Measurement of Transmited/Reflected Radiation and Calculation of Absorbance

The intensity of light in a medium in general or in tissue, I, drops exponentially as it propagates deeper, Figure 1.

$$I = I_0 \, e^{-\varepsilon \ell c}$$

where I_o is intensity of the incident radiation on the medium, ε Is the molar absorptivity coefficient of the medium, ℓ is the path length, and c is the concentration.

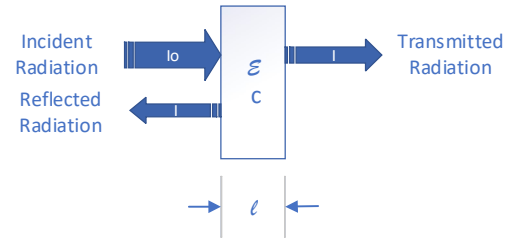

Figure 1

The transmittance is defined as

$$T = I / I_0, \text{ therefore } T = e^{-\varepsilon \ell c}$$

and the absorbance as

$$A = -\log(T), \text{ hence } A = 0.4343 \, \varepsilon \, \ell \, c, \text{ the Beer-Lambert law}$$

For blood glucose or other analytes, a part of skin is irradiated by $I = I_{skin}$ (transmitted or reflected radiation based on probe design) is measured. To avoid having to measure I_0, a measurement, I_{ref}, using a stable medium serving as reference baseline is used and the transmittance is calculated as:

$$T = (I_{skin} / I_o) / (I_{ref} / I_o) = I_{skin} / I_{ref}$$

In PDS, I_{max}, the signal at the peak of the systolic phase of the heart and I_{min}, the signal at the valley of the diastolic phase (see Figure 2 and Figure 4) are used to calculate the Transmittance as:

$$T = I_{max} / I_{min}$$

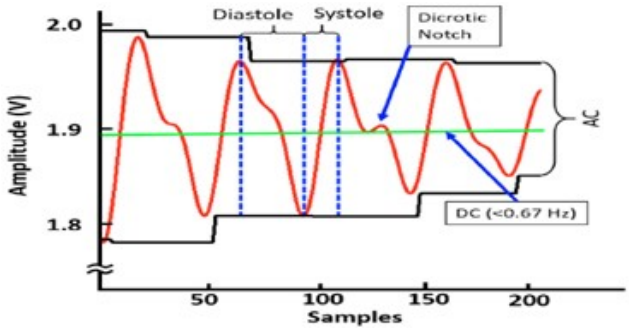

Figure 2

Transmitance is of course untitles and hence is Absorbance. The molar absortivity coeeficient is given in units of L / mol cm, the path length in cm, and the concentration in mol / L. For path length in mm and concentration in mg/dL, ε [dL/mg mm] = ε [L/g cm] / 0.645×10^6.

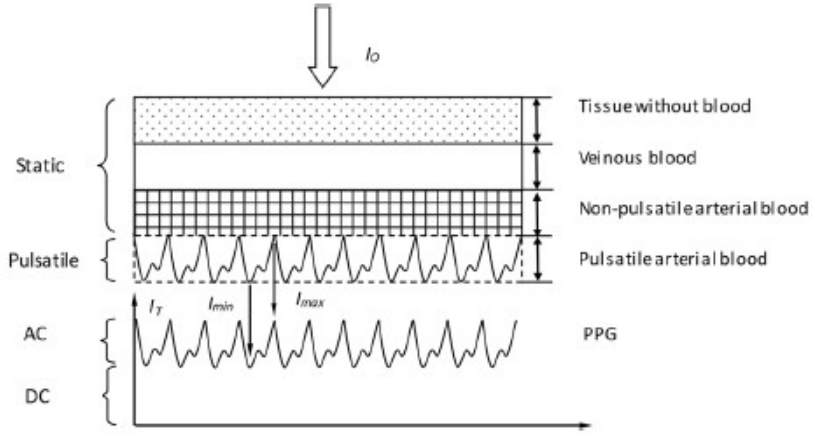

Figure 3

Skin Physiology and Spectra

The skin is made up of three distinct layers (see Figure 4).

- The top layer is called the epidermis. The epidermis is translucent. That is, it allows light to pass partially through it, rather as frosted glass does. The epidermis does not contain any blood vessels but gets its oxygen and nutrients from the deeper layers of the skin. At the bottom of the epidermis is a very thin membrane, called the basement membrane, which attaches the epidermis firmly, though not rigidly, to the layer below.
- The second layer lies deeper and is called the dermis. It contains blood vessels, nerves, hair roots and sweat glands.
- The third layer is called Subcutis. It lies below the dermis and consists of fat and larger blood vessels and nerves. The depth of this layer differs from one person to another.

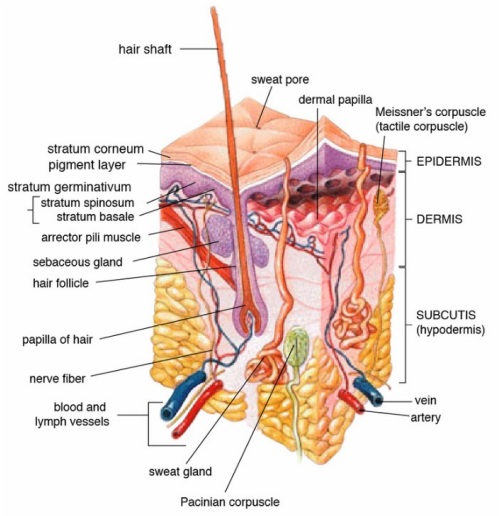

Figure 4

Light penetration into the skin differs over spectral bands (see Figure 5). A small percentage ~8% reaches the capilary bed in the dermis above 1000nm.

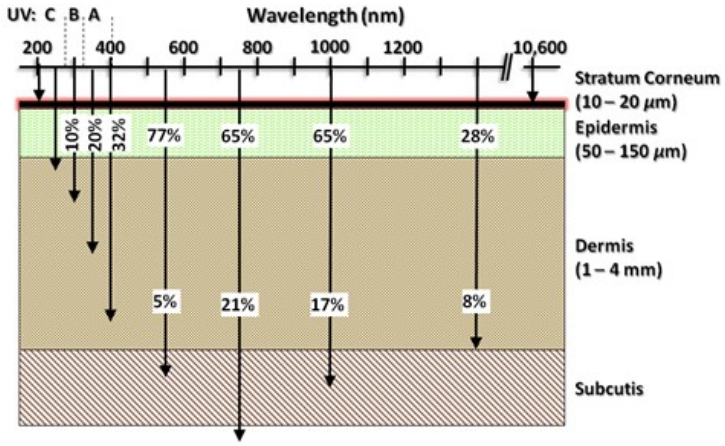

Figure 5

Figure 6 shows the NIR biological window. Artemis patetend band is from 1200nm to 1900nm. Figure 6 shows oxyhemoglobin, deoxyheamoglobin, melanin, and water absorbance spectra. Several absorbance samples at different wavelengths need to be acquired in order to get an accurate estimate of the perpective analyte.

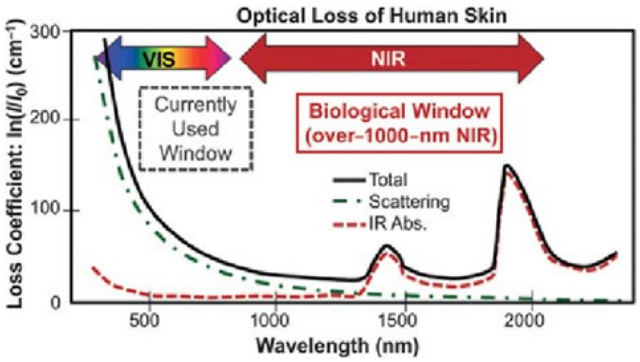

Figure 6

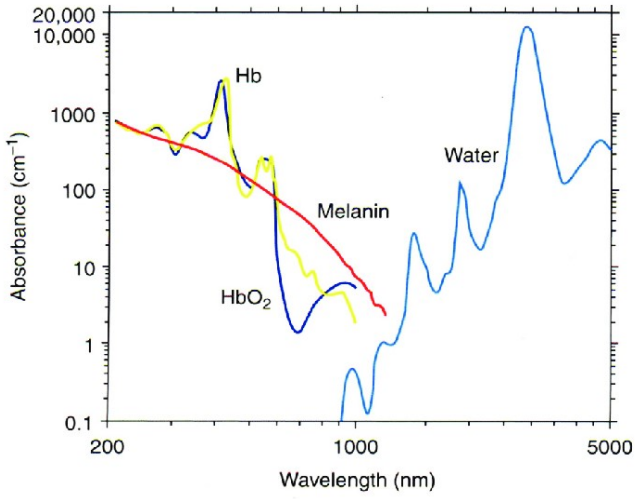

Figure 7

Calculation of Analyte Concentration

In measurement mode, the predicted glucose concentration, g_p, is calculated from a single measurement of the absorbance spectrum, **A** of size 1 X m, and a stored calibration vector, **b of size** m X 1.

$$\mathbf{g_p = A\ b}$$

Development of PLS Calibration Vector

Consider n measurements of absorbance at m wavelengths, forming a size n X m matrix, **A,** and n associated reference measurements of glucose (or other analyte of interest) concentration by a precise reference instrument, forming a vector, $\mathbf{g}_r$ of size n X 1.

A calibration vector, **b**, can be developed using n measurements in calibration mode by processing the following.

$\mathbf{b} = (\mathbf{A}^T\mathbf{A})^{-1}\ \mathbf{A}^T\mathbf{g}_r$, where $(\mathbf{A}^T\mathbf{A})^{-1}\ \mathbf{A}^T$ is the Moon-Penrose inverse

The above expression is also recognized as the realization of the causal Wiener filter allowing the number of required calibration measurements, n, to be reduced drastically per Marbach. Otherwise some measurements can be ignored based on some criteria developed by Grata in order to obtain a better calibration vector and more accurate predictions. There are other ways to estimate glucose or other analyte concentrations such as wavelet decomposition.