hg.
TMP13 pp. 519-521

33. E) Fick's law of diffusion states that the rate of diffusion (D) of a gas through a biological membrane is proportional to ΔP, A, and S, and inversely proportional to d and the square root of the MW of the gas (i.e., $D \alpha (\Delta P \times A \times S) / (d \times MW^{-2})$). The greater the pressure gradient, the faster the diffusion. The larger the cross-sectional area of the membrane, the higher will be the total number of molecules that can diffuse through the membrane. The higher the solubility of the gas, the higher will be the number of gas molecules available to diffuse for a given difference in pressure. When the distance of the diffusion pathway is shorter, it will take less time for the molecules to diffuse the entire distance. When the MW of the gas molecule is decreased, the velocity of kinetic movement of the molecule will be higher, which also increases the rate of diffusion.
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34. B) Normal alveolar Pco_2 is 40 mm Hg. Normal VA for this person is 3.6 L/min. On the ventilator the VA is 7.2 L/min. A doubling of VA results in a decrease in alveolar Pco_2 by one-half. Thus, alveolar Pco_2 would be 20.
TMP13 p. 520

35. B) Venous Po_2 and Pco_2 are measures of the balance between blood flow in and metabolism by the tissue. If metabolism does not change and blood flow decreases, then there will be greater diffusion of O_2 from the blood into the tissue to supply the same amount of O_2, leading to a decreased venous Po_2. With a decrease in blood flow, there will be a decreased washout of CO_2, leading to an increase in venous Pco_2.
TMP13 pp. 528-529, 533

36. B) Alveolar air normally equilibrates with the mixed venous blood that perfuses them; thus, the gas composition of alveolar air and pulmonary capillary blood are identical. When a group of alveoli are not perfused, the composition of the alveolar air becomes equal to the inspired gas composition, which has an O_2 tension of 149 mm Hg and CO_2 tension of about 0 mm Hg.
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37. A) Alveolar Po_2 depends on inspired gas and alveolar Pco_2. Alveolar Pco_2 is a balance between VA and CO_2 production. To decrease alveolar Pco_2, there must be increased VA in relation to metabolism. Low Po_2 will not directly affect Pco_2, but it can stimulate respiration (if Po_2 is sufficiently low), which would then reduce Pco_2. An increased metabolism with unchanged VA will increase Pco_2. A doubling in metabolism with a doubling in VA will have no effect on Pco_2.
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38. B) It is not practical to measure the O_2-diffusing capacity directly because it is not possible to measure accurately the O_2 tension of the pulmonary capillary blood. However, the diffusing capacity for CO can be measured accurately because the CO tension in pulmonary capillary blood is zero under normal conditions. The CO diffusing capacity is then used to calculate the O_2-diffusing capacity by taking into account the differences in diffusion coefficient between O_2 and CO. Knowing the rate of transfer of CO across the respiratory membrane is often helpful for evaluating the presence of possible parenchymal lung disease when spirometry and/or lung volume determinations suggest a reduced VC, RV, and/or TLC.
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39. D) A decrease in the VA/Q is depicted by moving to the left along the normal ventilation-perfusion line shown in the figure. Whenever the VA/Q is below normal, there is inadequate ventilation to provide the O_2 needed to fully oxygenate the blood flowing through the alveolar capillaries (i.e., alveolar Po_2 is low). Therefore, a certain fraction of the venous blood passing through the pulmonary capillaries does not become oxygenated. Poorly ventilated areas of the lung also accumulate CO_2 diffusing into the alveoli from the mixed venous blood. The result of decreasing VA/Q (moving to the left along the VA/Q line) on alveolar Po_2 and Pco_2 is shown in the figure; that is, Po_2 decreases and Pco_2 increases.
TMP13 pp. 524-526

40. C) Because the blood that perfuses the pulmonary capillaries is venous blood returning to the lungs (i.e., mixed venous blood) from the systemic circulation, it is the gases in this blood with which the alveolar gases equilibrate. Therefore, when an airway is blocked, the alveolar air equilibrates with the mixed venous blood and the partial pressures of the gases in both the blood and alveolar air become identical.
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41. B) When the ventilation is reduced to zero ($V_A/Q = 0$), alveolar air equilibrates with the mixed venous blood entering the lung, which causes the gas composition of the alveolar air to become identical to that of the blood. This occurs at point A, where the alveolar PO_2 is 40 mm Hg and the alveolar PCO_2 is 45 mm Hg, as shown in the figure. A reduction in V_A/Q (caused by the partially obstructed airway in this problem) causes the alveolar PO_2 and PCO_2 to approach the values achieved when $V_A/Q = 0$.

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42. E) A pulmonary embolism decreases blood flow to the affected lung, causing ventilation to exceed blood flow. When the embolism completely blocks all blood flow to an area of the lung, the gas composition of the inspired air entering the alveoli equilibrates with blood trapped in the alveolar capillaries so that within a short time, the gas composition of the alveolar air is identical to that of inspired air. An increase in V_A/Q caused by the partially obstructed blood flow in this problem causes the alveolar PO_2 and PCO_2 to approach the values achieved when $V_A/Q = \infty$. The point at which V_A/Q is equal to infinity corresponds to point E in the figure (inspired gas).

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43. C) Breathing 100% O_2 has a limited effect on the arterial PO_2 when the cause of arterial hypoxemia is a vascular shunt. However, breathing 100% O_2 raises the arterial PO_2 to more than 600 mm Hg in a normal subject. With a vascular shunt, the arterial PO_2 is determined by (a) highly oxygenated end-capillary blood (PO_2 > 600 mm Hg) that has passed through ventilated portions of the lung, and (b) shunted blood that has bypassed the ventilated portions of the lungs and thus has an O_2 partial pressure equal to that of mixed venous blood (PO_2 = 40 mm Hg). A mixture of the two bloods causes a large fall in PO_2 because the O_2 dissociation curve is so flat in its upper range.

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44. D) The anatomic dead space (D_{ANAT}) is the air that a person breathes in that fills the respiratory passageways but never reaches the alveoli. Alveolar dead space (D_{ALV}) is the air in the alveoli that are ventilated but not perfused. Physiologic dead space (D_{PHY}) is the sum of D_{ANAT} and D_{ALV} (i.e., $D_{PHY} = D_{ANAT} + D_{ALV}$). The D_{ALV} is zero in lung unit S (the ideal lung unit), and the D_{ANAT} and D_{PHY} are thus equal to each other. The figure shows a group of alveoli with a poor blood supply (lung unit T), which means that the D_{ALV} is substantial. Thus, D_{PHY} is greater than either D_{ANAT} or D_{ALV} in lung unit T.

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45. E) The PO_2 of mixed venous blood entering the pulmonary capillaries is normally about 40 mm Hg, and the PO_2 at the venous end of the capillaries is normally equal to that of the alveolar gas (104 mm Hg). The PO_2 of the pulmonary blood normally rises to equal that of the alveolar air by the time the blood has moved a third of the distance through the capillaries, becoming almost 104 mm Hg. Thus, curve B represents the normal resting state. During exercise, the cardiac output can increase severalfold, but the pulmonary capillary blood still becomes almost saturated with O_2 during its transit through the lungs. However, because of the faster flow of blood through the lungs during exercise, the O_2 has less time to diffuse into the pulmonary capillary blood, and therefore the PO_2 of the capillary blood does not reach its maximum value until it reaches the venous end of the pulmonary capillaries. Although curves D and E both show that O_2 saturation of blood occurs near the venous end, note that only curve E shows a low PO_2 of 25 mm Hg at the arterial end of the pulmonary capillaries, which is typical of mixed venous blood during strenuous exercise.

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46. A) The PO_2 of mixed venous blood entering the pulmonary capillaries increases during its transit through the pulmonary capillaries (from 40 mm Hg to 104 mm Hg), and the PCO_2 decreases simultaneously from 45 mm Hg to 40 mm Hg. Thus, PO_2 is represented by the red lines and PCO_2 is represented by the green lines in the various diagrams. During resting conditions, O_2 has a 64 mm Hg pressure gradient (104 − 64 = 64 mm Hg), and CO_2 has a 5 mm Hg pressure gradient (45 − 40 = 5 mm Hg) between the blood at the arterial end of the capillaries and the alveolar air. Despite this large difference in pressure gradients between O_2 and CO_2, both gases equilibrate with the alveolar air by the time the blood has moved a third of the distance through the capillaries in the normal resting state (choice A). This is possible because CO_2 can diffuse about 20 times as rapidly as O_2.

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47. A) O_2 diffuses from the lung into the blood and is both dissolved and bound to Hb. In spite of having no red blood cells, the PO_2 would be normal as the O_2 is dissolved in the plasma. The content would be minimal, just due to the dissolved O_2 in the plasma.

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48. C) Pulmonary venous blood is nearly 100% saturated with O_2 and has a PO_2 of about 104 mm Hg, and each 100 milliliters of blood carries about 20 m/s of O_2 (i.e., O_2 content is about 20 vol%). Approximately 25% of the O_2 carried in the arterial blood is used by the tissues under resting conditions. Thus, reduced blood returning to the lungs is about 75% saturated with O_2, has a PO_2 of about 40 mm Hg, and has an O_2 content of about 15 vol%. Note that it necessary to know only one value for oxygenated and reduced blood and that the other two values requested in the question can be read from the O_2-Hb dissociation curve.

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49. C) Each gram of Hb can normally carry 1.34 milliliters of O_2. Hb = 12 g/dl. Arterial oxygen content = 12 × 1.34 = 16 ml O_2/dl. Using 12 ml O_2/dl yields a mixed venous saturation of 25%. With a saturation of 25%, the venous Po_2 should be close to 20 mm Hg.
TMP13 pp. 531-532

50. D) When a person is anemic, there is a decrease in O_2 content. The O_2 saturation of Hb in the arterial blood and the arterial O_2 partial pressure are not affected by the Hb concentration of the blood.
TMP13 pp. 530-531

51. A) The respiratory area of the medulla controls all aspects of respiration, so a destruction of this area would cause a cessation of breathing.
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52. E) CO combines with Hb at the same point on the Hb molecule as O_2 and therefore can displace O_2 from the Hb, reducing the O_2 saturation of Hb. Because CO binds with Hb (to form carboxyhemoglobin) with about 250 times as much tenacity as O_2, even small amounts of CO in the blood can severely limit the O_2-carrying capacity of the blood. The presence of carboxyhemoglobin also shifts the O_2 dissociation curve to the left (which means that O_2 binds more tightly to Hb), which further limits the transfer of O_2 to the tissues.
TMP13 pp. 531, 533

53. B) In exercise, several factors shift the O_2-Hb curve to the right, which serves to deliver extra amounts of O_2 to the exercising muscle fibers. These factors include increased quantities of CO_2 released from the muscle fibers, increased H^+ concentration in the muscle capillary blood, and increased temperature resulting from heat generated by the exercising muscle. The right shift of the O_2-Hb curve allows more O_2 to be released to the muscle at a given O_2 partial pressure in the blood.
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54. C) Structural differences between fetal Hb and adult Hb make fetal Hb unable to react with 2,3 diphosphoglycerate (2,3-DPG) and thus to have a higher affinity for O_2 at a given Po_2. The fetal dissociation curve is thus shifted to the left relative to the adult curve. Typically, fetal arterial O_2 pressures are low, and hence the leftward shift enhances the placental uptake of O_2.
TMP13 pp. 531-532

55. B) Tissue Po_2 is a balance between delivery and usages. When a decrease in blood flow occurs with no change in metabolism, there will be a decrease in venous Po_2 (less delivery but no change in metabolism) and an increase in venous Pco_2 (less washout).
TMP13 pp. 528-529

56. D) CO_2 is the major controller of respiration as a result of a direct effect of H^+ on the chemosensitive area of the medulla. H^+ do not cross the blood-brain barrier. Thus, CO_2 diffuses across the blood-brain barrier and then is converted to H^+, which acts on the chemosensitive area. CO_2 and H^+ activation of carotid bodies is minimal under normal conditions.
TMP13 pp. 541-542

57. D) The pneumotaxic center transmits signals to the dorsal respiratory group that "switch off" inspiratory signals, thus controlling the duration of the filling phase of the lung cycle. This has a secondary effect of increasing the rate of breathing because limitation of inspiration also shortens expiration and the entire period of respiration.
TMP13 pp. 539-540

58. E) The basic rhythm of respiration is generated in the dorsal respiratory group of neurons, which is located almost entirely within the nucleus of the tractus solitarius. When the respiratory drive for increased pulmonary ventilation becomes greater than normal, respiratory signals spill over into the ventral respiratory neurons, causing the ventral respiratory area to contribute to the respiratory drive. However, neurons of the ventral respiratory group remain almost totally inactive during normal quiet breathing.
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59. C) The respiratory exchange ratio (R) is equal to the rate of CO_2 output divided by the rate of O_2 uptake. A value of 0.8 therefore means that the amount of CO_2 produced by the tissues is 80% of the amount of O_2 used by the tissues, which also means that the amount of CO_2 transported from the tissues to the lungs in each 100 milliliters of blood is 80% of the amount of O_2 transported from the lungs to the tissues in each 100 milliliters of blood. Choice C is the only answer in which the ratio of CO_2 to O_2 is 0.8 (4/5 = 0.8). Although R changes under different metabolic conditions, ranging from 1.00 in those who consume carbohydrates exclusively to 0.7 in those who consume fats exclusively, the average value for R is close to 0.8.
TMP13 p. 535

60. F) Dissolved CO_2 combines with water in red blood cells to form carbonic acid, which dissociates to form bicarbonate and H^+ ions. Many of the bicarbonate ions diffuse out of the red blood cells, whereas chloride ions diffuse into the red blood cells to maintain electrical neutrality. The phenomenon, called the chloride shift, is made possible by a special bicarbonate-chloride carrier protein in the red blood cell membrane that shuttles the ions in opposite directions. Water moves into the red blood cells to maintain osmotic equilibrium, which results in a slight swelling of the red blood cells in the venous blood.
TMP13 pp. 534-535

61. D) The Hering-Breuer reflex mechanoreceptors are located in the bronchi and bronchioles and respond to increased stretch to limit respiration.
TMP13 p. 540

62. C) This patient would have increased VA, therefore resulting in a decrease in arterial P_{CO_2}. The effect of this decrease in P_{CO_2} would be an inhibition of the chemosensitive area and a decrease in ventilation until P_{CO_2} was back to normal. Breathing high O_2 does not decrease nerve activity sufficient to decrease respiration. The response of peripheral chemoreceptors to CO_2 and pH is mild and does not play a major role in the control of respiration.
TMP13 pp. 541-543

63. F) A person with constricted lungs has a reduced TLC and RV. Because the lung cannot expand to a normal size, the MEF cannot equal normal values.
TMP13 p. 550

64. F) VA can increase by more than eightfold when the arterial CO_2 tension is increased over a physiological range from about 35 to 75 mm Hg. This demonstrates the tremendous effect that CO_2 changes have in controlling respiration. By contrast, the change in respiration caused by changing the blood pH over a normal range from 7.3 to 7.5 is more than 10 times less effective.
TMP13 p. 542

65. D) The arterial O_2 tension has essentially no effect on VA when it is higher than about 100 mm Hg, but ventilation approximately doubles when the arterial O_2 tension falls to 60 mm Hg and can increase as much as fivefold at very low O_2 tensions. This quantitative relationship between arterial O_2 tension and VA was established in an experimental setting in which the arterial CO_2 tension and pH were held constant. The student can imagine that the ventilatory response to hypoxia would be blunted if the CO_2 tension were permitted to decrease.
TMP13 p. 543

66. B) In a normal person the alveolar gases are the same as the arterial blood. With rebreathing, the exhaled CO_2 is never removed and continues to accumulate in the bag. This increase in alveolar and thus arterial P_{CO_2} will be the stimulus for the increased breathing. The alveolar P_{O_2} will be decreased, not increased, with the decreased P_{O_2} stimulating breathing. A decreased P_{CO_2} will not stimulate ventilation. An increased pH, alkalosis, will not stimulate ventilation.
TMP13 pp. 541-543

67. A) Because strenuous exercise does not significantly change the mean arterial P_{O_2}, P_{CO_2}, or pH, it is unlikely that these play an important role in stimulating the immense increase in ventilation. Although the mean venous P_{O_2} decreases during exercise, the venous vasculature does not contain chemoreceptors that can sense P_{O_2}. The brain, upon transmitting motor impulses to the contracting muscles, is believed to transmit collateral impulses to the brain stem to excite the respiratory center. Also, the movement of body parts during exercise is believed to excite joint and muscle proprioceptors that then transmit excitatory impulses to the respiratory center.
TMP13 pp. 546-547

68. E) It is remarkable that the arterial P_{O_2}, P_{CO_2}, and pH remain almost exactly normal in a healthy athlete during strenuous exercise despite the 20-fold increase in O_2 consumption and CO_2 formation. This interesting phenomenon begs the question: What is it during exercise that causes the intense ventilation?
TMP13 pp. 546-547

69. D) A person with emphysema has an increase in airway resistance, a decrease in diffusing capacity (affecting gas exchange), an abnormal V/Q ratio (possible shunt), and a loss of large portions of the alveolar walls and capillaries. This loss of capillaries leads to an increase in pulmonary vascular resistance and the development of pulmonary hypertension.
TMP13 pp. 551-552

70. B) The basic mechanism of Cheyne-Stokes breathing can be attributed to a buildup of CO_2 that stimulates overventilation, followed by a depression of the respiratory center because of a low P_{CO_2} of the respiratory neurons. It should be clear that the greatest depth of breathing occurs when the neurons of the respiratory center are exposed to the highest levels of CO_2 (point W). This increase in breathing causes CO_2 to be blown off, and thus the P_{CO_2} of the lung blood is at its lowest value at about point Y in the figure. The P_{CO_2} of the pulmonary blood gradually increases from point Y to point Z, reaching its maximum value at point V. Thus, it is the phase lag between the P_{CO_2} at the respiratory center and the P_{CO_2} of the pulmonary blood that leads to this type of breathing. The phase-lag often occurs with left heart failure due to enlargement of the left ventricle, which increases the time required for blood to reach the respiratory center. Another cause of Cheyne-Stokes breathing is increased negative feedback gain in the respiratory control areas, which can be caused by head trauma, stroke, and other types of brain damage.
TMP13 pp. 546-548

71. D) The FVC is equal to the difference between the TLC and the RV. The TLC and RV are the points of intersection between the abscissa and flow-volume curve; that is, TLC = 5.5 liters and RV = 1.0 liter. Therefore, FVC = 5.5 − 1.0 = 4.5 liters.
TMP13 p. 550

72. D) The MEFV curve is created when a person inhales as much air as possible (point A, total lung capacity = 5.5 liters) and then expires the air with a maximum effort until no more air can be expired (point E, residual volume = 1.0 liter). The descending portion of the curve indicated by the downward pointing arrow represents the MEF at each lung volume. This descending portion of the curve is sometimes referred to as the "effort-independent" portion of the curve because the patient cannot increase expiratory flow rate to a higher level even when a greater expiratory effort is expended.
TMP13 p. 550

73. B) In obstructive diseases such as emphysema and asthma, the MEFV curve begins and ends at abnormally high lung volumes, and the flow rates are lower than normal at any given lung volume. The curve may also have a scooped out appearance, as shown in the figure. The other diseases listed as answer choices are constricted lung diseases (often called restrictive lung diseases). Lung volumes are lower than normal in constricted lung diseases.
TMP13 p. 550

74. A) Asbestosis is a constricted lung disease characterized by diffuse interstitial fibrosis. In constricted lung disease (more commonly called restrictive lung disease), the MEFV curve begins and ends at abnormally low lung volumes, and the flow rates are often higher than normal at any given lung volume, as shown in the figure. Lung volumes are expected to be higher than normal in asthma, bronchospasm, emphysema, old age, and in other instances in which the airways are narrowed or radial traction of the airways is reduced, allowing them to close more easily.
TMP13 p. 550

75. B) The figure shows that a maximum respiratory effort is needed during resting conditions because the MEF rate is achieved during resting conditions. It should be clear that his ability to exercise is greatly diminished. The man has smoked for 60 years and is likely to have emphysema. Therefore, the student can surmise that the TLC, FRC, and RV are greater than normal. The VC is only about 3.4 liters, as shown in the figure.
TMP13 pp. 550-551

76. A) The FVC is the VC measured with a forced expiration. The FEV_1 is the amount of air that can be expelled from the lungs during the first second of a forced expiration. The FEV_1/FVC for the normal individual (curve X) is 4 L/5 L = 80% and 2 L/4 L = 50% for the patient (curve Z). The FEV_1/FVC ratio has diagnostic value for differentiating between normal, obstructive, and constricted patterns of a forced expiration.
TMP13 p. 551

77. E) The FVC is the VC measured with a forced expiration. The FEV_1 is the amount of air that can be expelled from the lungs during the first second of a forced expiration. The FEV_1/FVC ratio for the healthy individual (X) is 4 L/5 L = 80%; FEV_1/FVC for patient Z is 3.0/3.5 = 86%. FEV_1/FVC is often increased in silicosis and other diseases characterized by interstitial fibrosis because of increased radial traction of the airways; that is, the airways are held open to a greater extent at any given lung volume, reducing their resistance to air flow. Airway resistance is increased (and therefore FEV_1/FVC is decreased) in asthma, bronchospasm, emphysema, and old age.
TMP13 p. 551

78. D) With consolidated pneumonia, the lung is filled with fluid and cellular debris, which results in a decreased area for diffusion. In addition, the V/Q ratio is decreased, which will lead to hypoxia (decreased Po_2 and content) and hypercapnia (increased Pco_2).
TMP13 pp. 552-553

79. D) With atelectasis of one lung, a collapse of the lung tissue occurs, which increases the resistance to blood flow. In addition, the hypoxia in the collapsed lung causes an additional vasoconstriction. The net effect is to shift blood to the opposite, ventilated lung, resulting in the majority of flow in the ventilated lung. A slight compromise in V/Q ratio will occur. With minimal changes in the V/Q ratio, there will be minimal changes in Po_2 and Pco_2. Thus there should be a slight decrease in arterial Po_2 and a slight decrease in saturation and content.
TMP13 p. 553

80. B) The loss of alveolar walls with destruction of associated capillary beds in the emphysematous lung reduces the elastic recoil and increases the compliance. The student should recall that compliance is equal to the change in lung volume for a given change in transpulmonary pressure; that is, compliance is equal to the slopes of the volume-pressure relationships shown in the figure. Asbestosis, silicosis, and tuberculosis are associated with deposition of fibrous tissue in the lungs, which decreases the compliance. Mitral obstruction and rheumatic heart disease can cause pulmonary edema, which also decreases the pulmonary compliance.
TMP13 p. 499

81. C) Curve X represents heavy exercise with a VT of about 3 liters. Note that the expiratory flow rate has reached a maximum value of nearly 4.5 L/sec during the heavy exercise. This effect occurred because a maximum expiratory air flow is required to move the air through the airways with the high ventilatory frequency associated with heavy exercise. Normal breathing at rest is represented by curve Z; note that the VT

is less than 1 liter during resting conditions. Curve Y was recorded during mild exercise. An asthma attack or aspiration of meat would increase the resistance to air flow from the lungs, making it unlikely that expiratory air flow rate could approach its maximum value at a given lung volume. The VT should not increase greatly with pneumonia or tuberculosis, and it should not be possible to achieve a maximum expiratory air flow at a given lung volume with these diseases.
TMP13 pp. 550-551

82. C) A premature infant with respiratory distress syndrome has absent or reduced levels of surfactant. Loss of surfactant creates a greater surface tension. Because surface tension accounts for a large portion of lung elasticity, increasing surface tension will increase lung elasticity, making the lung stiffer and less compliant.
TMP13 p. 553

83. C) Asbestosis is associated with deposition of fibrous material in the lungs, which causes the pulmonary compliance (i.e., distensibility) to decrease and the elastic recoil to increase. Pulmonary compliance and elastic recoil change in opposite directions because compliance is proportional to 1/elastic recoil. It is somewhat surprising to learn that the elastic recoil of a rock is greater than the elastic recoil of a rubber band; that is, the more difficult it is to deform an object, the greater the elastic recoil of the object. The TLC, FRC, RV, and VC are decreased in all types of fibrotic lung disease.
TMP13 p. 499

84. E) Loss of lung tissue in emphysema leads to an increase in the compliance of the lungs and a decrease in the elastic recoil of the lungs. Pulmonary compliance and elastic recoil always change in opposite directions; that is, compliance is proportional to 1/elastic recoil. The TLC, RV, and FRC are increased in emphysema, but the VC is decreased.
TMP13 p. 499

85. C) There was an increase in P_{O_2}, but not to normal levels. The increase in P_{CO_2} means that the V_A decreased. In this patient the V_A was driven by the decreased O_2 levels. If P_{CO_2} increased, there is no increased pulmonary excretion of CO_2.
TMP13 pp. 541-542, 551-552

86. D) Diffusing capacity is directly related to alveolar surface area. It increases during exercise due to opening of capillaries and better V/Q match. The diffusing capacity of CO_2 is 20 times that of O_2. When one goes to a high altitude, an opening of blood vessels and alveoli occurs to increase the diffusion of O_2, resulting in an increased diffusing capacity.
TMP13 pp. 523-525

87. B) Total lung capacity and MEF are reduced in restrictive lung disease.
TMP13 p. 550