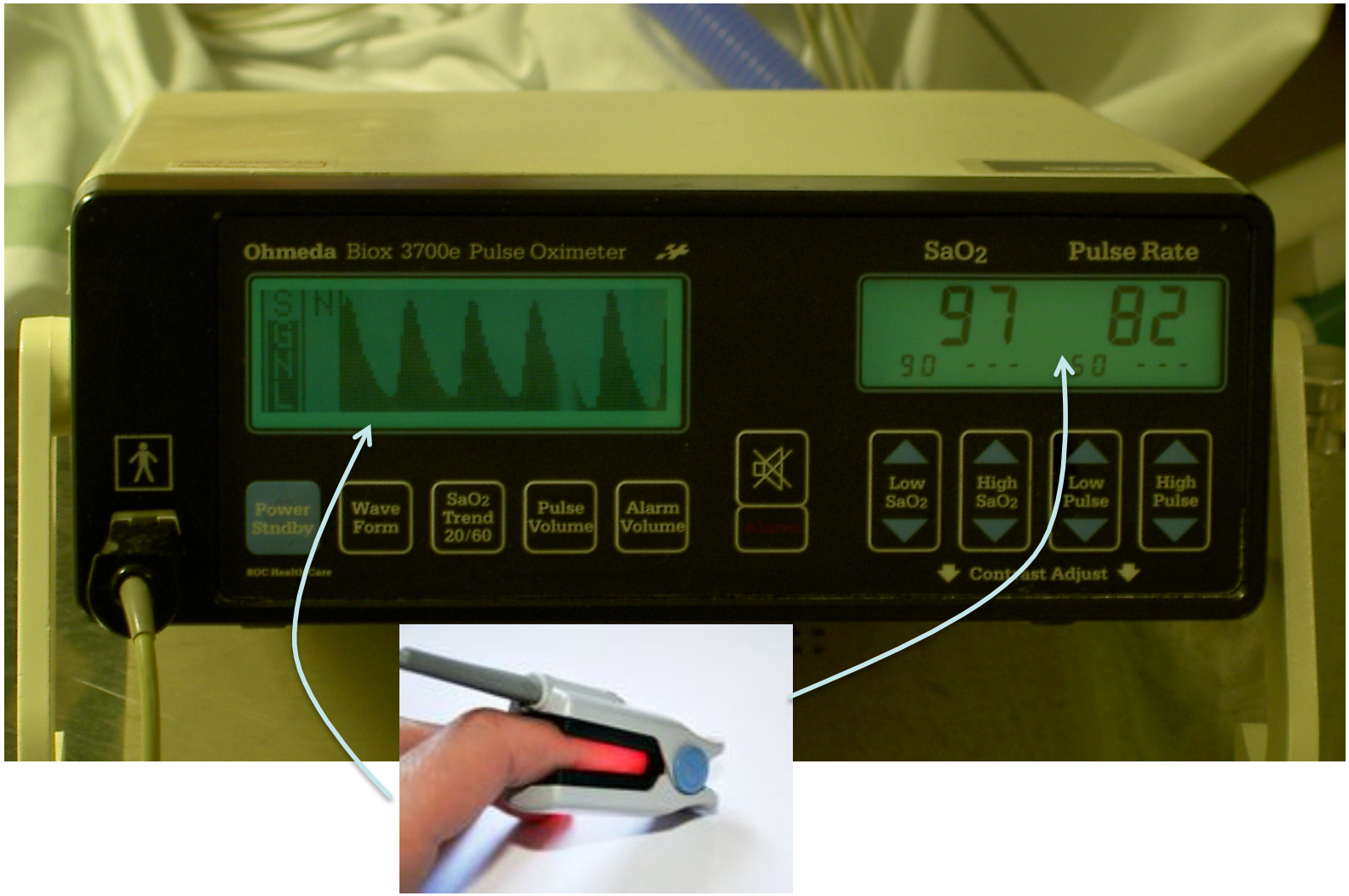
Pulse Oximetry



Pulse oximetry

Combination of two technologies:

1. Photospectrometry, whereby the saturation of haemoglobin with oxygen is estimated

2. Optical plethysmography, which focuses the measurement on pulsatile arterial blood

5 things we need to know

1. Absorption spectrum for different Hbs
2. Beer-Lambert's law about absorption of light
3. A/C and D/C components
4. Absorption ratio and the saturation algorithm
5. Limitations and errors

Pulse Oximeter

- Estimates SpO_2 from the differential absorption of red (660nm) and infrared (940nm) light in tissue

- Two wavelengths allow differentiation of reduced hemoglobin and oxyhemoglobin

- Reduced hemoglobin absorbs more light in the red band (660nm) than oxyhemoglobin

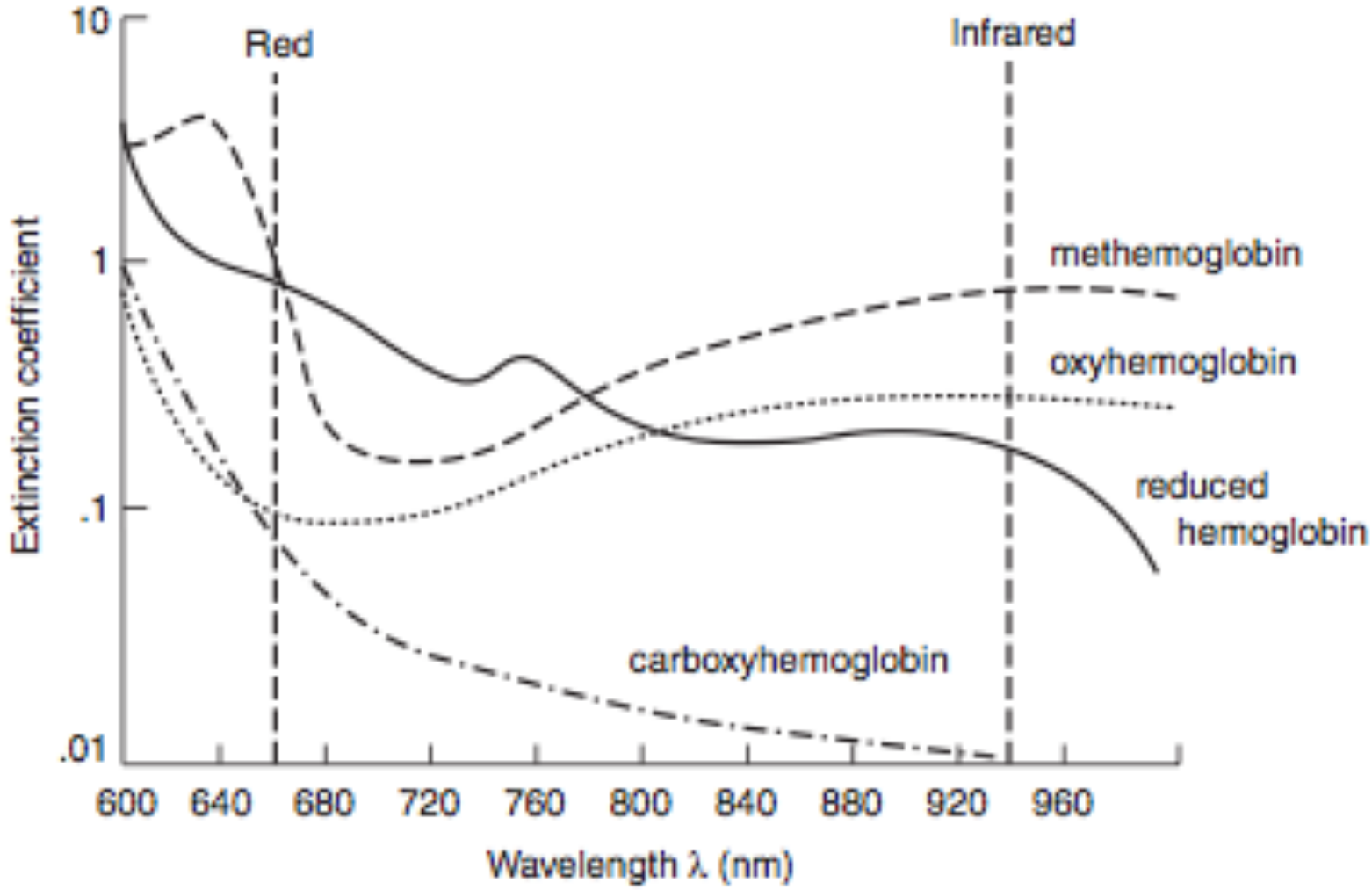
Pulse Oximeter

- Oxyhemoglobin absorbs more light in the infrared band (940nm)

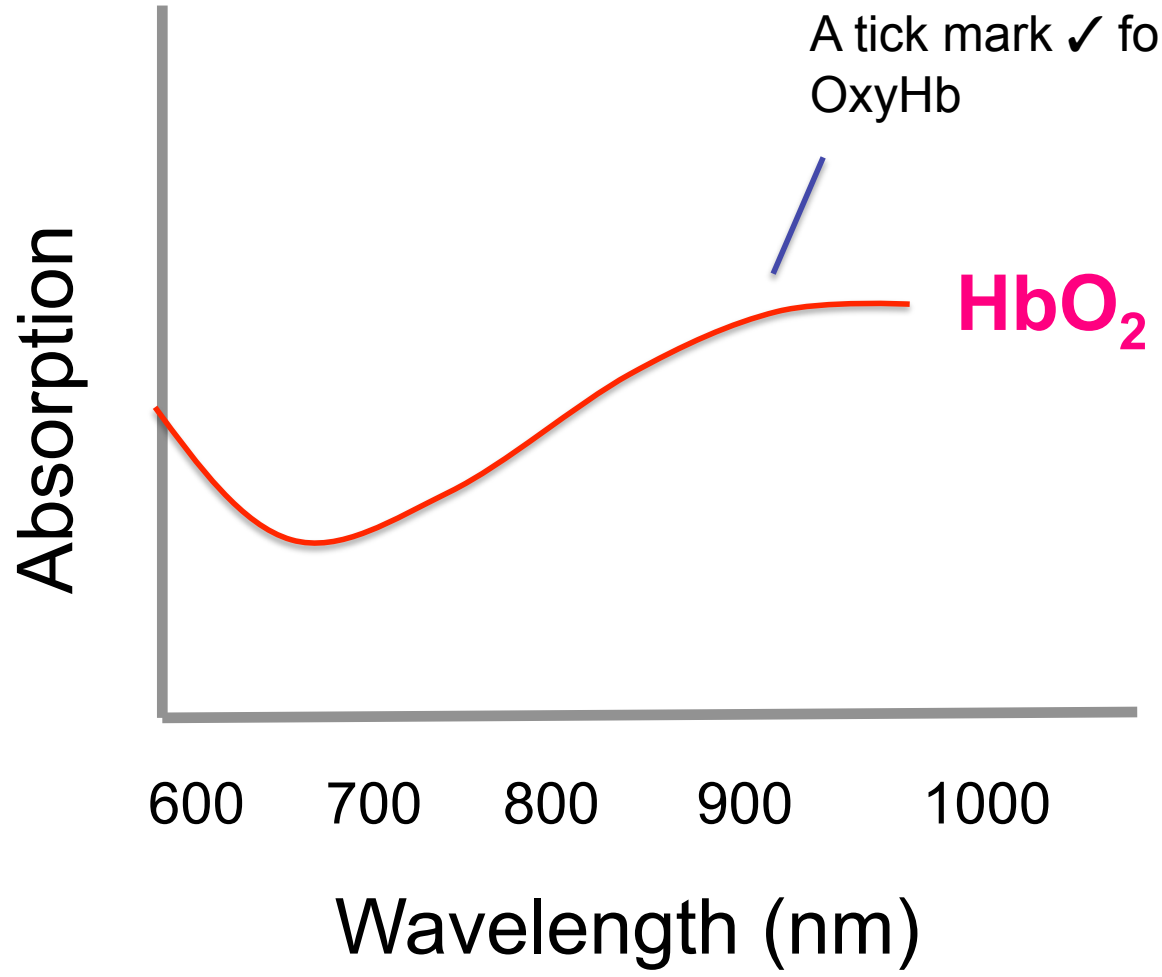
- Computes the ratio between these two signals and relates this ratio to the arterial oxygen saturation, using an empirical algorithm

Absorption Spectrum

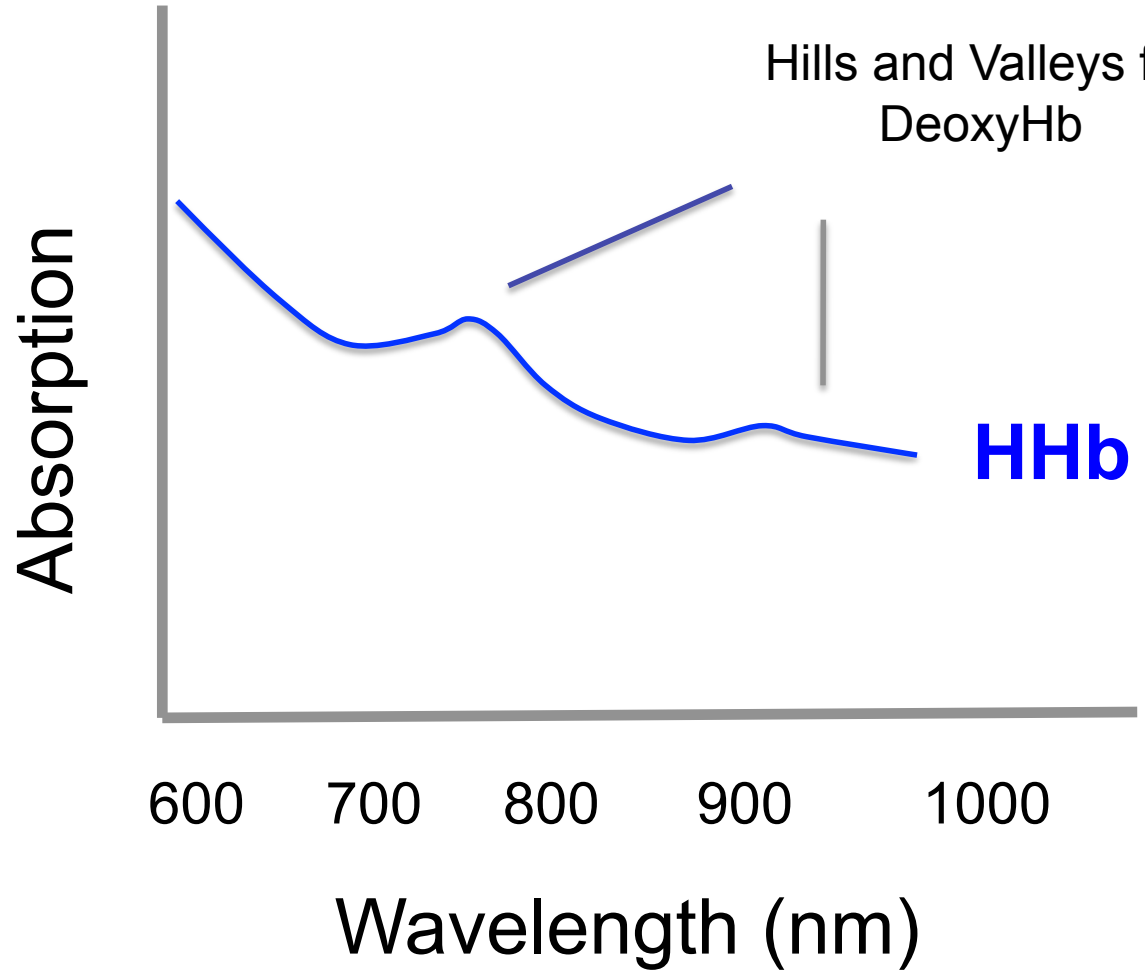
Absorption spectrum



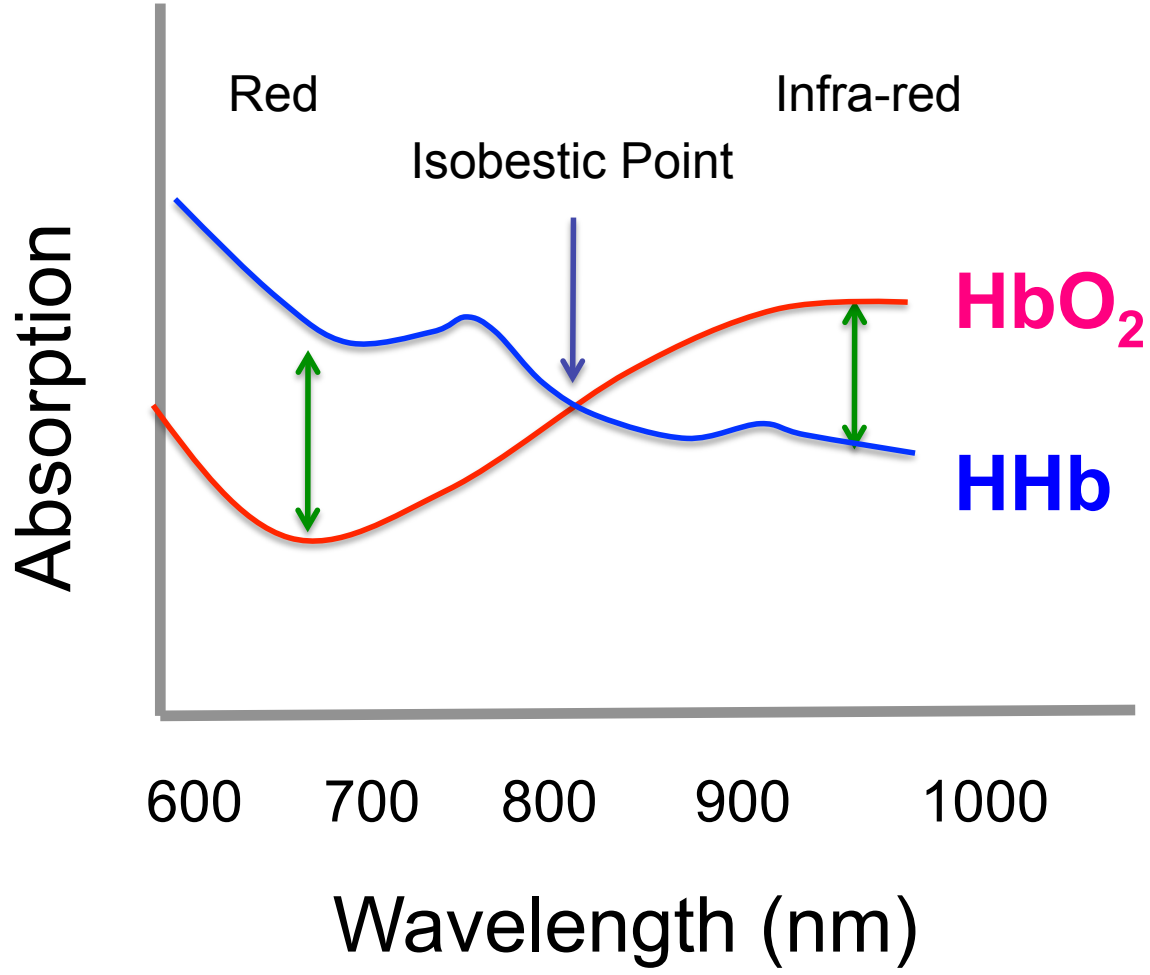
Absorption Spectrum HbO_2



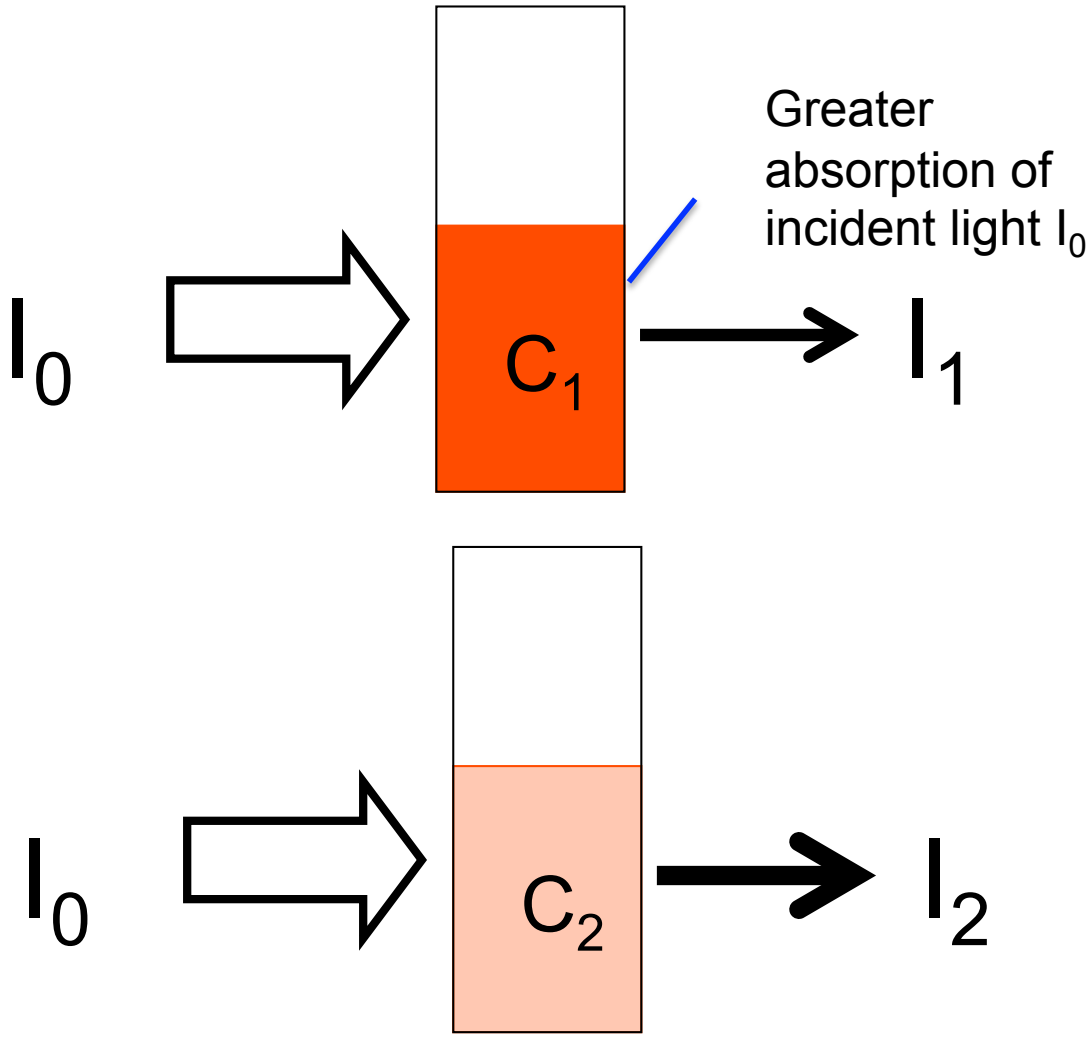
Absorption Spectrum Deoxy Hb



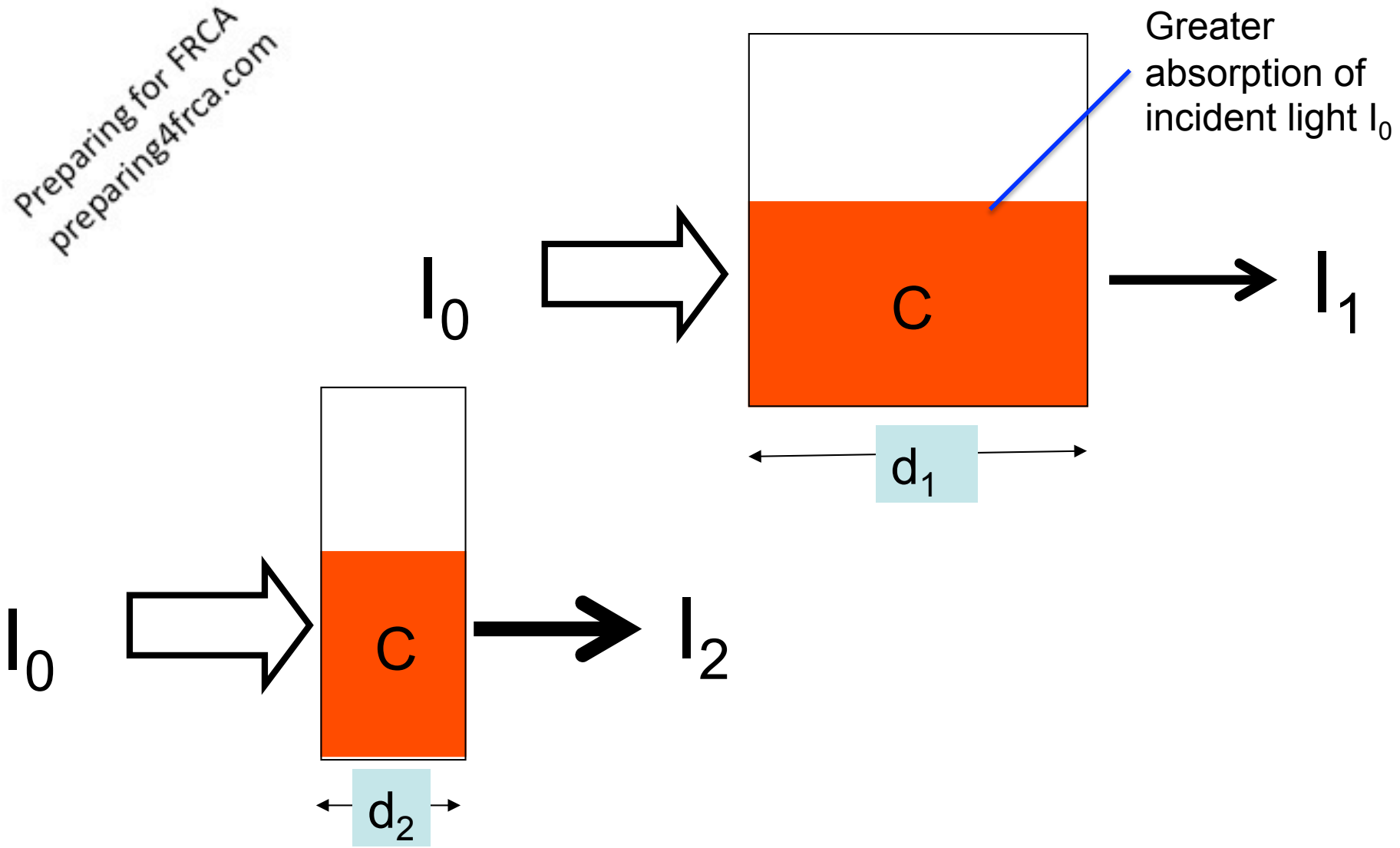
Absorption Spectrum Oxy and Deoxy Hb*



Beer Lambert’s Law

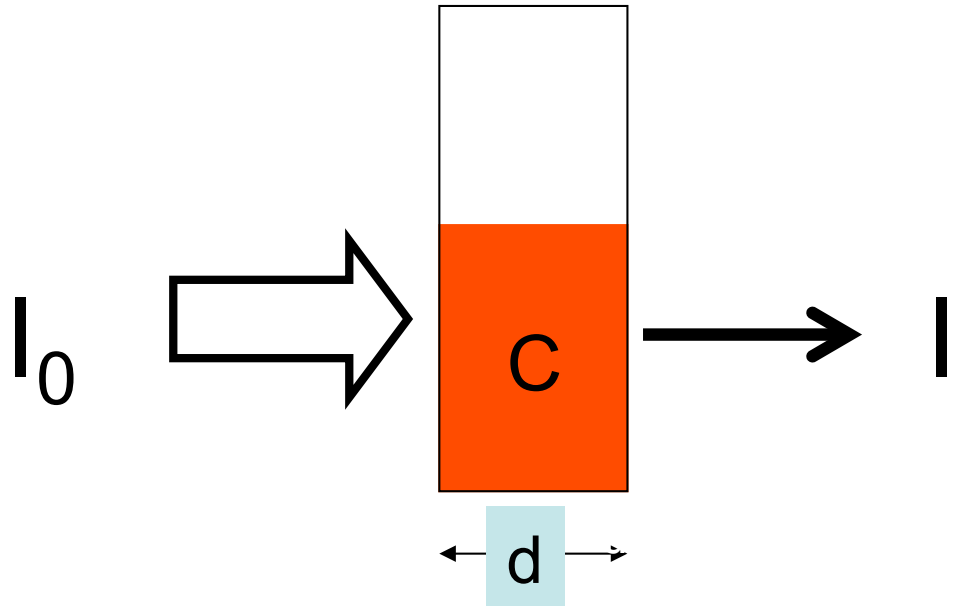


$I_2 > I_1$, Absorption proportional to concentration; Beer's law



$I_2 > I_1$, absorption is proportional to the distance light travels; Lambert's law

Combining the two laws



$$I_0 / I = e^{-EdC}$$

E: Extinction coefficient, a constant

e: natural log

In simple terms

Absorption of light passing through a medium increases with

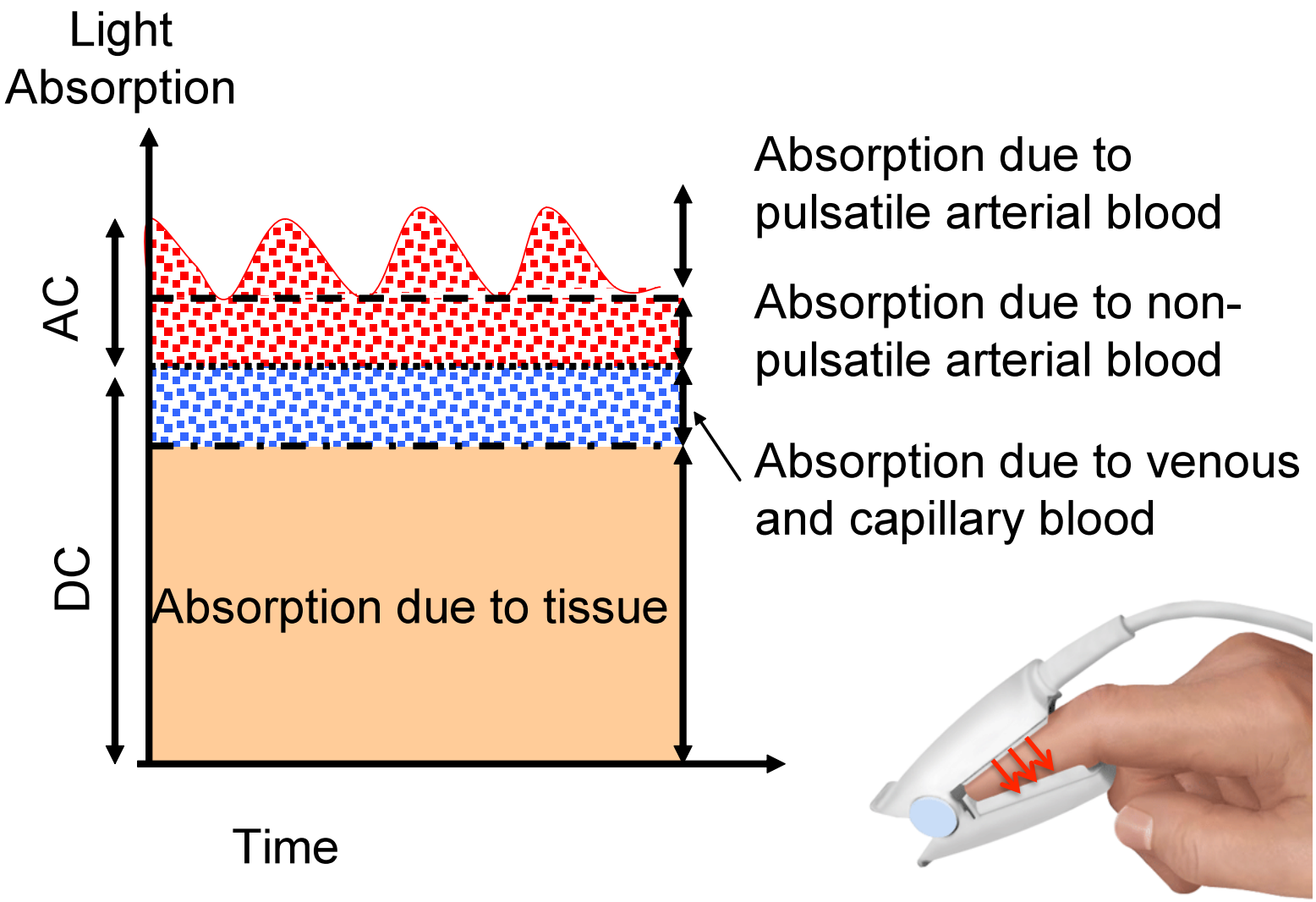
1. Concentration: greater the number of molecules, greater the absorption

2. The distance through which the light travels: greater the distance, more the number of molecules it encounters on the way, greater the absorption

AC/DC Components

Pulsatile and Non Pulsatile components

Skin and Subcutaneous Tissues
Muscle and Bones
Blood Vessels


Light Absorption
AC
DC
Absorption due to pulsatile arterial blood
Absorption due to non-pulsatile arterial blood
Absorption due to venous and capillary blood
Absorption due to tissue
Time

Pulse oximeters

- Discriminates between arterial blood and other components by determining the change in transmitted light caused by the flow of arterial blood

- The two LEDs cycle ON and OFF between 2000 and 3000 times / sec, with only one ON at a time, and a third point in the cycle when both are OFF, so the photodetector can adjust for ambient light

Pulse oximeters

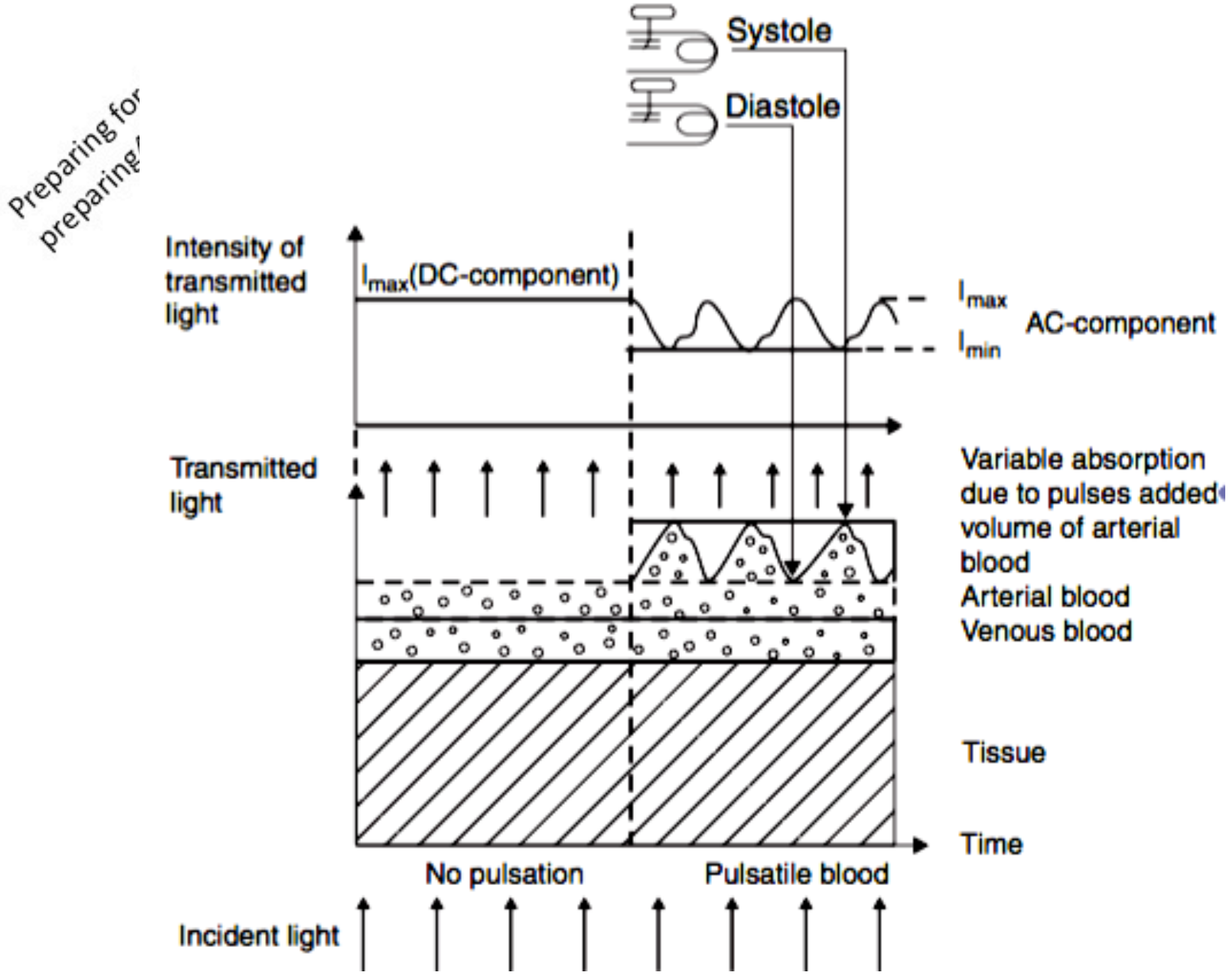
- At the trough, the light is transmitted through a vascular bed that contains mainly capillary and venous blood as well as intervening tissue

- At the peak, it shines through all this plus arterial blood

- The rapid sampling rate allows recognition of the peak and trough of each pulse wave

Pulse oximeters

- A photodiode collects the transmitted light and converts it into electrical signals
- The emitted signals are then amplified, processed, and displayed on the monitor


Preparing for
preparing
Systole
Diastole
Intensity of
transmitted
light
I_{max}(DC-component)
I_{max}
I_{min}
AC-component
Transmitted
light
Variable absorption
due to pulses added
volume of arterial
blood
Arterial blood
Venous blood
Tissue
Time
No pulsation
Pulsatile blood
Incident light

Plethysmography

- During each arterial pulsation the site expands in volume as arterial blood enters during systole, and then contracts as the blood leaves during diastole

- The path length of light through the finger- tip increases and decreases cyclically with each pulsation, and is “seen” by the photodetector as pulsatile changes in absorbance at the two wavelengths of light, 660 nm and 940 nm

Light absorbance in tissue

1. Nonpulsatile component: nonpulsatile blood and tissue (i.e., bone, skin, muscle) pigmentation that produces a (non-pulsatile) direct current (DC)

2. Pulsatile component: pulsation of the artery, which produces an alternating current (AC)

Light absorption

- During diastole, only by deoxygenated (venous blood, DC components)
- During systole, is increased at both wavelengths, and these pulse-added absorbances are therefore caused by hemoglobin in the arterial blood (in addition to DC components).

Absorption ratio

- The ratio of pulse-added absorbances AC_{660}/ AC_{940} nm is made independent of the intensity of the incident light by calculating the absorption ratio, R, where

$$R = \frac{(AC_{660}/DC_{660})}{(AC_{940}/DC_{940})}$$

The Value

The algorithm

Oxygen saturation

- Fractional oxygen saturation (% HbO_2) is the ratio of oxyhemoglobin to the sum of all hemoglobin species present, whether available for reversible binding to oxygen or not

- Functional oxygen saturation (SaO_2) is defined as the ratio of oxyhemoglobin to all functional hemoglobins

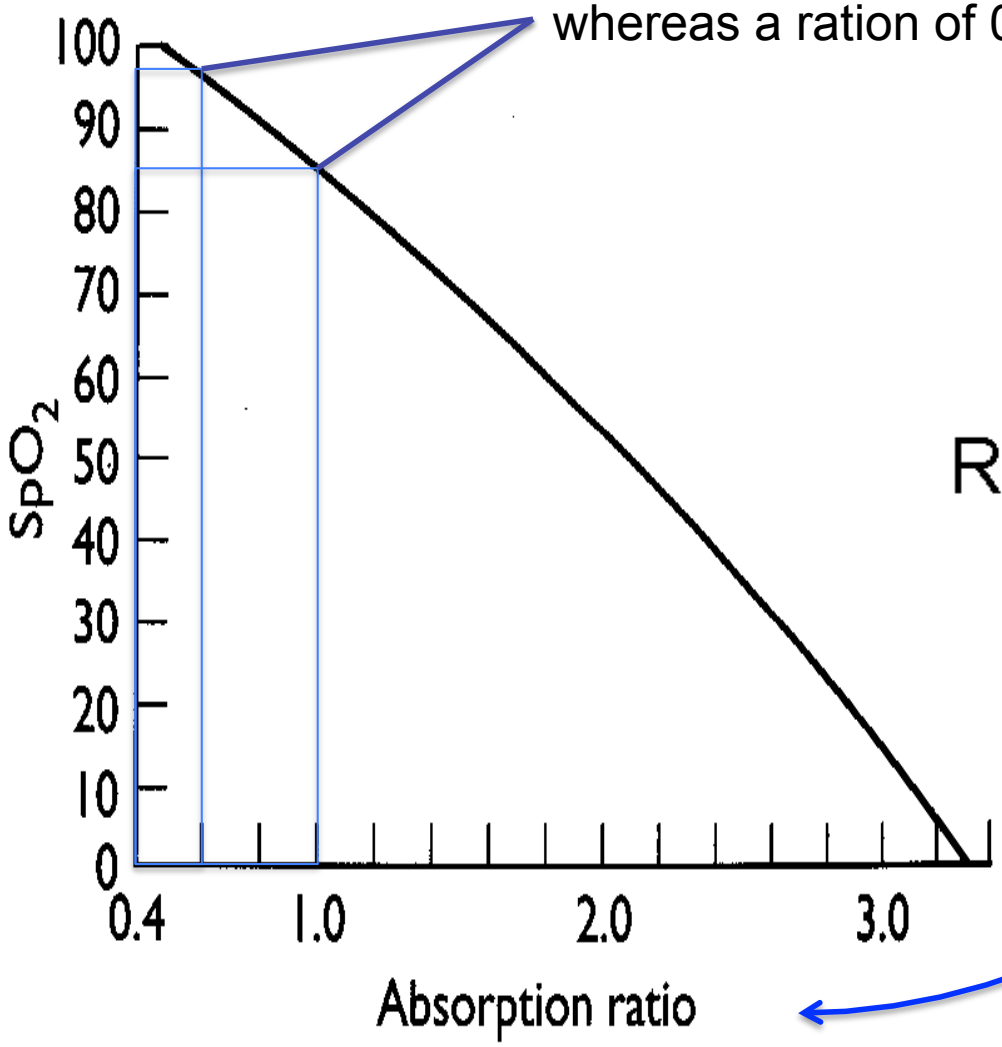
Functional vs fractional

HHb = 0, HbO2 = 96%, COHb = 2%, metHb = 2%

- Functional saturation (SaO_2) = 96/(96 + 0) = 100%
- Fractional saturation (HbO_2 %) = 96/(96 + 2 + 2) = 96%
- Most manufacturers chose to use functional saturation in creating their algorithms

The algorithm

Absorption ration of 1.0 corresponds to 85%
whereas a ration of 0.6 corresponds to 97%



$$R = \frac{AC_{660} / DC_{660}}{AC_{940} / DC_{940}}$$

Limitations

Safe Limitations

Technical

- Mechanical/Motion artefacts
- Electromagnetic - interference
- M.R.I

Physiological

- Pulse dependence
- Pulse Volume
- Pulse Rhythm

Dangerous Limitations

Technical

- Accuracy
- Calibration
- Flooding
- Penumbra

Physiological

- Abnormal Hb
- Other absorbents and pigmentations
- Dyes
- Delay
- Pulsatile veins

Artifacts in pulse oximetry

Toxic Alterations in Hemoglobin

Carboxyhemoglobin (COHb)	Slight reduction of the assessment of oxygen saturation (SaO_2) by pulse oximetry (SpO_2) (i.e., overestimates the fraction of hemoglobin available for O_2 transport)
Cyanmethemoglobin	Not reported
Methemoglobin (MetHb)	At high levels of MetHb, SpO_2 approaches 85%, independent of actual SaO_2
Sulfhemoglobin	Not reported (affects CO oximetry by producing a falsely high reading of MetHb)

Structural Hemoglobinopathies

Hemoglobin F	No significant effect
Hemoglobin H	No significant effect (i.e., overestimates the fraction of hemoglobin available for O2 transport)
Hemoglobin Köln	Artifactual reduction in SpO_2 of 8% to 10%
Hemoglobin S	No significant effect

Hb substitutes

Diaspirin cross-linked hemoglobin	No significant effect
Bovine polymerized hemoglobin (oxygen carrier-201)	No significant effect

Dyes

Fluorescein	No significant effect
Indigo carmine	Transient decrease
Indocyanine green	Transient decrease
Isosulfan blue (patent blue V)	No significant effect at low dose; prolonged reduction in SpO_2 at high dose
Methylene blue	Transient, marked decrease in SpO_2 lasting up to several minutes; possible secondary effects as a result of effects on hemodynamics

Hb Concentration

Anemia	If SaO_2 is normal, no effect; during hypoxemia with Hb values less than 14.5 g/dL, progressive underestimation of actual SaO_2
Polycythemia	No significant effect

Others

Acrylic fingernails	No significant effect
Ambient light interference	Bright light, particularly if flicker frequency is close to a harmonic of the light-emitting diode switching frequency, can falsely elevate the SpO_2 reading
Arterial O_2 saturation	Depends on manufacturer; during hypoxemia, SpO_2 tends to be artifactually
low Blood flow	Reduced amplitude of pulsations can hinder obtaining a reading or cause a falsely low reading
Henna	Red henna, no effect; black henna, may block light sufficiently to preclude measurement

Others

Jaundice	No effect; multiwavelength laboratory oximeters may register a falsely low SaO_2 and falsely high COHb and MetHb
Motion	Movement, especially shivering, may depress the SpO_2 reading
Nail polish	Slight decrease in SpO_2 reading, with greatest effect using blue nail polish, or no change
Sensor contact	“Optical shunting” of light from source to detector directly or by reflection from skin results in falsely low SpO_2 reading

Others

Skin pigmentation	Small errors or no significant effect reported; deep pigmentation can result in reduced signal
Tape	Transparent tape between sensor and skin has little effect; falsely low SpO_2 has been reported when smeared adhesive is in the optical path
Vasodilatation	Slight decrease
Venous pulsation (e.g., tricuspid insufficiency)	Artifactual decrease in SpO_2

Preparing4frca.com

Dr S Singh
Consultant in Anaesthesia
Royal Liverpool University Hospitals