Chapter 16 Outline

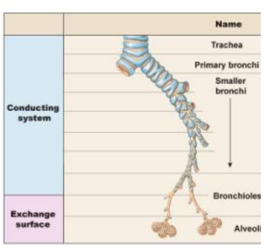
Respiration

- Encompasses 3 related functions: ventilation, gas exchange, and O_2 utilization (cellular respiration)

1. Ventilation moves air in and out of lungs for gas exchange with blood (external respiration)
2. Gas exchange between blood and tissues, and O_2 use by tissues is internal respiration
3. Gas exchange is passive via diffusion

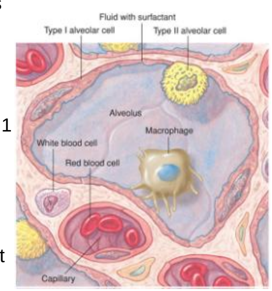
Structure of Respiratory System

- Gas exchange occurs only in respiratory bronchioles and alveoli (= respiratory zone)
- All other structures constitute the conducting zone



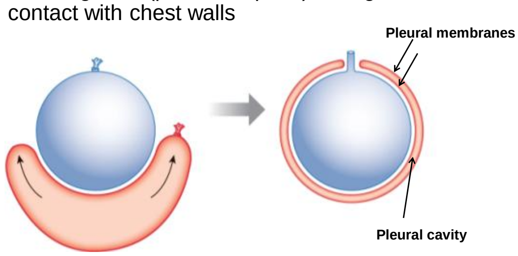
Structure of Respiratory System

- Gas exchange occurs across 300 million alveoli
  - (60-80 m^2 total surface area)
- 2 thin cells are between lung air and blood: 1 alveolar and 1 endothelial cell
- Alveolar cells
  - Type 1: Most numerous
  - Type 2: Secrete surfactant



Thoracic Cavity

- Intrapleural space fluid layer between visceral pleura and parietal pleura
- Stick together (potential space) – lungs remain in contact with chest walls

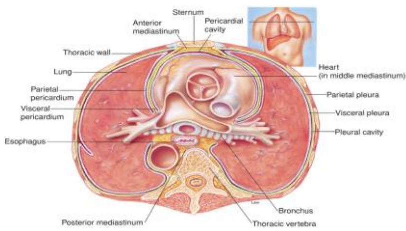


Physical Aspects of Ventilation

- Ventilation results from pressure differences induced by changes in lung volumes
  - Air moves from higher to lower pressure
  - Compliance, elasticity, and surface tension of lungs influence ventilation

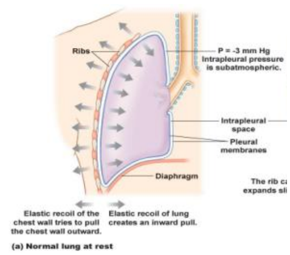
Intrapulmonary and Intrapleural Pressures

- Intrapulmonar pressure: pressure within lungs
- Intrapleural pressure: pressure in intraplural space
- Intrapulmonary – Intrapleural = Transpleural pressure



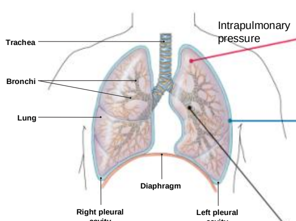
Intrapulmonary and Intrapleural Pressures

- **Intrarapulmonary pressure** is about -3 mm Hg pressure (subatmospheric)
  - Fluid keeps lung adhered to chest
  - Recoil of lung creates inward pull
    - = negative intraplueral pressure
- During inspiration Intrapulmonary pressure decreases further



During expiration:
- Lungs allowed to recoil and intrapulmonary pressure decreases

Pressure Changes During Quiet Breathing



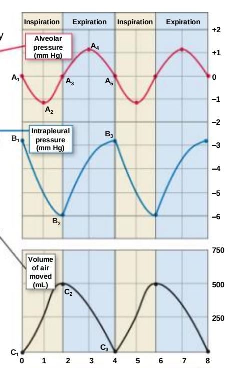


Figure 17-11

Positive transpulmonary pressure (difference across wall of lung) keeps lungs inflated)
- i.e., intrapleural is always less than intrapulmonary!!
- i.e., lungs kept against chest wall

Because intraplueral is always less than Intrapulmonary pressure

Compliance, elasticity, and surface tension of lungs influence ease of ventilation

Compliance
- How easily lung expands with pressure
- Reduced by factors that cause resistance to distension

Elasticity
- Tendency to return to initial size after distension
- elastin proteins!!!
- Tension increases during inspiration - reduced by recoil during expiration
  - There is always some elastic tension!

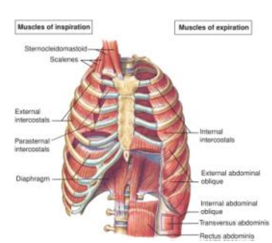
Airway Diameter also influences Airway resistance!

Surface Tension (ST)

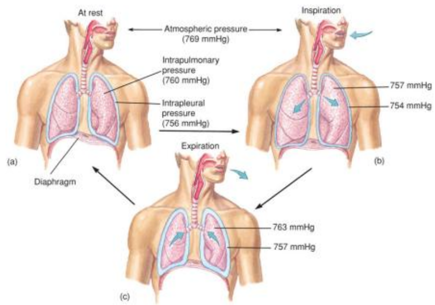
- Promotes alveolar collapse - resists distension (expansion)
- Lungs secrete and absorb fluid, normally leaving a thin film of fluid on alveolar surface
  - Film causes ST because H_20 molecules are attracted to other H_2O molecules
  - Thus, ST acts to collapse alveoli;
    - increasing pressure of air within alveoli
- But Phospholipids secreted by Type II alveolar cells lowers ST by getting between H_2O molecules

Mechanics of Breathing:

- Quiet Inspiration
  - diaphragm
  - external intercostals & parasternal intercostals
- Quiet Expiration = passive recoil
- Deep inhalation - add
  - scalenes, pectoralis minor, and sternocleidomastoid
- Deep exhalation
  - internal intercostals, abdominals

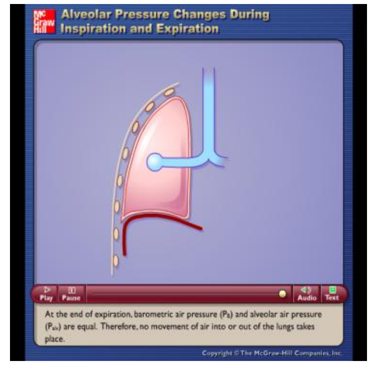


Mechanics of Pulmonary Ventilation



Boyle's Law (P = 1/V)

16-28



Partial Pressure of Gases

- Partial pressure is pressure that a particular gas in a mixture exerts independently
- Dalton's Law: total pressure of a gas mixture is the sum of partial pressures of each gas in mixture
- Atmospheric pressure at sea level is 760 mm Hg
  - $\mathbf{P_{ATM} = P_{N2} + P_{O2} + P_{CO2} + P_{H_2O}}$ = 760 mm Hg
    - H_2O vapor decreases pressures of other gases

16-41

Partial Pressure of gases in lungs

- **Influence of H_2O – changes Partial Pressures**
- **Fully saturated air has a P_{O_2} = 47 mmHg**
- **Low alveolar P_{O_2} decreases O_2 uptake**
- **Low blood flow to aveoli decreases O_2 uptake**

	Inspired air	Alveolar air
H_2O	Variable	47 mmHg
CO_2	000.3 mmHg	40 mmHg
O_2	159 mmHg	105 mmHg
N_2	601 mmHg	568 mmHg
Total pressure	760 mmHg	760 mmHg

16-42

Gas solubility Affects Diffusion

- Movement of gas molecules from air into liquid depend on:
  - 1. Pressure gradient of the gas
  - 2. Solubility of the gas in the liquid (how easy it diffuses into liquid)
  - 3. Temperature (which is largely constant)

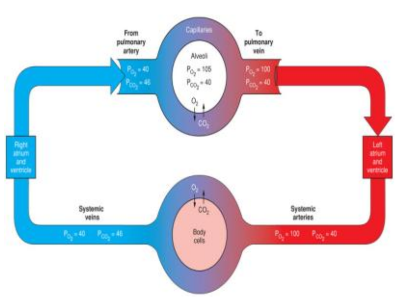
O_2 is not very soluble – thus little is dissolved in plasma – it doesn't have time in alveolar caps to come to equilibrium before blood has left

Compare CO2 – 20X more soluble than O_2!

16-44

Gases diffuse down concentration gradients

- normal arterial blood has about $\mathbf{P_{O2}}$= 100mmHg
- $\mathbf{P_{O2}}$ = 40mmHg in systemic veins
- $\mathbf{P_{CO2}}$ = 46mmHg in systemic veins



CO_2 soluability is 20 x greater than O_2 (i.e., despite much lower partial pressure of CO_2 equal amounts of 2 gases are exchanged

16-45

Pulmonary Circulation

- Rate of blood flow through pulmonary circuit equals flow through systemic circulation
  - Pumped at lower pressure (about 15 mm Hg)
  - Pulmonary vascular resistance is low!
  - Low pressure produces less net filtration than in systemic capillaries
- Pulmonary arterioles constrict where alveolar P_{O_2} is low and dilate where its high!!
  - This matches ventilation to perfusion (blood flow)

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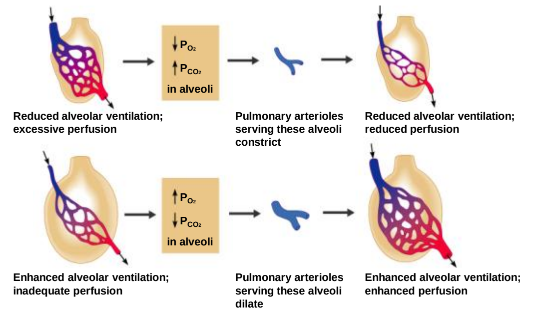

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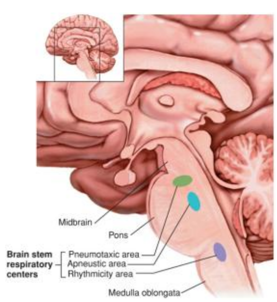
Regulation of Breathing: Brain Stem Respiratory Centers

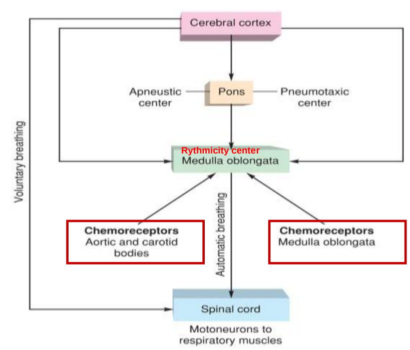
- Automatic breathing is generated by a rhythmicity center in medulla oblongata
  - Dorsal/Ventral Respiratory groups
  - Inspiratory neurons stimulate nerves that innervate respiratory muscles
  - Expiration occurs when expiratory neurons inhibit phrenic nerve
  - Pacemaker cells



Apneustic area Stimulates inspiratory neurons of medulla
Pnueumotaxic area (pontine respiratory group)– inhibits inspiratory neurons of medulla

16-51

CNS Control of Breathing



16-55

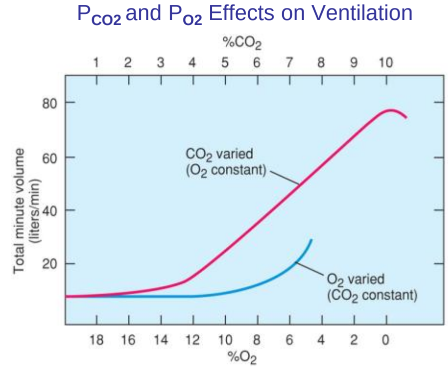
Effects of Blood P_{CO_2} and pH on Ventilation

- Chemoreceptors modify ventilation to maintain homeostasis of **CO_2**, O_2, and pH levels
  - P_{CO_2} is most crucial because of its effects on blood pH
    - **$H_2O + CO_2 \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^-$**

      Carbonic Acid **Bicarbonate**
  - **Also,** P_{CO_2} (and H+) more influenced by breathing changes compared to O_2 because lots of "stored" O_2

16-56

P_{CO_2} and P_{O_2} Effects on Ventilation



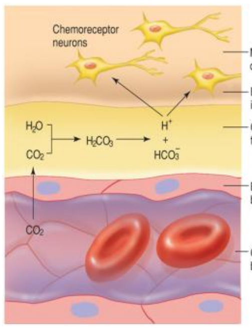
- Breathing rate increases with small increases in CO_2
- O_2 values must decrease by ½ before increased breathing occurs

16-61

Effects of Blood P_{CO2} and pH on Ventilation

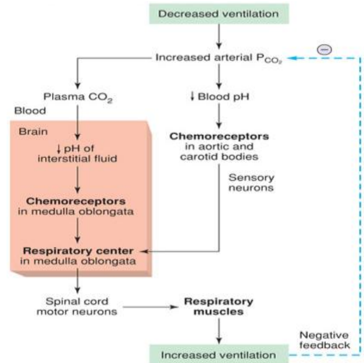
- Medulla oblongata chemoreceptors (central chemoreceptors) have effect on ventilation
- Monitor CO_2 – kind of!
  - H+ can't cross BBB but CO_2 can
  - Low pH causes in crease in breathing
  - Rate and depth of ventilation adjusted to maintain arterial **P_{CO2}** of ~40 mm Hg
- **Peripheral chemoreceptors**: respond to **PO2**, **P_{CO2}**, pH
  - aorta & corotid arteries

- Increase in P_{CO2} or decrease in O_2 or pH causes increased ventilation



16-58

Effects of Blood P_{CO2} and pH on Ventilation



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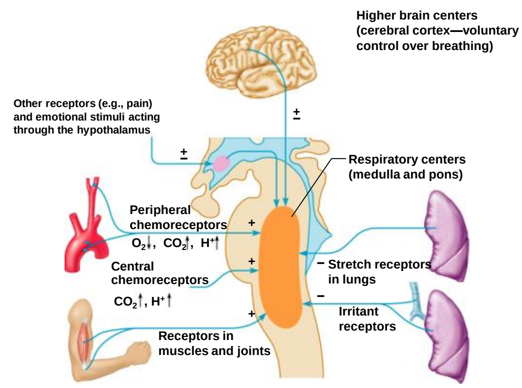
Pulmonary Receptors & Ventilation

- Lungs have receptors that influence brain respiratory control centers via sensory fibers in vagus nerve
- Unmyelinated C fibers stimulated by noxious substances such as capsaicin
  - Causes apnea followed by rapid, shallow breathing
- Irritant receptors are rapidly adapting; respond to smoke, smog, and particulates
  - Causes cough
- Stretch receptors activated during inspiration (Hering-Breuer reflex)
  - Inhibits respiratory centers to prevent over-inflation of lungs

16-62



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Hemoglobin (Hb) and O_2 Transport

- Loading of Hb with O_2 occurs in lungs; unloading in tissues
- Affinity of Hb for O_2 changes with a number of physiological variables
- Each RBC has about 280 million molecules of Hb
- Most O_2 in blood is bound to Hb inside RBCs as oxyhemoglobin
  - It's a week bond between O_2 and hemaglobin

1. Depends on the PO2 in plasma surrounding the red blood cells
2. Number of potential Hb binding sites available in red blood cells

16-65

Hemoglobin (Hb) and O_2 Transport

- In anemia, Hb levels are below normal
- In polycythemia, Hb levels are above normal

- Hb production controlled by erythropoietin (EPO)
  - Production stimulated by low P_{O_2} in kidneys

- High P_{O2} of lungs favors loading; low P_{O2} in tissues favors unloading

16-69

Oxhemaglobin

- Systemic arteries with P_{O2} of 100 mmHg have a percent oxhemaglobin of 97%
  - i.e., 97% of the hemaglobin is bonded to oxygen
    - i.e., 97% is in the form of oxyhemaglobin
- Blood leaving tissue capillaries is P_{O2} of 40 mmHg and has a percent oxyhemaglobin of ~75%.

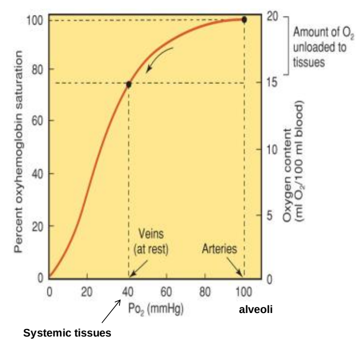
Key factor that drives bonding (and unbonding) is P_{O2}

- **Hemaglobin + O_2 ⟷ Oxyhemaglobin**
  - High P_{O2} = bonding O_2 to hemaglobin
  - Low P_{O2} = dissociation of oxyhemaglobin

16-69

Oxyhemoglobin Dissociation Curve

- Provides % of Hb that have bound O_2 at different P_{O2}s
- Reflects loading and unloading of O_2
- Where $\mathbf{P_{O2}}$ is high OxyHb occurs
- Where $\mathbf{P_{O2}}$ is low OxyHb dissociates
- In steep part of curve, small changes in $\mathbf{P_{O2}}$ cause big changes in % saturation of hemoglobin



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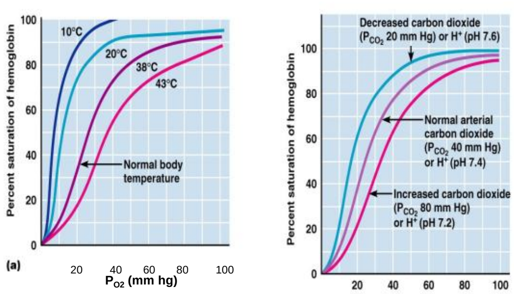
pH & temp. influence Hb-O_2 affinity



Shifting curve to right = lowers affinity of oxyhemaglobin bond - more likely to unload O_2

16-72

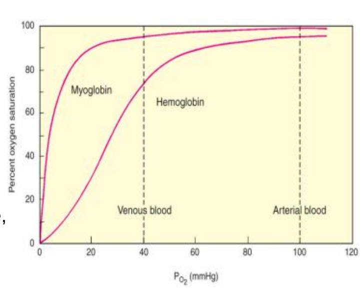
Another factor: Effect of 2,3 DPG on O_2 Transport

- RBCs have no mitochondria; can't perform aerobic respiration
- 2,3-DPG (2-3 disphosphoglyceric acid) is a byproduct of glycolysis in anaerobic respiration in RBCs
  - 2,3 DPG lowers affinity of Hb for O_2
  - i.e. high levels of 2,3 DPG increases unloading of O_2
- Enzyme that produces 2,3-DPG is inhibited by Oxyhemaglobin
  - i.e., Saturated Hb inhibits 2,3-DPG formation
  - i.e., 2,3-DPG formation production increased by low oxyhemaglobin
- High altitude & anemia increase 2,3 DPG production – lowers Hg affinity for $\mathbf{O_2}$

16-74

Myoglobin

- Has only 1 globin; binds only 1 O_2
- Has higher affinity for O_2 than Hb; is shifted to extreme left
- Releases O_2 only at low P_{O2}
- Serves as O_2 storage, in heart (systole) & skeletal muscles



16-79

CO_2 Transport

- CO_2 transported in blood

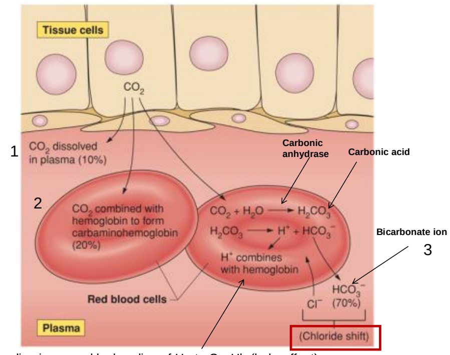
1. dissolved CO_2 (10%)
2. carbaminohemoglobin (20%)
3. bicarbonate ion, HCO_3^-, (70%)

- In RBCs **carbonic anhydrase** catalyzes formation of $\mathbf{H_2CO_3}$ (carbonic acid) from $CO_2 + H_2O$

- $\mathbf{H_2O + CO_2 \leftrightarrow H_2CO_3}$

16-81

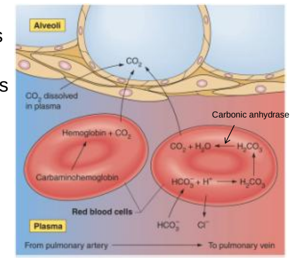
CO2 transport in Blood

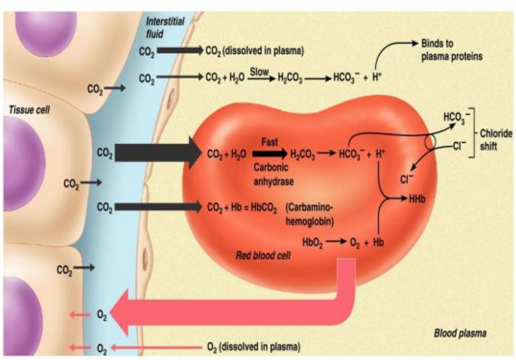


O₂ unloading increased by bonding of H+ to OxyHb (bohr affect)

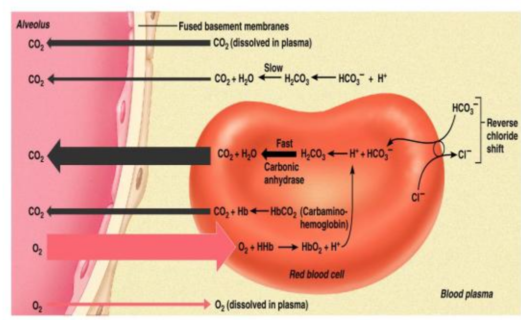
Reverse Chloride Shift

- **In lungs**, $CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^-$, moves to left as CO_2 is breathed out
- Binding of O_2 to Hb decreases its affinity for H+
  - H+ combines with HCO_3^- and more CO_2 is formed
- Cl- diffuses down concentration and charge gradient out of RBC (reverse chloride shift)





(a) Oxygen release and carbon dioxide pickup at the tissues

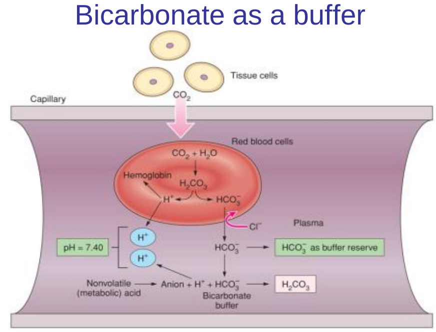


(b) Oxygen pickup and carbon dioxide release in the lungs

Acid-Base Balance of the Blood

- Blood pH is maintained within narrow pH range by lungs and kidneys (normal = 7.4)
- Most important buffer in blood is **bicarbonate**
  - $\mathbf{H_2O + CO_2 \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^-}$
  - Excess H^+ is buffered by HCO_3^-
- Kidney's role is to excrete H^+ into urine

Bicarbonate as a buffer



Acid-Base Balance of the Blood

- Acidosis is when pH < 7.35; alkalosis is pH > 7.45
- Respiratory acidosis caused by hypoventilation
  - Causes rise in blood CO_2 and thus carbonic acid
  - Hypoventilation causes high CO_2 (hypercapnia)
- Respiratory alkalosis caused by hyperventilation
- Results in too little CO_2
  - Hyperventilation causes low CO_2 (hypocapnia)

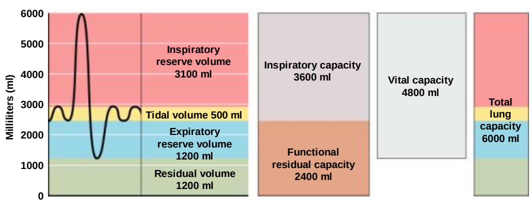
16-88

Ventilation and Acid-Base Balance

- Ventilation usually adjusted to metabolic rate to maintain normal CO_2 levels
- Hypoventilation: not enough CO_2 is removed from lungs
  - Acidity builds, causing respiratory acidosis
- Hyperventilation: too much CO_2 is removed
  - pH rises, causing respiratory alkalosis
  - Dizziness: decrease in CO_2 causes pH of CSF to increase = = alkadosis results in cerebral vascoconstrinction

16-91

Figure 22.16a: Respiratory volumes and capacities, p. 852.



(a) Spirographic record for a male

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