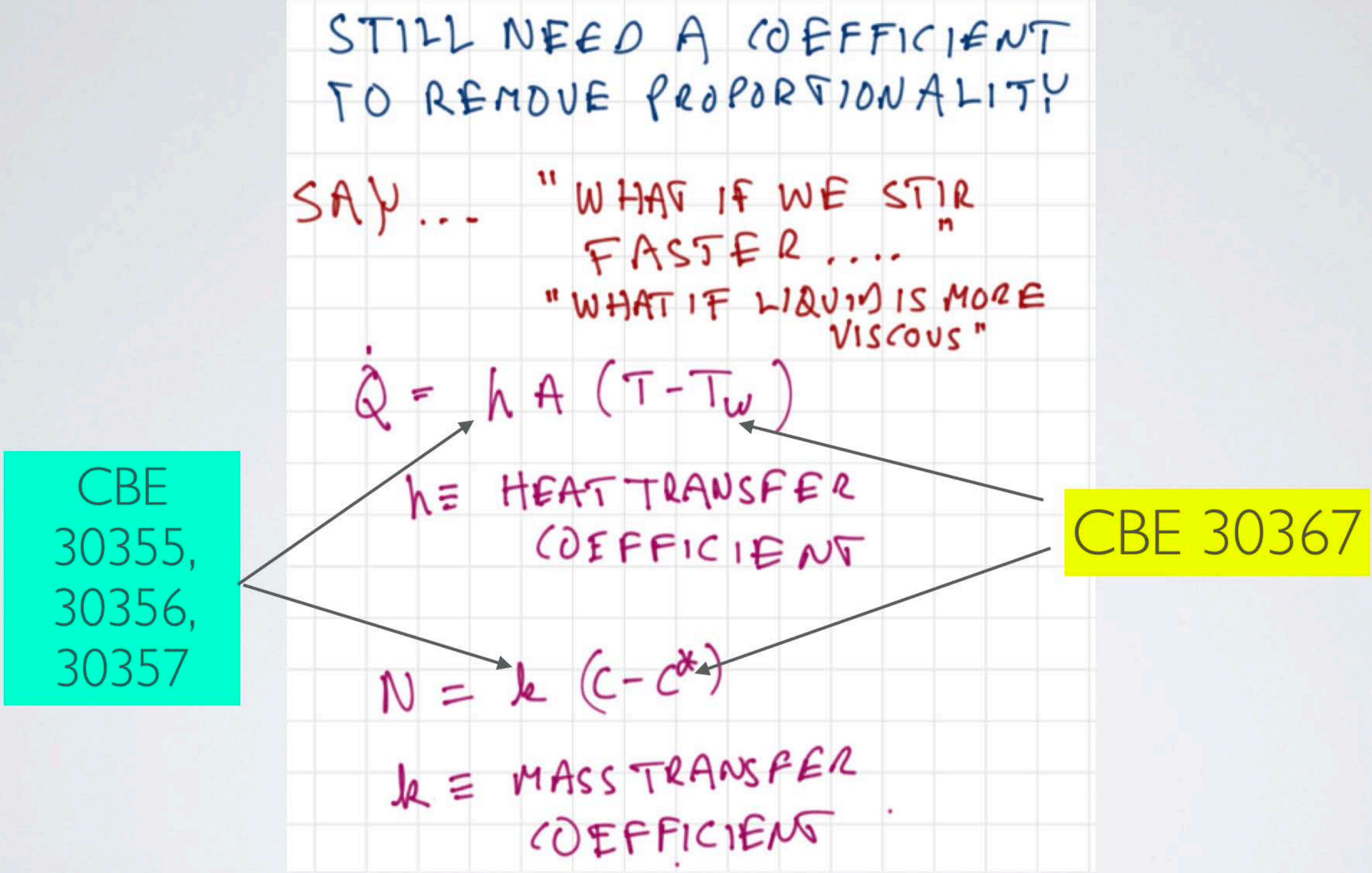
CBE 30357
BIOLOGICAL TRANSPORT PHENOMENA

8/24/2017
Lecture 2

HIGHLIGHTS FROM TUESDAY

- Transport phenomena is the collective study of momentum transfer, heat transfer and mass transfer within a coherent mathematical framework.
- Thermodynamics establishes what can happen, Transport Phenomena regulates how fast the change will occur.
- While new opportunities for chemical engineers are emerging, particularly in medicine and materials, we are not as hardwired in with major US companies as we were 30 years ago.

“NEWTON’S LAW OF COOLING



STILL NEED A COEFFICIENT TO REMOVE PROPORTIONALITY

SAY... "WHAT IF WE STIR FASTER...."

"WHAT IF LIQUID IS MORE VISCOUS"

$$\dot{Q} = h A (T - T_w)$$

h ≡ HEAT TRANSFER COEFFICIENT

$$N = k (C - C^*)$$

k ≡ MASS TRANSFER COEFFICIENT

CBE 30355, 30356, 30357

CBE 30367

“Greatest of all equations!”

SUMMARY FOR TODAY

- Show numerous examples where the subject is relevant
- Examine the particular case of oxygen solubility in blood

CONSERVATION OF MOMENTUM

- Momentum, is a vector quantity. We will thus have to deal with this.
- In terms of a full differential analysis, we will have 3 equations, one for each of the coordinate directions.
- This are "coupled" and nonlinear partial differential equations.
- We are engineers just learning the subject so we will approach the subject systematically with as much simplification as possible.

$\vec{p} \equiv$ momentum

NEWTON:

$$\frac{d\bar{p}}{dt} = \Sigma \vec{F}$$

$$\left(m\bar{a} = \Sigma \bar{F} \right)$$

$$\frac{D(\rho \vec{v})}{Dt} = \vec{\nabla} \cdot \vec{T}$$

$$\rho\left(\frac{\partial \vec{v}}{\partial t} + \vec{v} \cdot \vec{\nabla} \vec{v} \right) = \vec{\nabla} \cdot \vec{T}$$

NAVIER-STOKES EQUATIONS

Constant **μ** and **ρ**

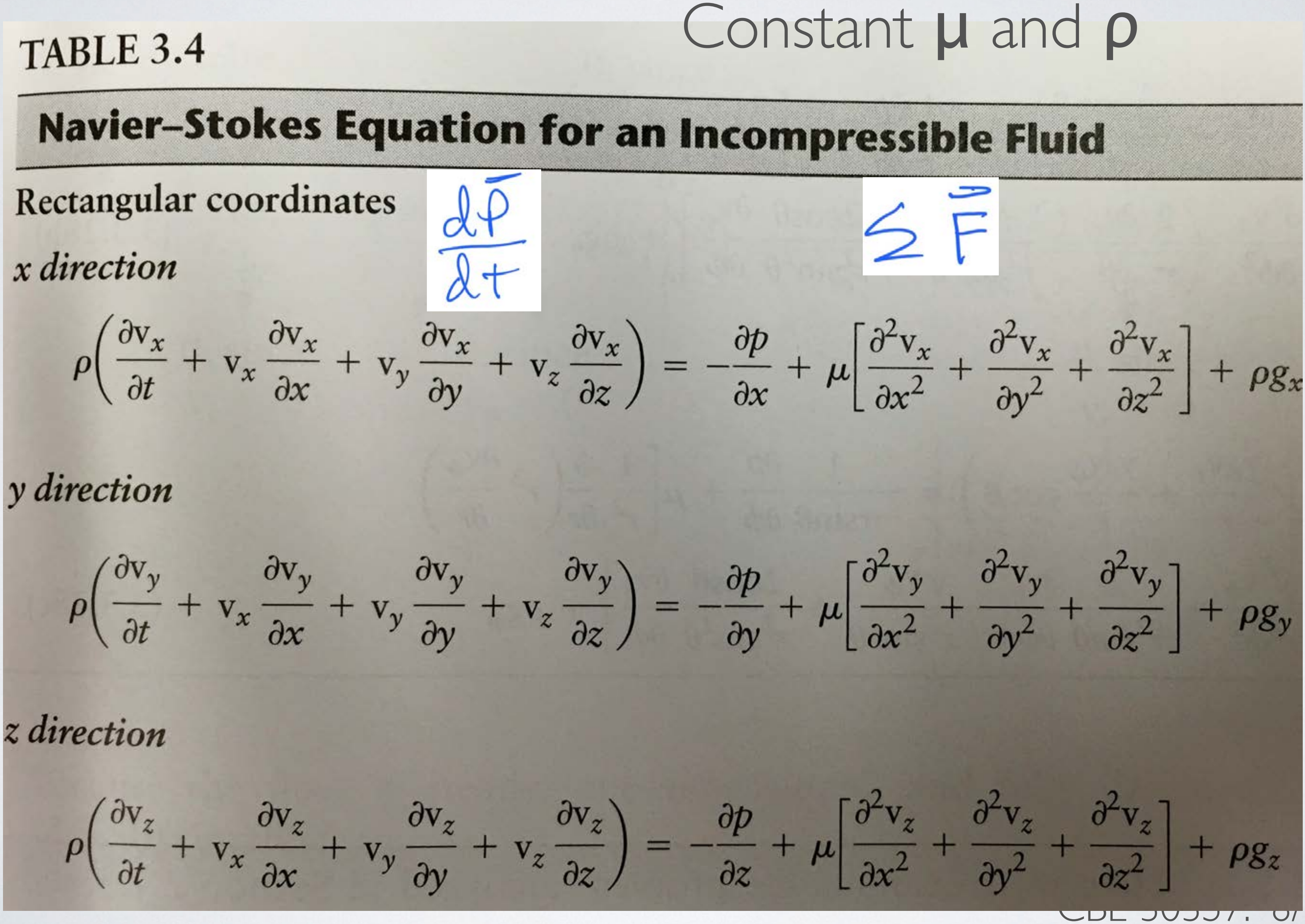


TABLE 3.4

Navier–Stokes Equation for an Incompressible Fluid

Rectangular coordinates

$\frac{d\bar{\rho}}{dt}$

$\Sigma \vec{F}$

x direction

$$\rho\left(\frac{\partial v_x}{\partial t} + v_x \frac{\partial v_x}{\partial x} + v_y \frac{\partial v_x}{\partial y} + v_z \frac{\partial v_x}{\partial z}\right) = -\frac{\partial p}{\partial x} + \mu\left[\frac{\partial^2 v_x}{\partial x^2} + \frac{\partial^2 v_x}{\partial y^2} + \frac{\partial^2 v_x}{\partial z^2}\right] + \rho g_x$$

y direction

$$\rho\left(\frac{\partial v_y}{\partial t} + v_x \frac{\partial v_y}{\partial x} + v_y \frac{\partial v_y}{\partial y} + v_z \frac{\partial v_y}{\partial z}\right) = -\frac{\partial p}{\partial y} + \mu\left[\frac{\partial^2 v_y}{\partial x^2} + \frac{\partial^2 v_y}{\partial y^2} + \frac{\partial^2 v_y}{\partial z^2}\right] + \rho g_y$$

z direction

$$\rho\left(\frac{\partial v_z}{\partial t} + v_x \frac{\partial v_z}{\partial x} + v_y \frac{\partial v_z}{\partial y} + v_z \frac{\partial v_z}{\partial z}\right) = -\frac{\partial p}{\partial z} + \mu\left[\frac{\partial^2 v_z}{\partial x^2} + \frac{\partial^2 v_z}{\partial y^2} + \frac{\partial^2 v_z}{\partial z^2}\right] + \rho g_z$$

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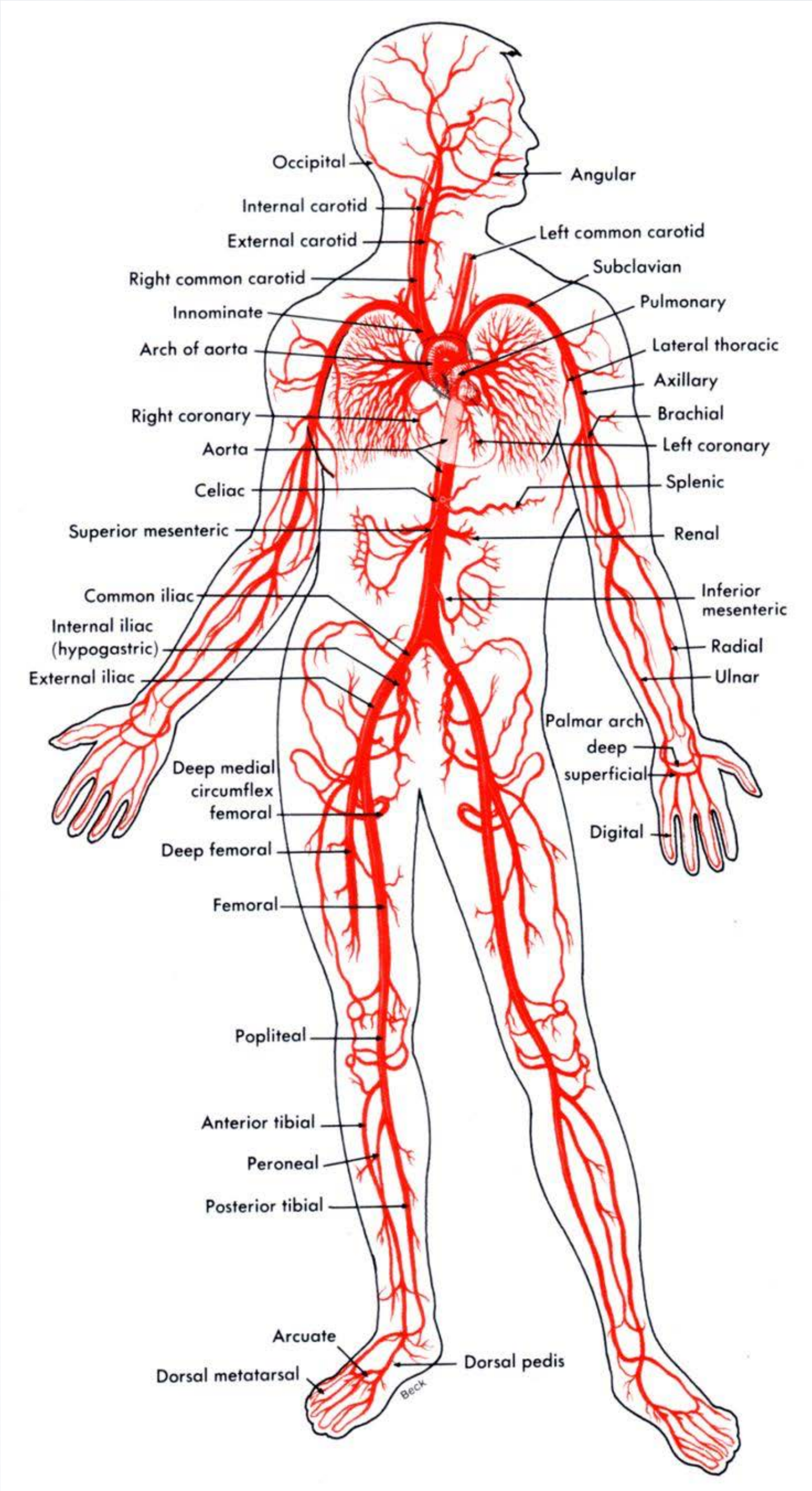
- Use these equations for flows of physiological, medical or biological interest
  - Blood flow
  - Air flow
  - Esophageal flows
  - Intestinal flows
  - Medical devices (heart-lung machine, various sensors and microfluidics)
  - Maybe a creature or two.

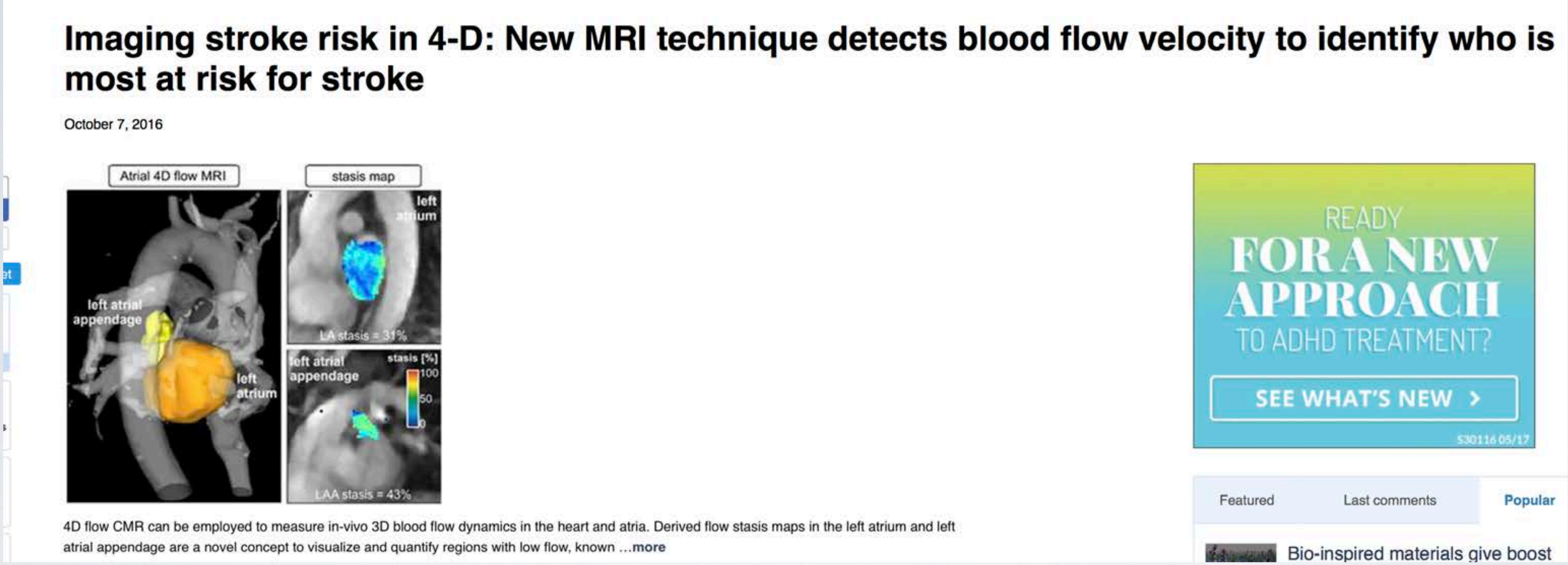
GLYMPHATIC SYSTEM

- https://www.youtube.com/watch?feature=player_embedded&v=ci5NMscKJws
- https://www.youtube.com/watch?v=VN3p3muXDgA
- https://www.youtube.com/watch?v=MJK-dMIATmM

BLOOD FLOW


Occipital
Internal carotid
External carotid
Right common carotid
Innominate
Arch of aorta
Right coronary
Aorta
Celiac
Superior mesenteric
Common iliac
Internal iliac (hypogastric)
External iliac
Deep medial circumflex femoral
Deep femoral
Femoral
Popliteal
Anterior tibial
Peroneal
Posterior tibial
Arcuate
Dorsal metatarsal
Angular
Left common carotid
Subclavian
Pulmonary
Lateral thoracic
Axillary
Brachial
Left coronary
Splenic
Renal
Inferior mesenteric
Radial
Ulnar
Palmar arch
deep
superficial
Digital
Dorsal pedis
Beck

BLOOD FLOW: STROKE RISK



Imaging stroke risk in 4-D: New MRI technique detects blood flow velocity to identify who is most at risk for stroke

October 7, 2016

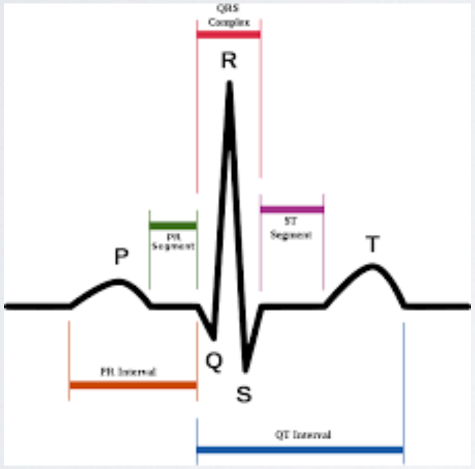
4D flow CMR can be employed to measure in-vivo 3D blood flow dynamics in the heart and atria. Derived flow stasis maps in the left atrium and left atrial appendage are a novel concept to visualize and quantify regions with low flow, known …more

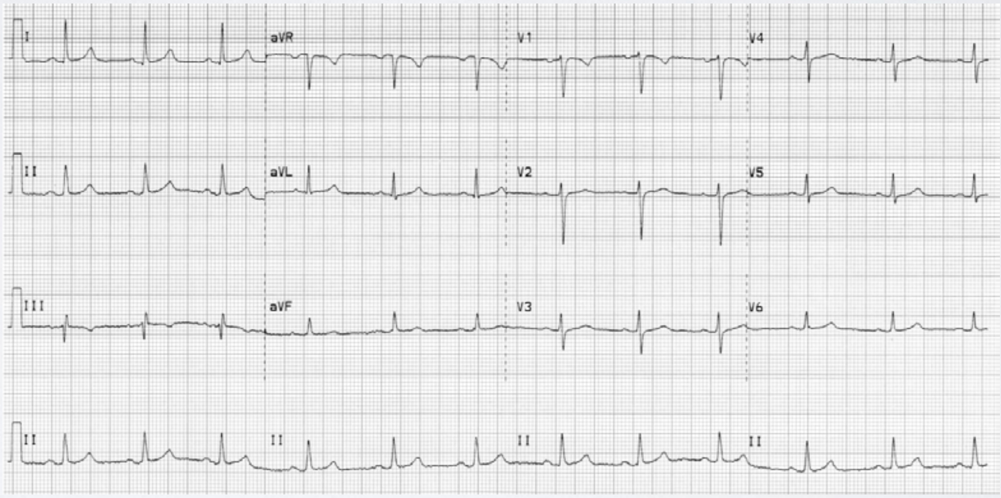
Bio-inspired materials give boost

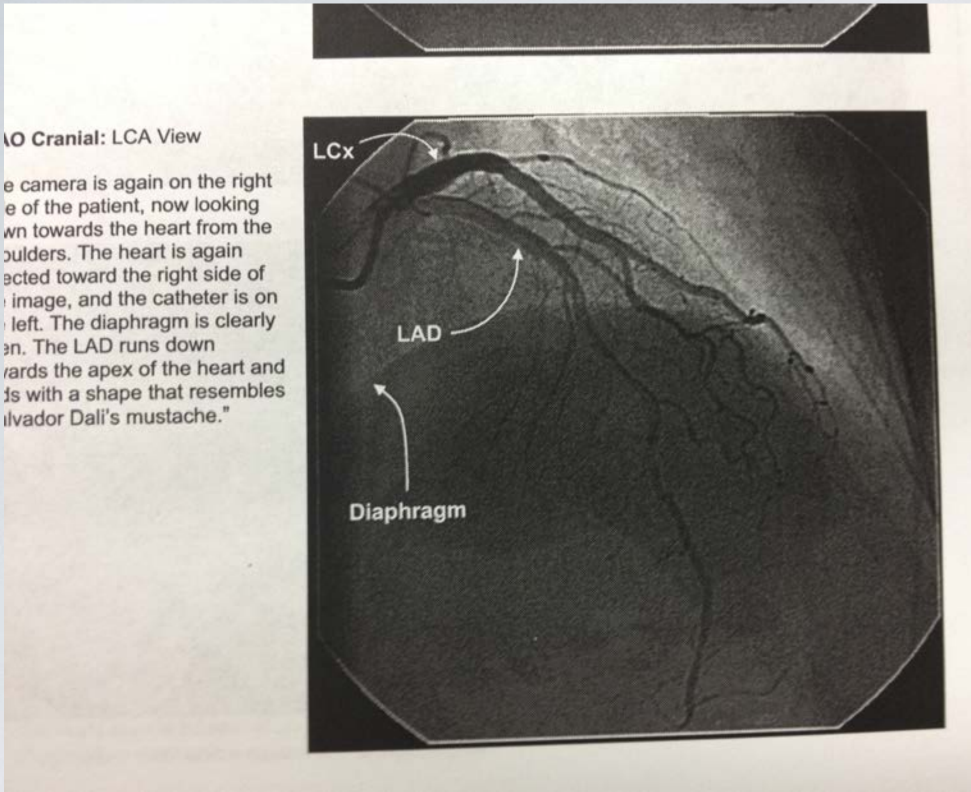
- https://medicalxpress.com/news/2016-10-imaging-d-mri-technique-blood.html

HEART PUMPING

- https://www.youtube.com/watch?v=oHMmtqKgs50

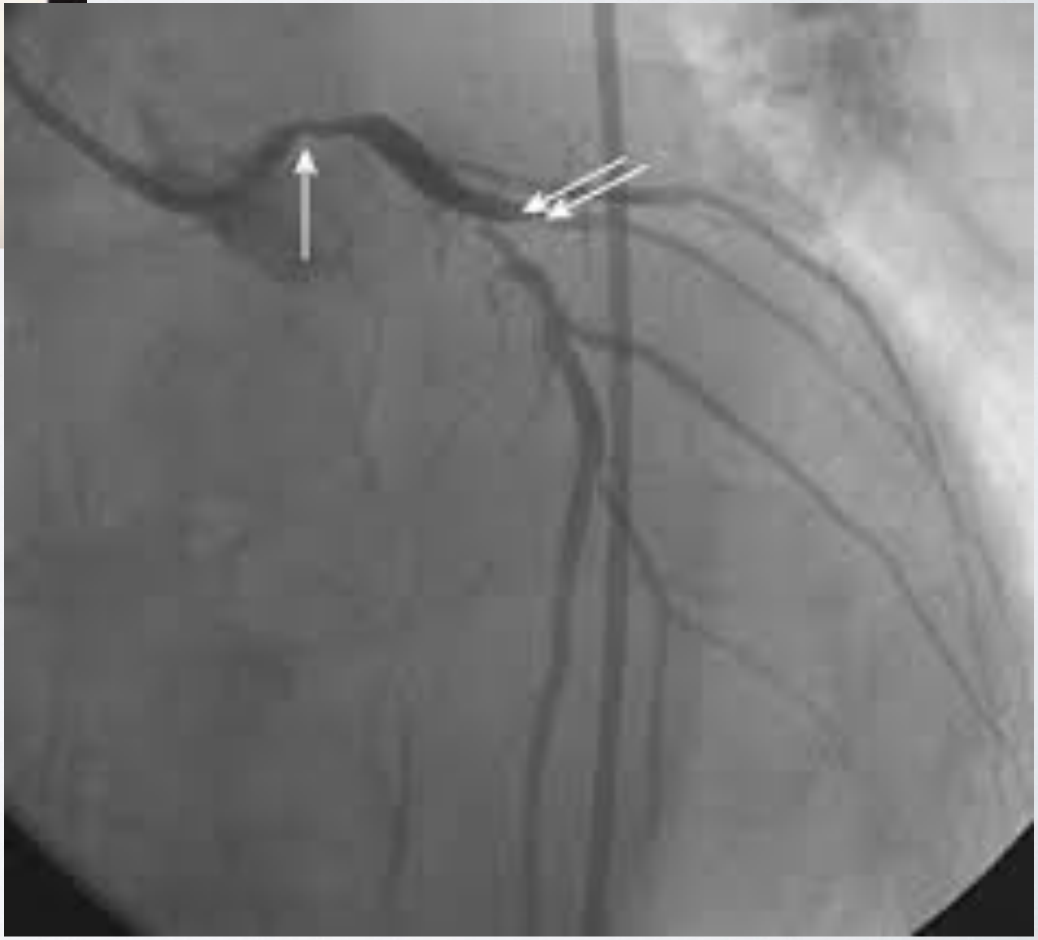






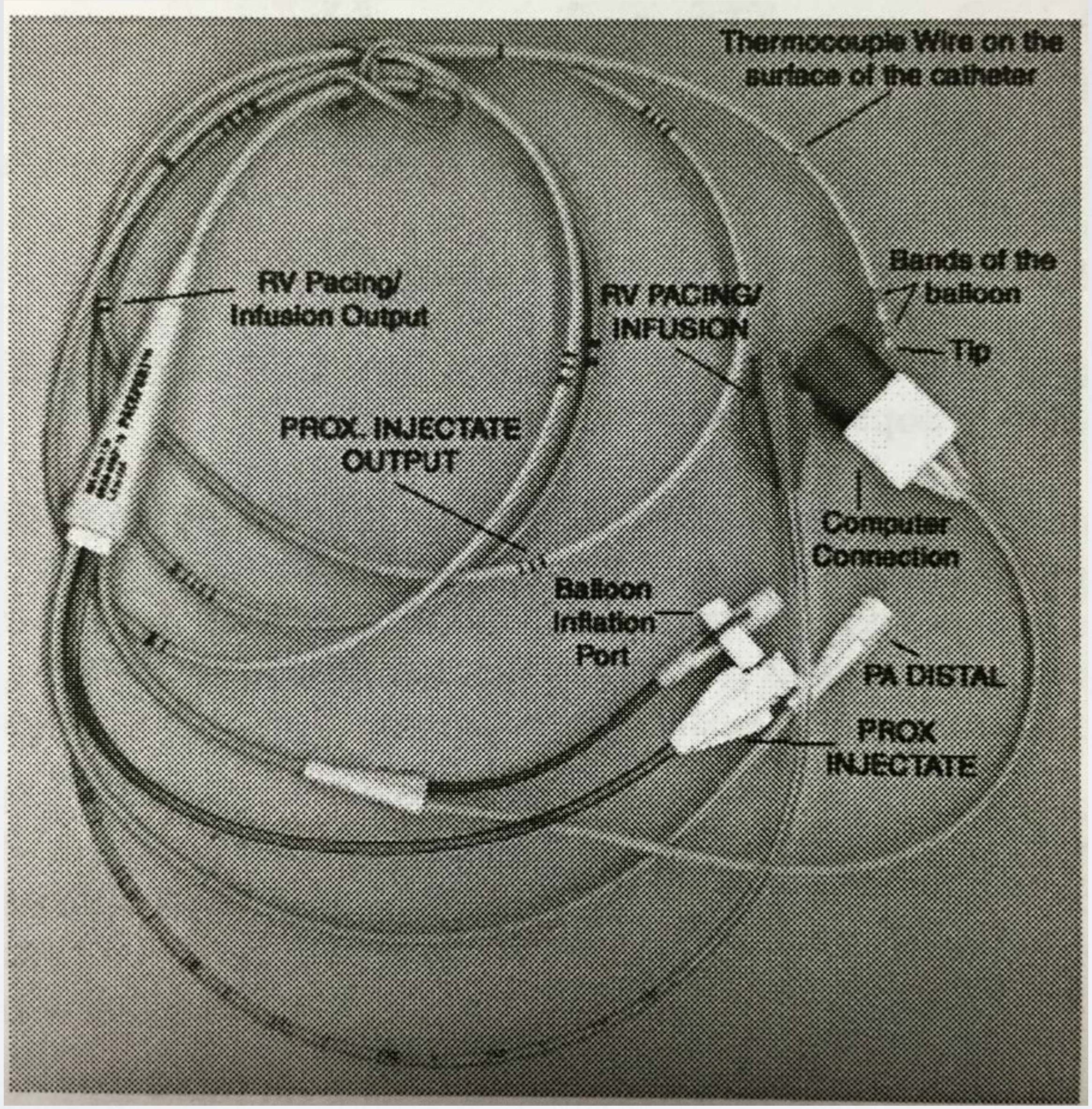
AO Cranial: LCA View

e camera is again on the right
e of the patient, now looking
wn towards the heart from the
oulders. The heart is again
ected toward the right side of
image, and the catheter is on
left. The diaphragm is clearly
en. The LAD runs down
vards the apex of the heart and
ds with a shape that resembles
lvador Dali's mustache."

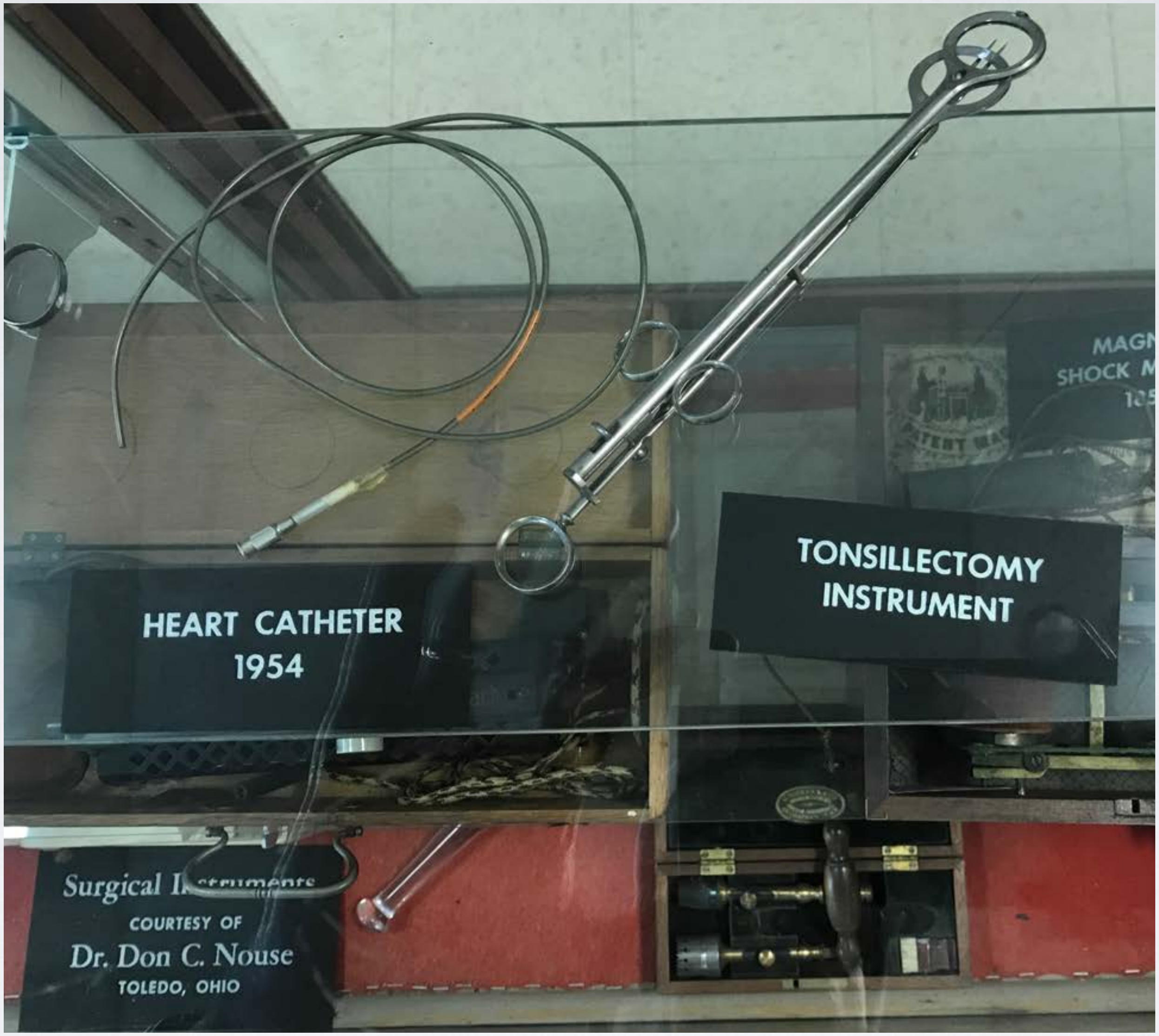



IntelliVue
75
Clock
1413
PVC 0
Pulse 75
Pleth
SpO₂
100
Resp
23
NBP
97/48 (58)
Central Recorder Out of paper
PHILIPS

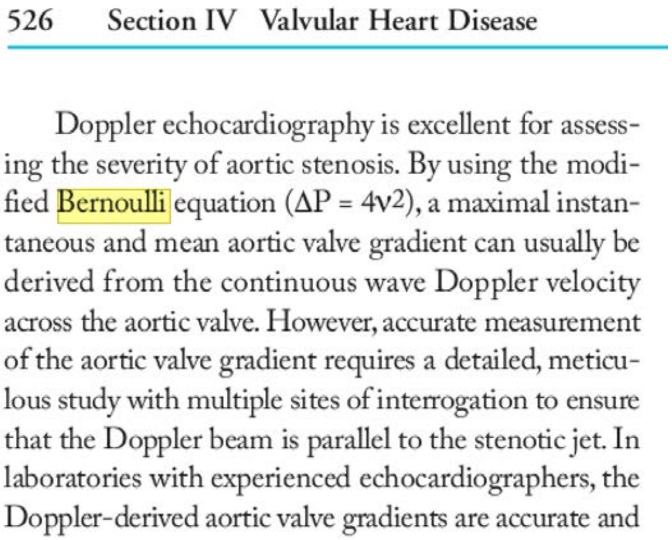
HEART CATHETER ASSEMBLY



NOT A NEW DEVICE

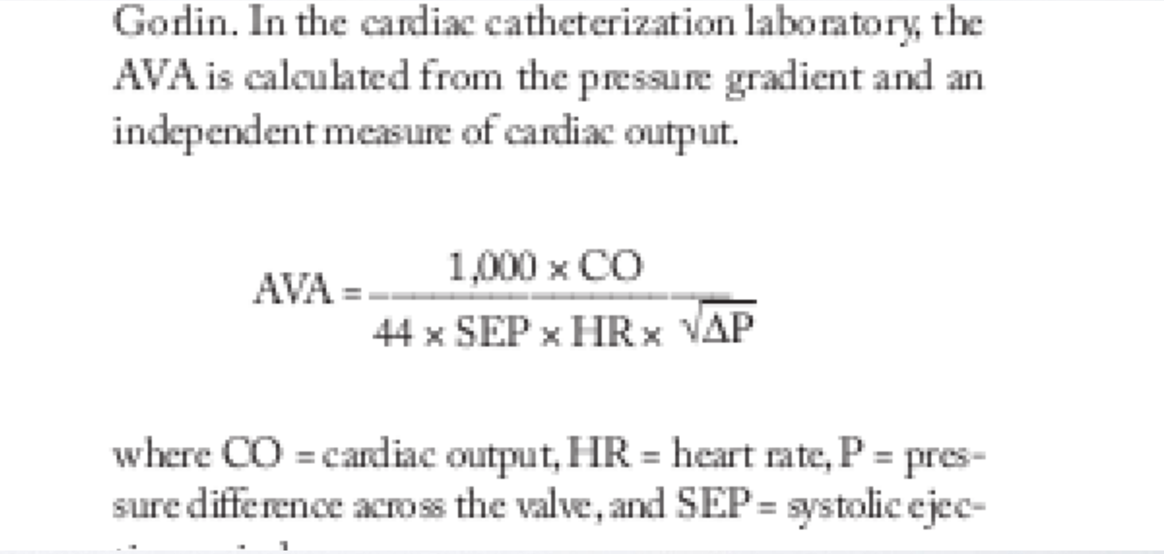


1. Some equations from a Cardiology textbook.



526 Section IV Valvular Heart Disease

Doppler echocardiography is excellent for assessing the severity of aortic stenosis. By using the modified Bernoulli equation ($\Delta P = 4v^2$), a maximal instantaneous and mean aortic valve gradient can usually be derived from the continuous wave Doppler velocity across the aortic valve. However, accurate measurement of the aortic valve gradient requires a detailed, meticulous study with multiple sites of interrogation to ensure that the Doppler beam is parallel to the stenotic jet. In laboratories with experienced echocardiographers, the Doppler-derived aortic valve gradients are accurate and

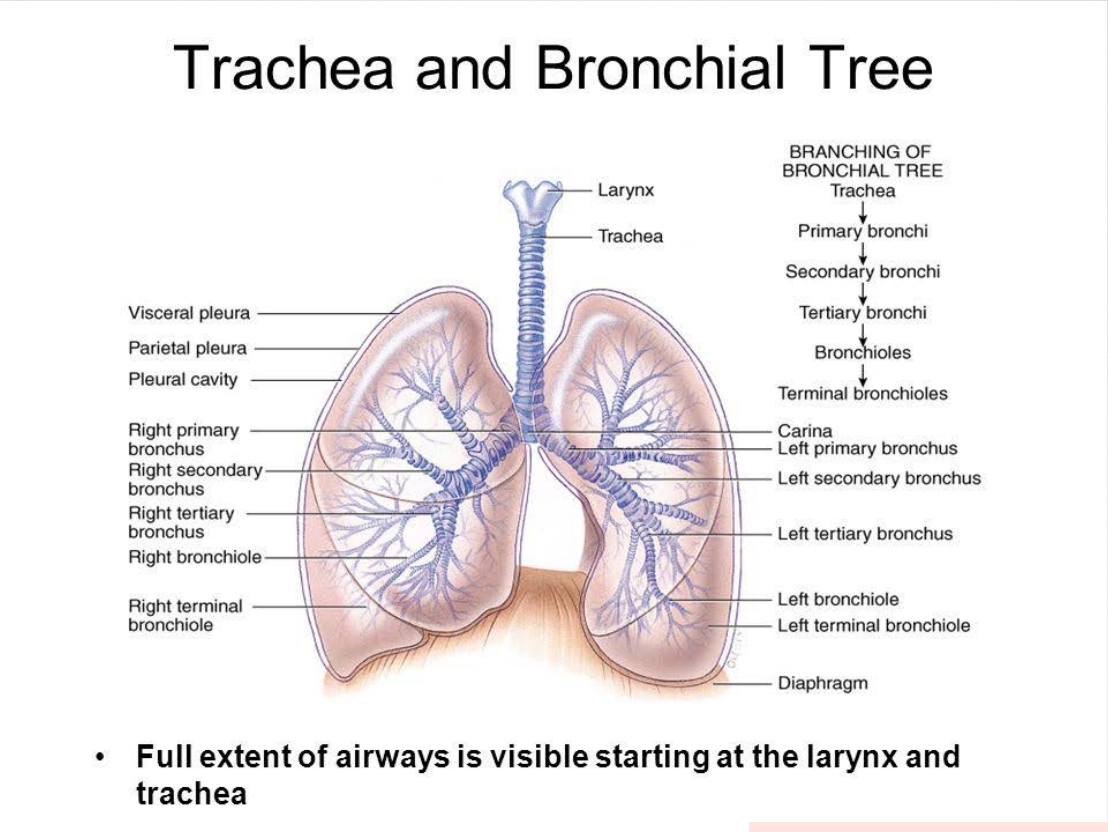


Gorlin. In the cardiac catheterization laboratory, the AVA is calculated from the pressure gradient and an independent measure of cardiac output.

$$AVA = \frac{1{,}000 \times CO}{44 \times SEP \times HR \times \sqrt{\Delta P}}$$

where CO = cardiac output, HR = heart rate, P = pressure difference across the valve, and SEP = systolic ejec-

- A Cardiologist once said to me: "I have to do some calculations…"

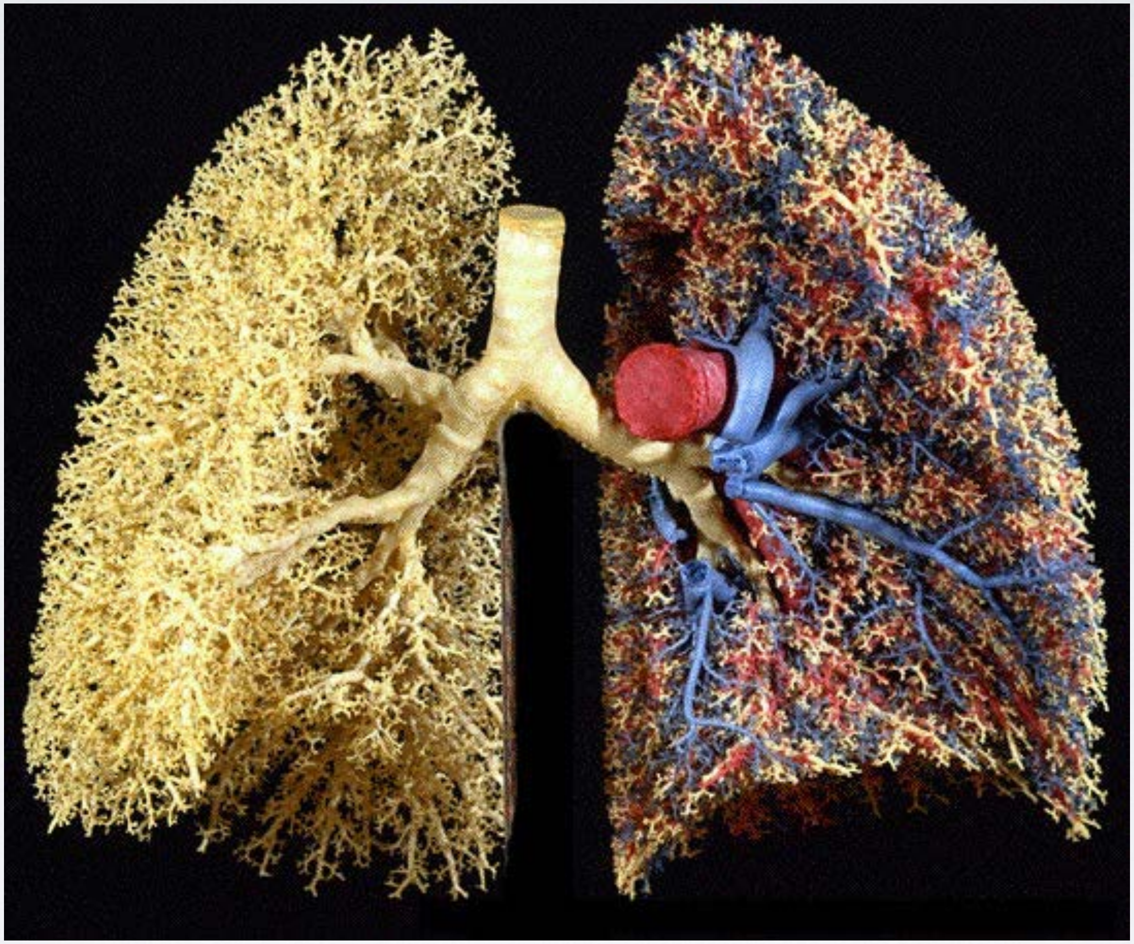


Trachea and Bronchial Tree

- **Full extent of airways is visible starting at the larynx and trachea**

- Premature babies often have trouble breathing
  - They don't have sufficient surfactant production to keep alveoli open
    - http://www.curoservice.com/parents_visitors/surfactant/surfactant_composition_action.php

LUNGS



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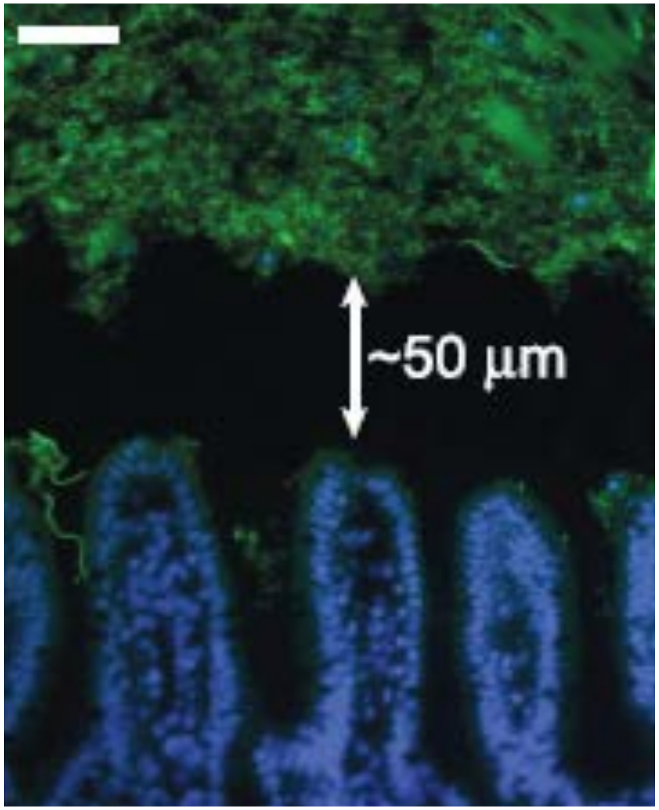
PERISTALSIS

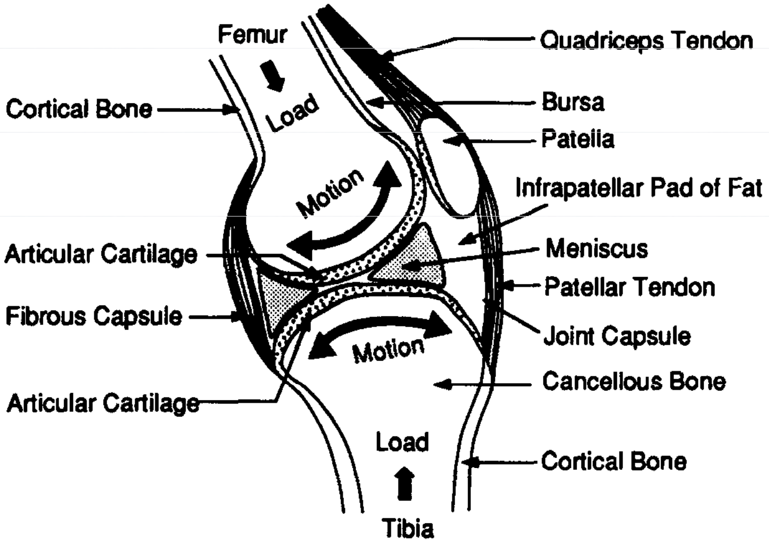
- https://en.wikipedia.org/wiki/Peristalsis
- https://medlineplus.gov/ency/anatomyvideos/000097.htm

LARGE INTESTINE

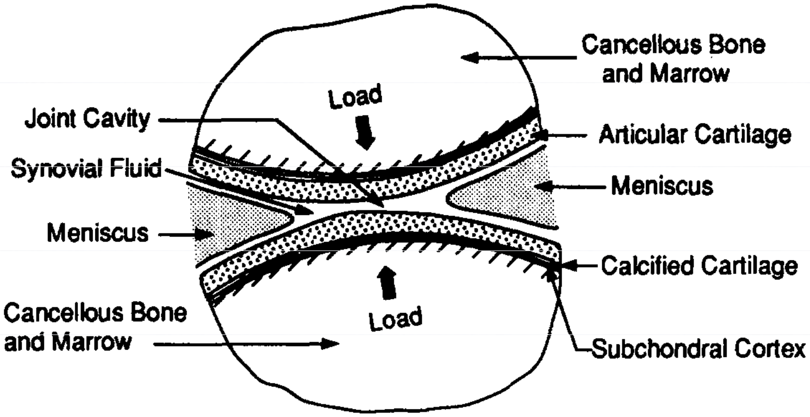
Colon cells and bacterial biofilms are separated



Science DOI: 10.1126/science.1110591



(a) Human Knee Joint

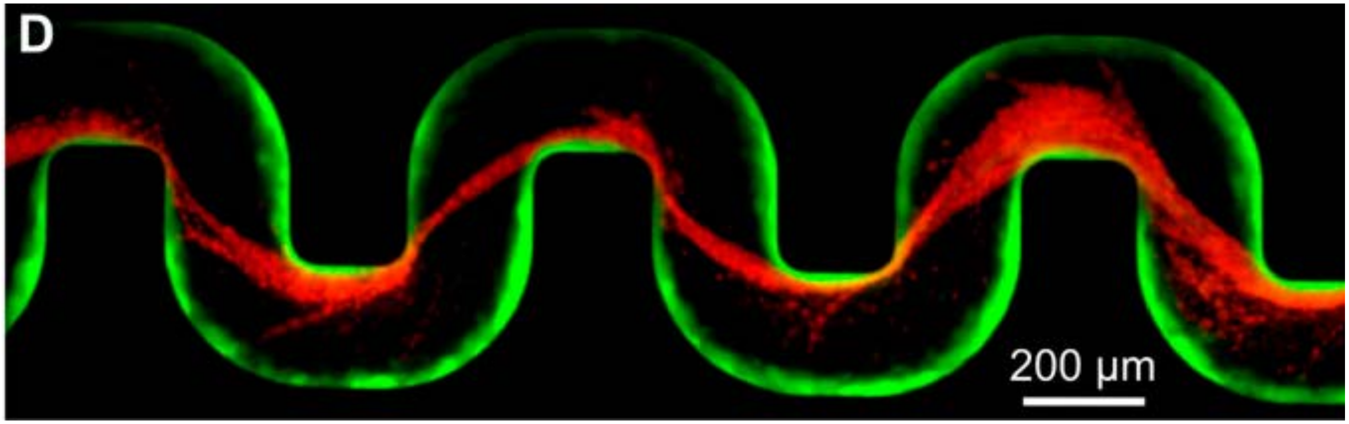


(b) Load Bearing Region

Fig. 1. (a) A diagram of a generic diarthrodial joint showing important anatomical features, loading and motion. (b) Schematic diagram of the load-bearing region of an idealized knee joint.

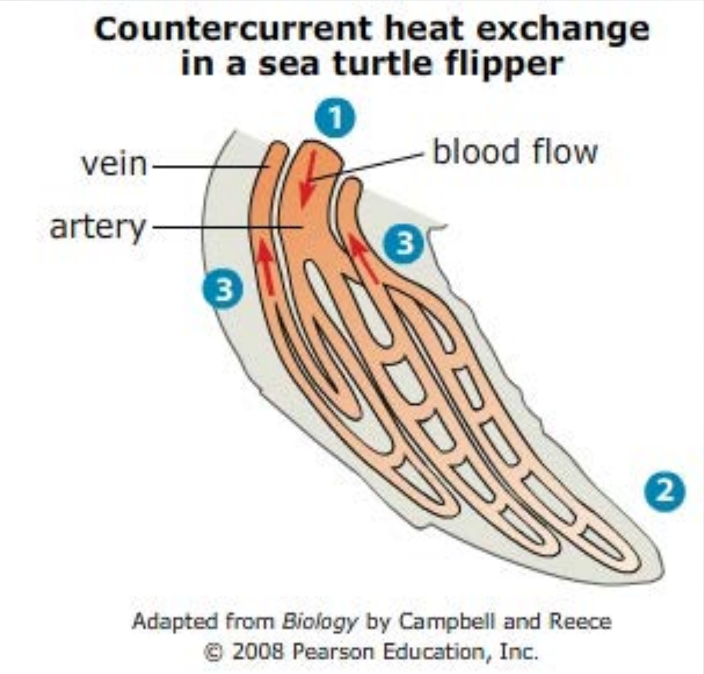
“FOULING” OF MEDICAL DEVICES

Understanding how flow effects quorum sensing helps understand bacterial behavior

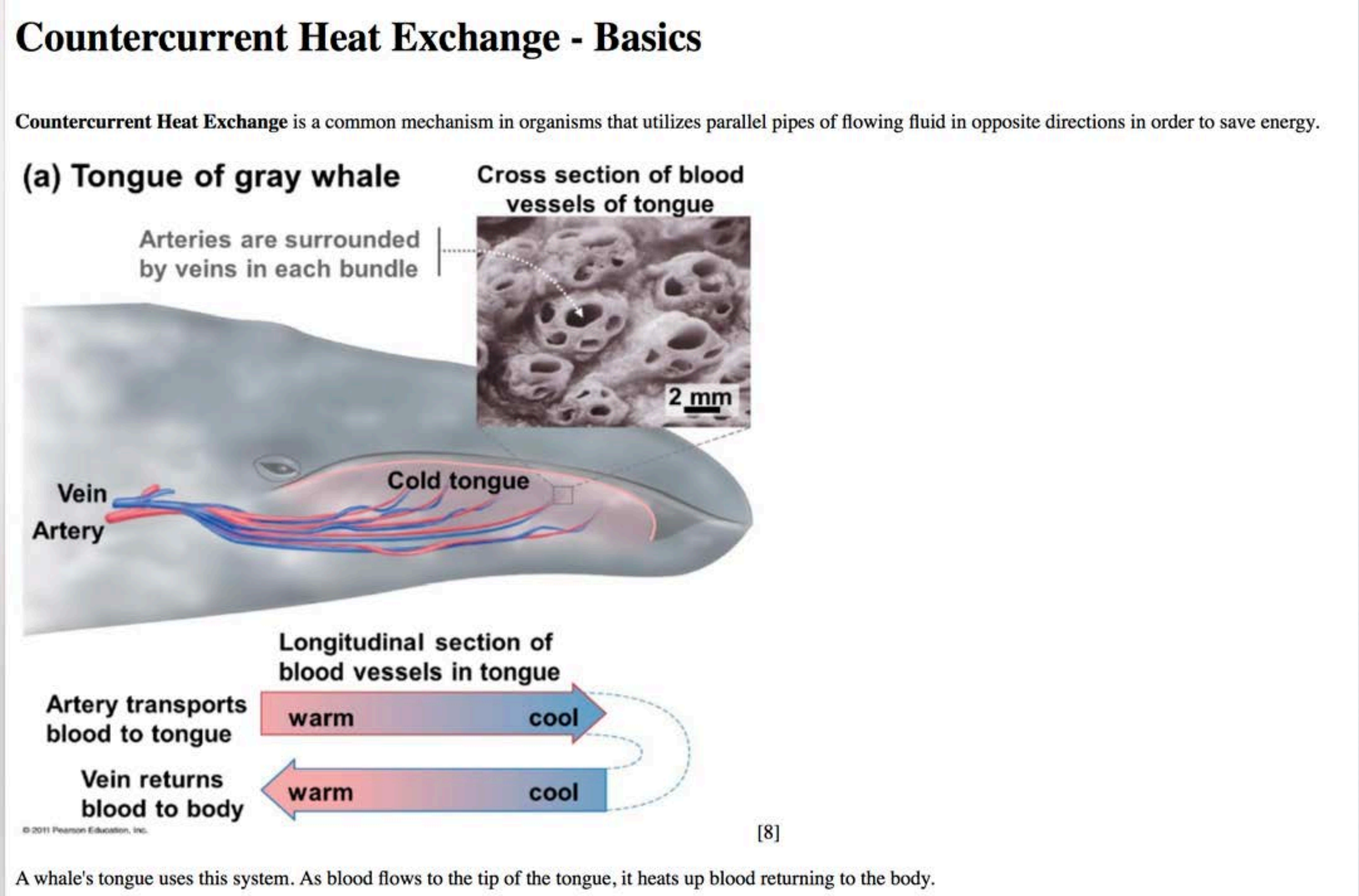


Drescher et al 2013

HEAT EXCHANGE BY ANIMALS



Adapted from *Biology* by Campbell and Reece
© 2008 Pearson Education, Inc.



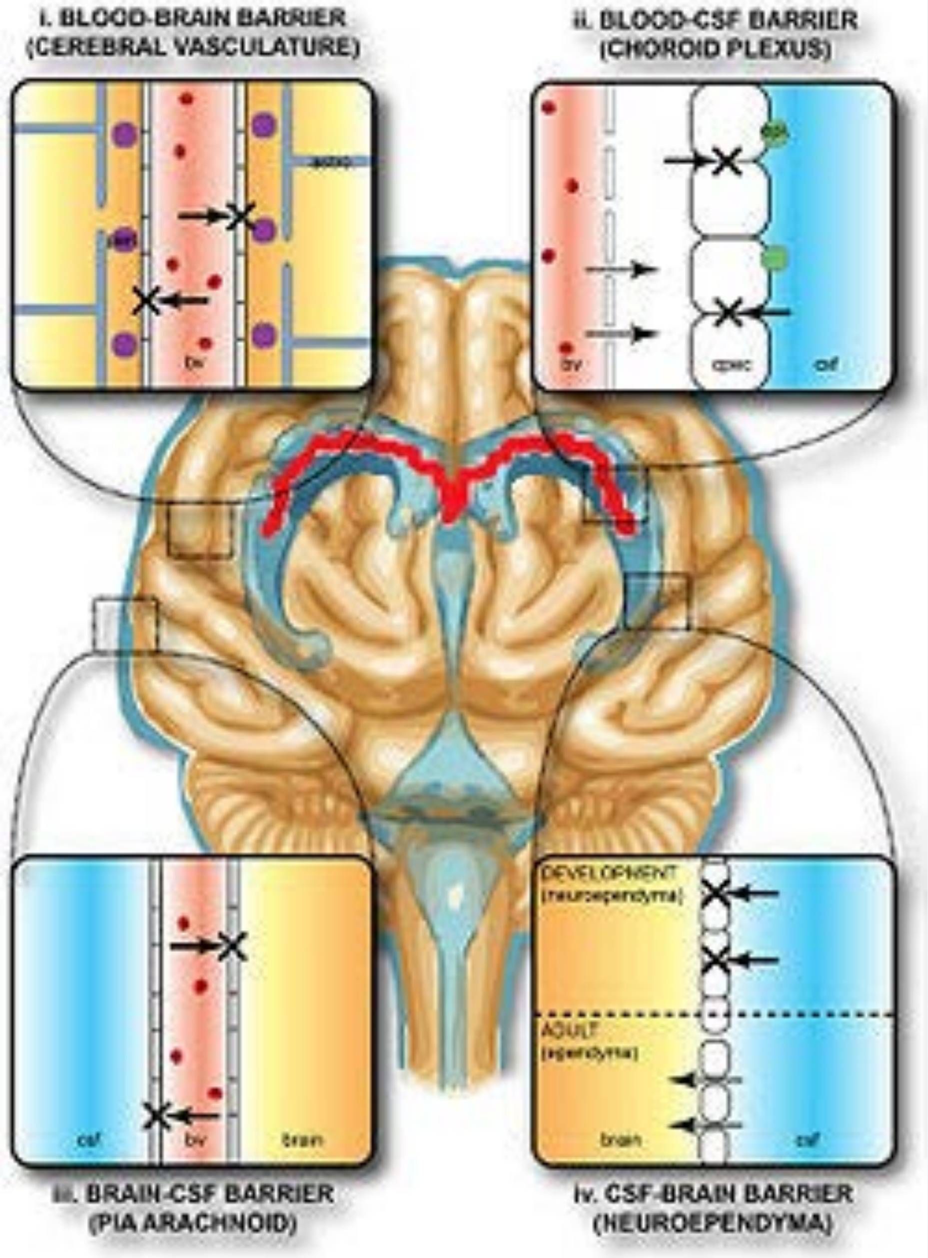
Countercurrent Heat Exchange - Basics

Countercurrent Heat Exchange is a common mechanism in organisms that utilizes parallel pipes of flowing fluid in opposite directions in order to save energy.

[8]

A whale's tongue uses this system. As blood flows to the tip of the tongue, it heats up blood returning to the body.

BLOOD-BRAIN BARRIER



- From Wikipedia
- Mass transfer

CHAPTER 1 FROM THE TEXT

- Except for the basic descriptions of diffusion and convection, pp: 2-9, this is not the main subject matter of the class
- What you don't know about biology or physiology will not hurt you.
    - However, the equations and principles of transport phenomena may enhance what you do know about biology
- Fluid mechanics is central to the heart and blood circulation and to breathing, so we will use these as examples as we begin our study of momentum transport.

CBE 30357

8/24/17

O_2 SOLUBILITY IN BLOOD

- IMPLICATIONS

O_2 SOLUBILITY IN BLOOD

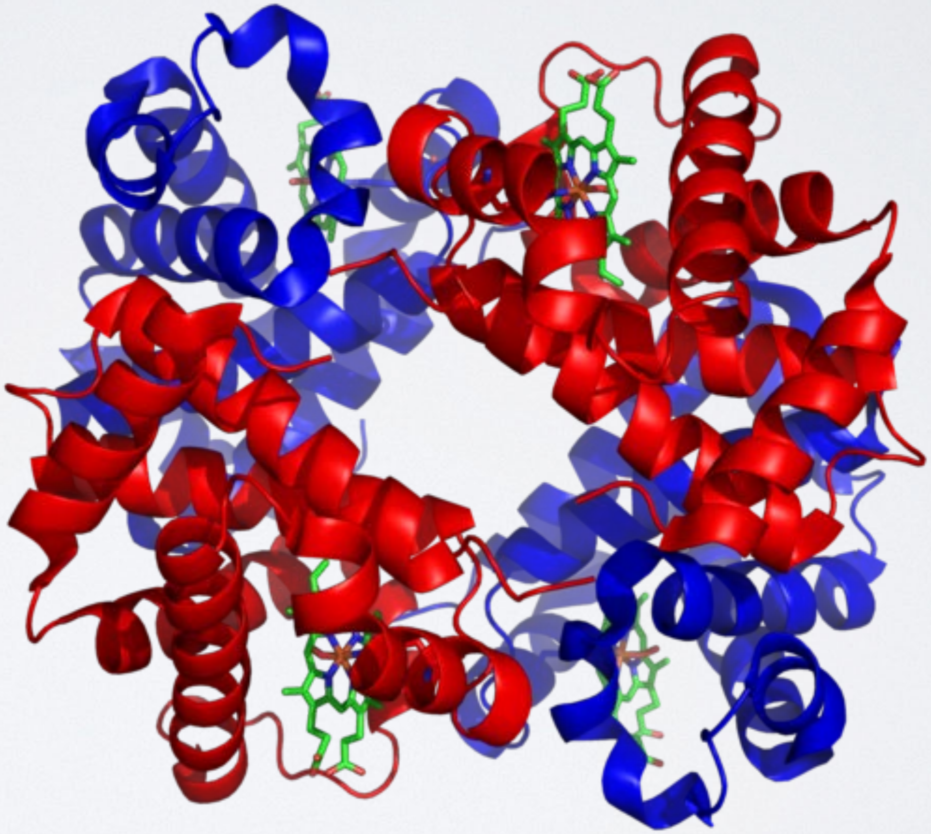
PHYSICAL SOLUBILITY

"HENRY'S LAW"

$$C_{O_2} = \underset{\substack{\uparrow \\ \text{HENRY'S} \\ \text{CONSTANT}}}{H_{O_2}} \; \underset{\substack{\uparrow \\ \text{PARTIAL} \\ \text{PRESSURE}}}{P_{O_2}}$$

LIMITED TO LOW CONCENTRATION
~ PPM, "FLAT EARTH",
FIRST TERM IN TAYOR SERIES..

HEMOGLOBIN



- O2: Cooperative binding

TO SUSTAIN ROBUST LIFE O_2 SOLUBILITY MUCH HIGHER THAN HENRY'S LAW RANGE IS NEEDED

- CHEMICAL COMPLEXATION

A.K.A.: HEMOGLOBIN

THE EQUATION O_2 IN BLOOD IS

$$C_{O_2} = \underline{H_{O_2} P_{O_2}}(1-H_{ct}) + \left(\underline{4 C_{Hb} \bar{S}} + \underline{H_{Hb} P_{O_2}}\right) H_{ct}$$

PHYSICAL SOLUBILITY

FRACTION OF BLOOD THAT IS RED BLOOD CELLS

CHEMICAL COMPLEXATION

$\bar{S}$ FRACTIONAL LOADING OF O_2 ONTO HEMOGLOBIN BINDING SITES

OXYGEN CAPACITY OF BLOOD

$$C_{O_2} == H_{O_2}P_{O_2}(1-Hct)+(4C_{Hb}\overline{S}+H_{Hb}P_{O_2})Hct$$

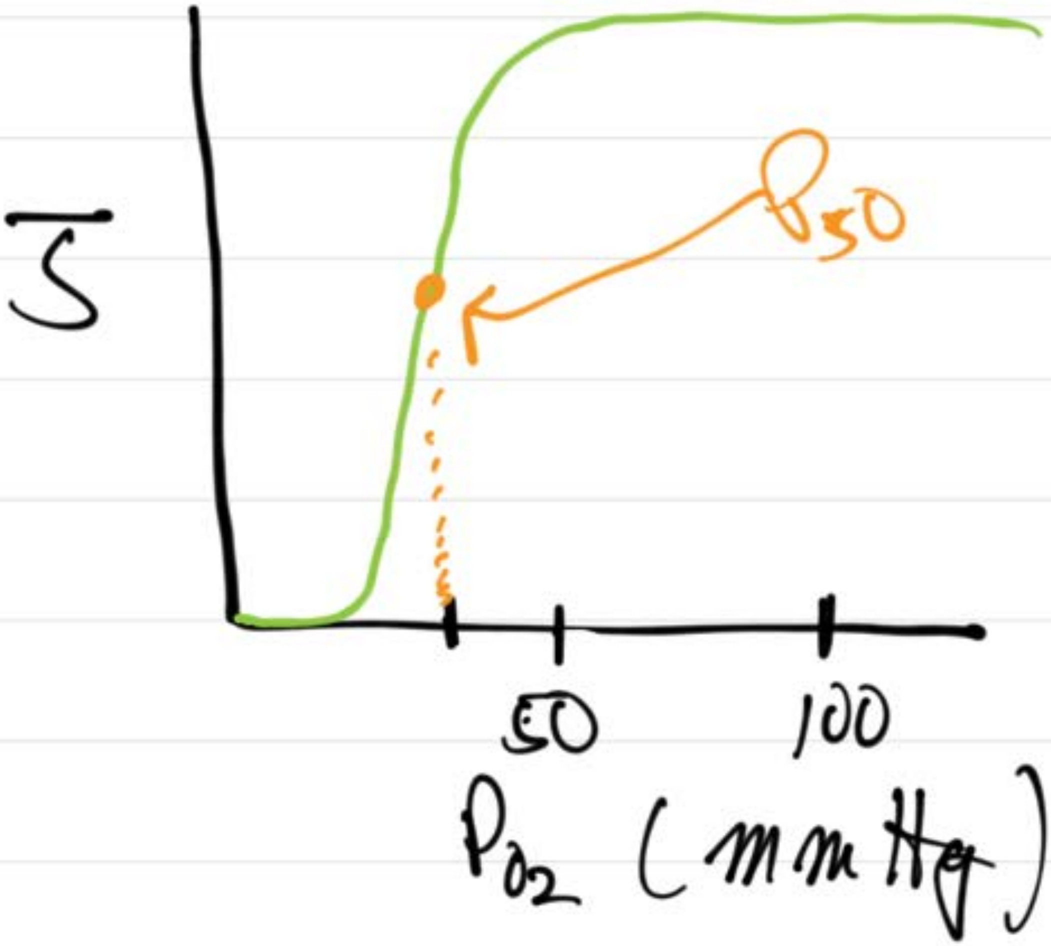
$C_{O_2}, C_{Hb} ==$ Concentrations of O2 and hemoglobin

$H_{O_2}, H_{Hb} ==$ "Henry's" constants for oxygen in plasma and hemoglobin

$P_{O_2} ==$ partial pressure of oxygen

$Hct ==$ "hematocrit", the volume fraction of red blood cells

$\overline{S} ==$ The fractional saturation of oxygen on the hemoglobir



$$\bar{S} = \frac{\left(P_{O2}/P_{50}\right)^{2.6}}{\left(1 + P_{O2}/P_{50}\right)^{2.6}}$$

Figure 1.14 Oxygen–hemoglobin and oxygen–myoglobin dissociation curves. The fractional saturation is the relative amount of heme groups bound to molecular oxygen.

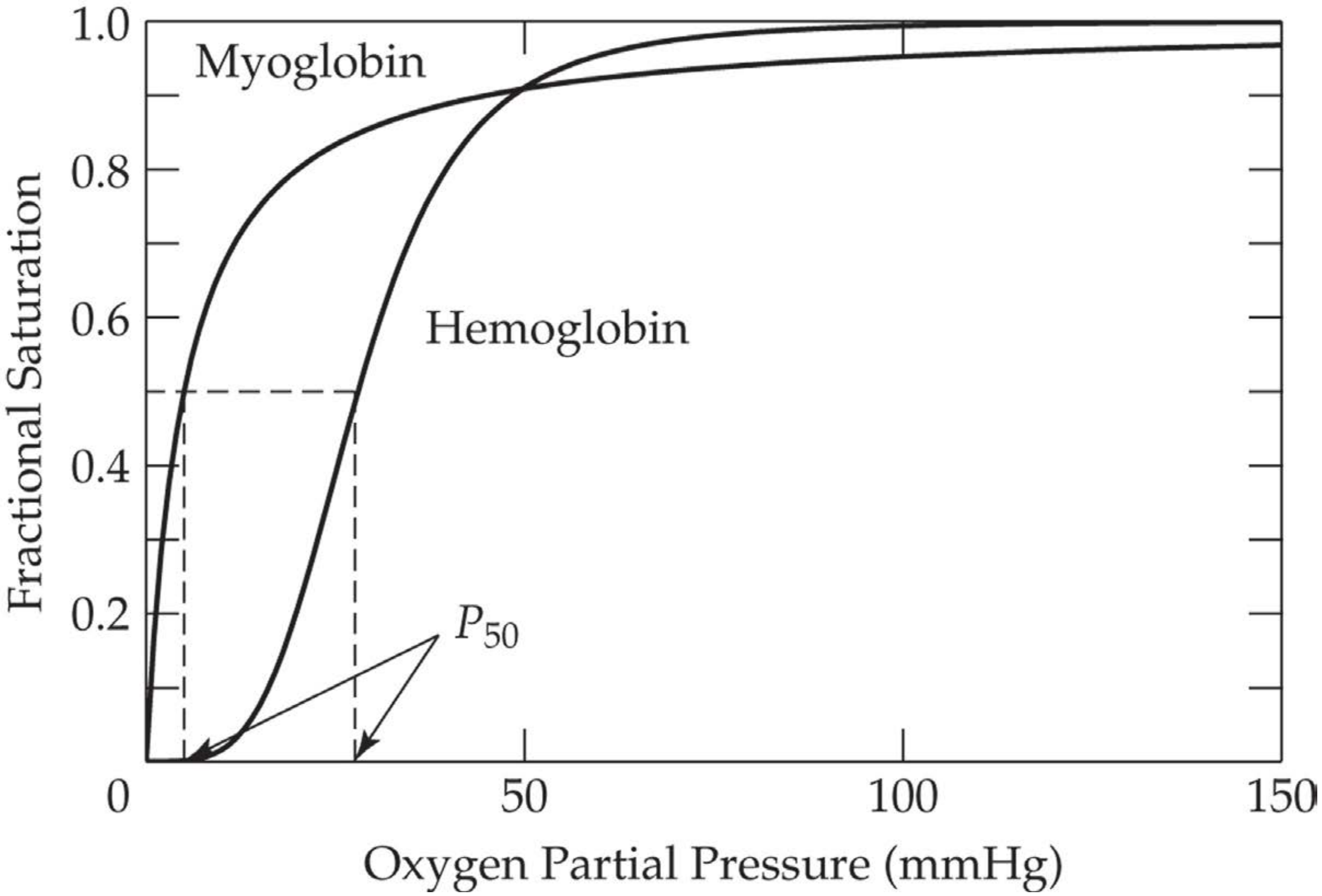
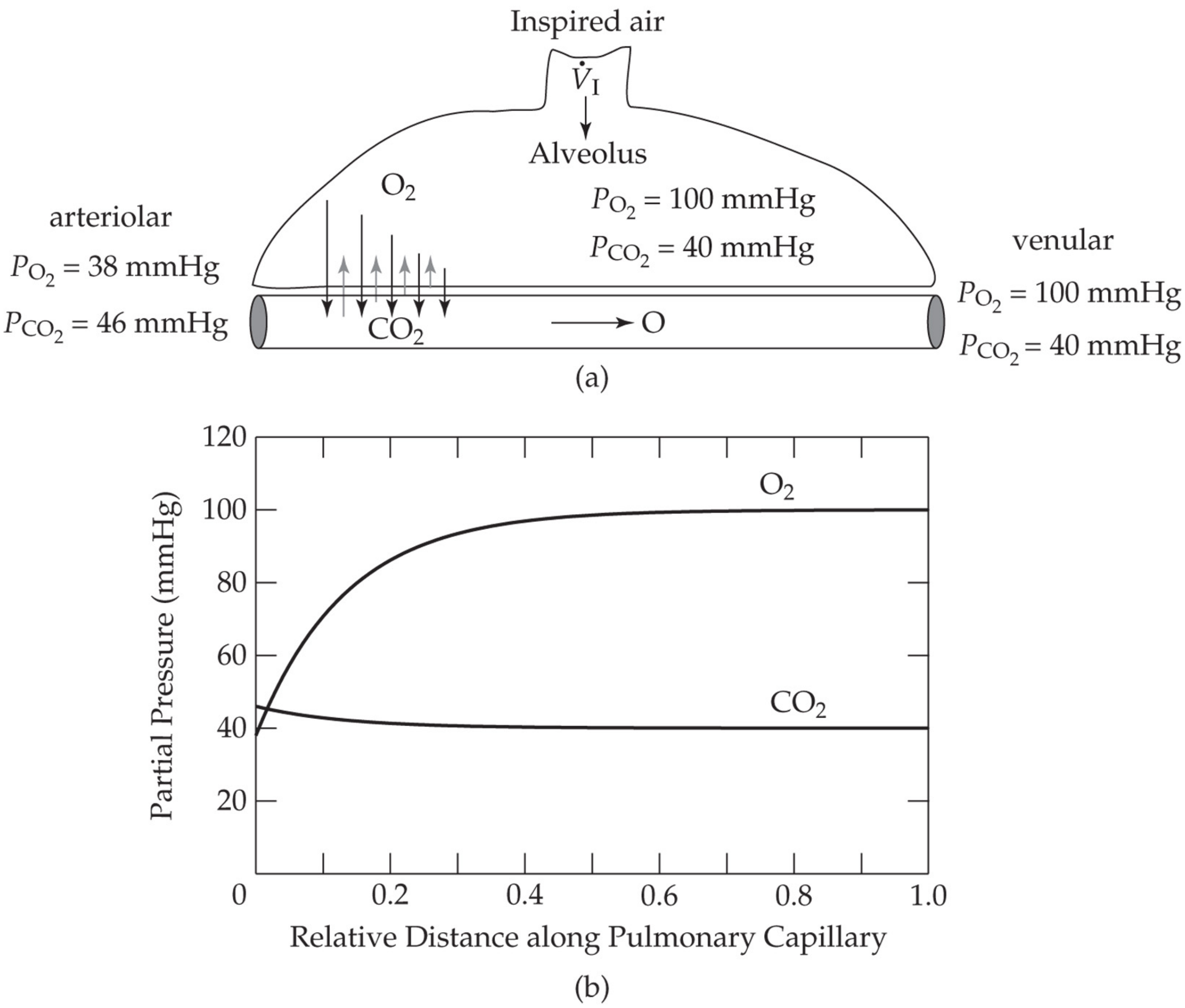


Figure 1.16 Oxygen and carbon dioxide exchange across the alveolar capillaries.



Transport Phenomena in Biological Systems, Second Edition
George A. Truskey, Fan Yuan, and David F. Katz

WHILE YOU MAY (AT LEAST NOW)

NOT LOVE TO "WALLOW"

IN E@UATIONS AS MUCH

AS I DO...

LET'S !!

EX: WHEN IS PURE O_2 AN EFFECTIVE MEDICAL TREATMENT?

WE SEE THE 3 TERMS

$H_{O_2} P_{O_2} (1 - H_{ct})$

$H_{O_2} = 1.4 \times 10^{-6} \frac{mol}{L - mmHg}$

$P_{O_2} \sim .21 * 760$

$= 160 \ mmHg$

$H_{ct} \sim .45$ OR $.4$

$= .00012 \frac{mol}{LITER}$

$= \sim 3$ PPM (MASS)

LOOK AT LAST TERM

$$H_{Hb} P_{O_2} H_{ct}$$

$$1\times10^{-6}(160)\cdot .45$$

$$= .00007 \frac{mol}{L}$$

MIDDLE TERM

$$\underbrace{4C_{Hb}}_{\substack{O_2 \text{ ON} \\ Hb \\ = .0203\, M/L}} \overset{\uparrow \sim 1}{\bar{S}}\; H_{ct} \approx .45$$

$$= .009$$

CHEMICAL COMPLEXATION

.009 MOL/L.

PHYSICAL SOLUBILITY

= .00012 + .00007

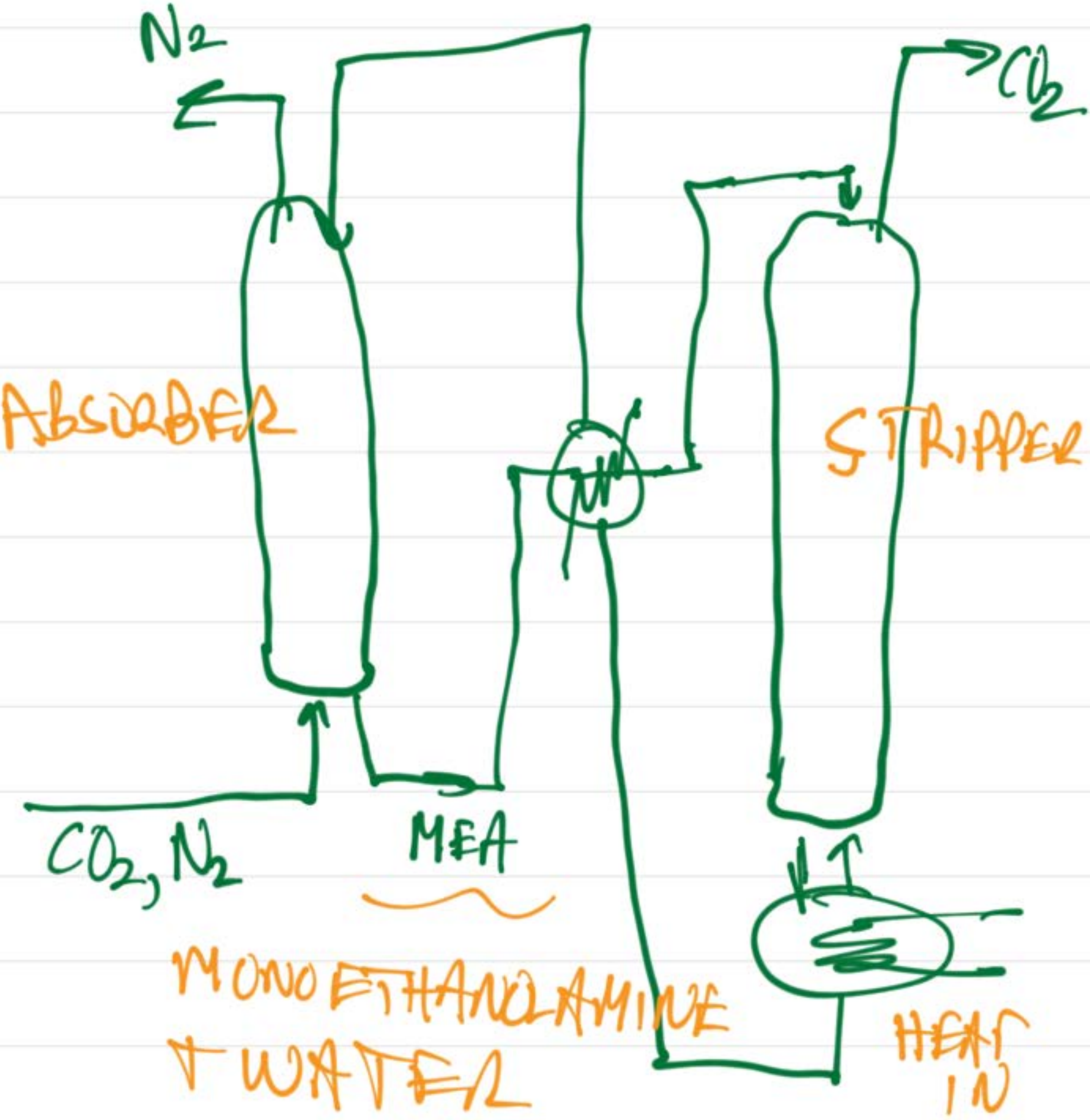
RATIO: $\frac{.009}{.00019} = 47$

HW PROBLEM GIVES
A CHANCE TO TRY TO
SEE WHAT LEVEL OF
LIFE IS POSSIBLE WITH
ONLY PHYSICAL SOLUBILITY

ALSO, THIS IS

"JUST LIKE" . . .

??


N_2
CO_2
ABSORBER
STRIPPER
CO_2, N_2
MEA
MONOETHANOLAMINE + WATER
HEAT IN


$N_2 + CO_2$
N_2
CO_2

THIS EQUATION ALSO "INFORMS" M.O.N.A.

https://lifeinthefastlane.com/oxygen-in-acute-myocardial-infarction/

https://acls.com/free-resources/knowledge-base/acute-coronary-syndrome/mona-morphine-oxygen-nitroglycerin-and-aspirin

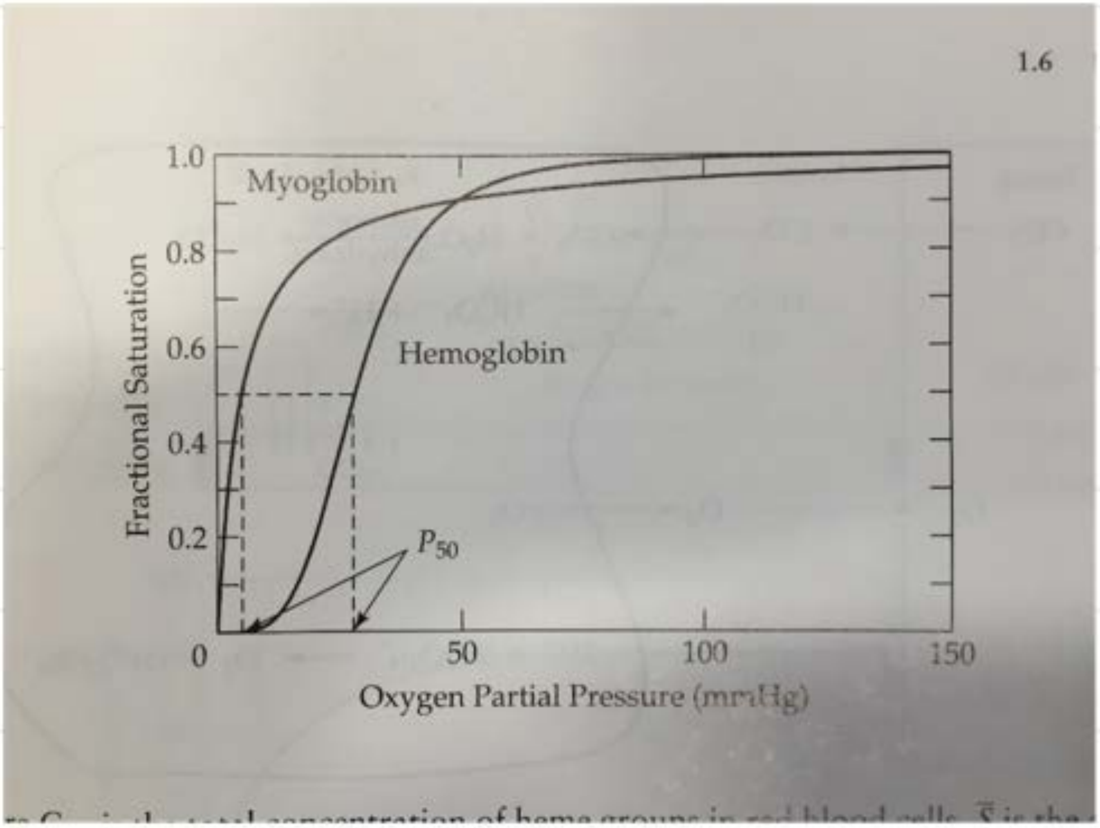
M: MORHINE

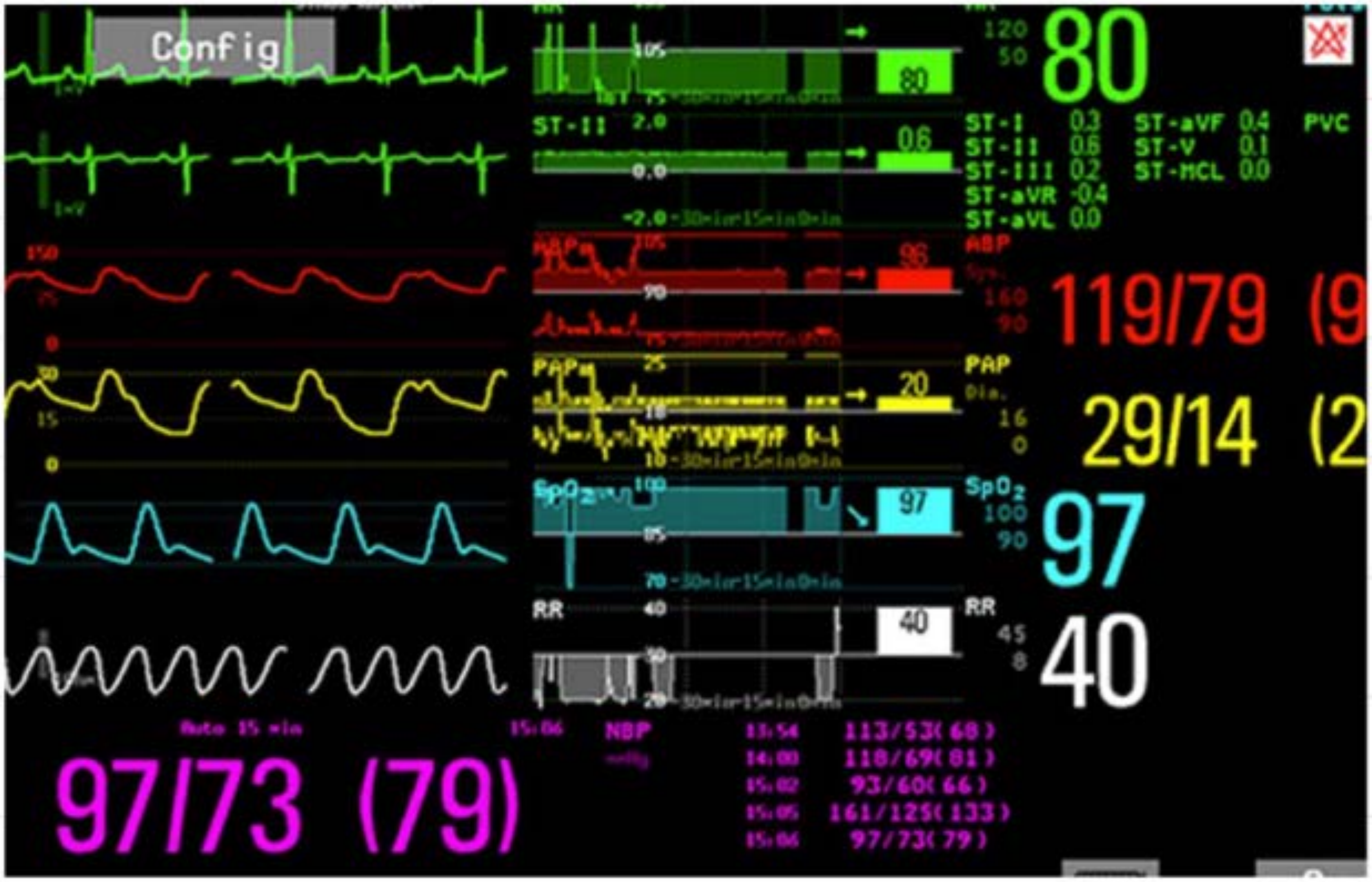
O: OXYGEN ??

N: NITRO GYLCERINE

A: ASPIRIN

WILL IT HELP?


1.6
1.0
0.8
0.6
0.4
0.2
0
50
100
150
Fractional Saturation
Oxygen Partial Pressure (mmHg)
Myoglobin
Hemoglobin
P_{50}


Config
1mV
1mV
150
75
0
30
15
0
HR
105
80
75
ST-II
2.0
0.0
-2.0
0.6
ABP
105
96
90
75
PAP
25
20
18
10
SpO2
100
97
85
70
RR
40
40
20
-30min -15min 0min
120
50
80
ST-I 0.3
ST-II 0.6
ST-III 0.2
ST-aVR -0.4
ST-aVL 0.0
ST-aVF 0.4
ST-V 0.1
ST-MCL 0.0
PVC
ABP
Sys.
160
90
119/79 (9
PAP
Dia.
16
0
29/14 (2
SpO2
100
90
97
RR
45
8
40
Auto 15 min
15:06
97/73 (79)
NBP
mmHg
13:54 113/53(68)
14:00 118/69(81)
15:02 93/60(66)
15:05 161/125(133)
15:06 97/73(79)