# MiPArt – Mitchell's dream

by Odra Noel
http://odranoel.eu/category/mitochondrial-art

*Science is beautiful: it has truth, it has drama, it is full of wonder. The **Mitchell's dream** series is a vision of some aspects of science through art. I hope it explains, inspires or makes you curious to find out more.*
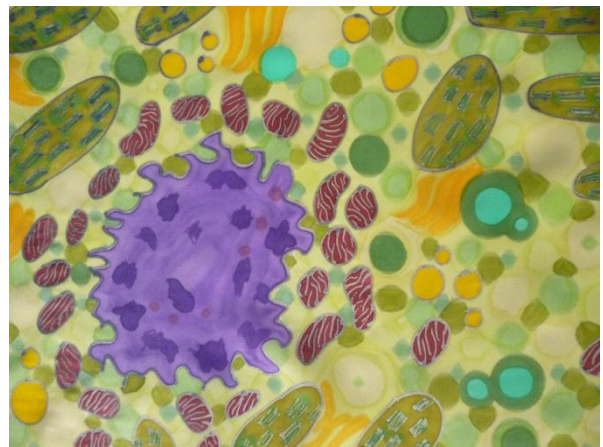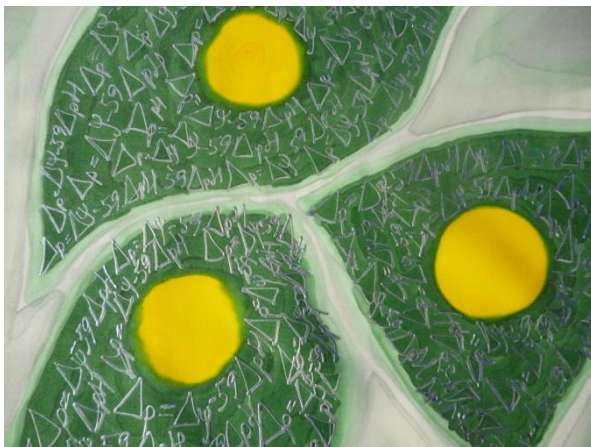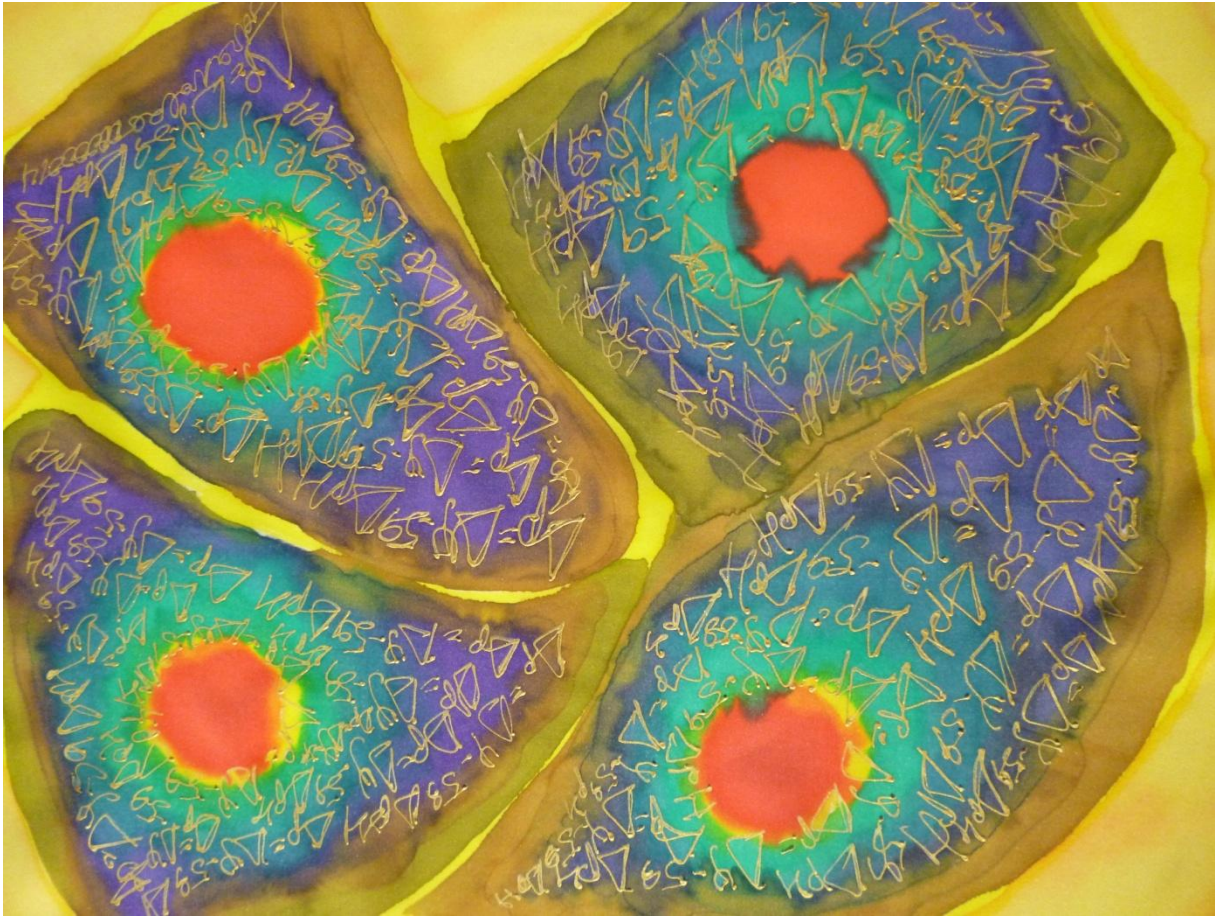
MiPArt – Mitchell's equation

by Erich Gnaiger

Do you ever dream about an equation?

The *Mitchell's dream series* by Odra Noel is a dream on equations and shows a dream on the equation that penetrates all of biology since Peter D Mitchell started publishing on the protonmotive force equation [1]. Can we imagine how many dreaming was required until the chemiosmotic hypothesis emerged on energy coupling by the protonmotive force of oxidative phosphorylation in the bioblasts, which comprise the mitochondria, chloroplasts, bacteria and archaea? Seeing Odra Noel's pictures on *Mitchell's dream* provides insights into the equations of biophysics and biochemistry: these equations do not just belong to our books. They do belong to our cells, our bioblasts, to the living world. It is the mitochondria that help us to understand these equations, since the equations are in the mitochondria, they are the visible parts of the mitochondria and open in*sights* into function beyond the visible form – this is mitochondrial physiology.

Do you feel part of the equation?

An equation (or it's opposite) connects two sides by the equal (or unequal) sign,

$$= \tag{1}$$

The left side may show simply a symbol,

$$\Delta p_{mt} =$$

This symbol is defined as being equal to a combination of various parts on the right side,

$$\Delta p_{mt} = \textit{electric part} + \textit{chemical part} \tag{2}$$

and these parts may again be shown simply as symbols,

$$\Delta p_{mt} = \Delta \Psi_{mt} + \Delta \mu_{H+}/F \tag{3}$$

The *electric* part is the potential difference across the inner mitochondrial (mt) membrane, $\Delta \Psi_{mt}$. This suggests that the protonmotive force in the form of Equation 3 should be expressed in the electric unit of volt [V]. *Electric* force of the mitochondrial membrane potential is the electric energy change per 'motive' electron or per electron moved across the transmembrane potential difference, with the number of 'motive' electrons expressed in the unit coulomb [C].

Therefore, the *chemical* part, $\Delta \mu_{H+}/F$, which stems from the difference of pH across the mt-membrane, contains a factor that bridges the gap between the *electric* force [J/C] and the *chemical* force [J/mol]. This factor is the Faraday constant, F, for conversion between *electric* force expressed in joules per coulomb or Volt [V=J/C] and *chemical* force with the unit joules per mole or Jol [Jol=J/mol],

$$F = 96.4853 \text{ kJol/V} = 96{,}485.3 \text{ C/mol}$$

Generally, a force is the change of potentially available or 'free' energy (exergy) per 'motive' unit [2]. The *chemical* force or chemical potential of the 'motive' proton is the exergy change [J] per 'motive' amount of substance [mol]. Protonmotive means that the proton is moved across the mt-membrane at ΔpH maintained across the mt-membrane,

$$\Delta \mu_{H+} = -2.3 \cdot RT \cdot \Delta \text{pH} \tag{4}$$

This chemical force is the *difference* (Δ) of chemical potential across the inner mitochondrial membrane. Mitchell's equation and Odra Noel's pictures don't show proton *gradients* or membrane potential *gradients* – this dream belongs to another group.

The right side of Equations (2) and (3) helps us to separate the different parts, which require different methods of measurement, are expressed in different units, confuse us with different sign conventions and scientific nomenclature with terminological incompatibilities. On which side of the equation are you at home? Which part is more your part? Do you feel part of the equation?

On the other hand, the left side of the equation brings the different parts together in a unifying concept. With full focus on the equation, do we still see the mitochondria? Odra Noel places the sides and parts of the equation where they belong: They are parts of the bioblasts, they are the essence of the mitochondria themselves. Unification is brought to the limit of reduction in the form of Equation 1:

We have to write $\Delta \Psi_{mt}$ to point out that the mitochondrial membrane potential difference is in our mind. However, $\Delta \Psi$ in Odra Noel's pictures **is** the mitochondrion, the mt does not have to be written *into* the pictures, mt is essentially shown *by* the pictures. The *Mitchell's dream series* illustrates the importance of putting a symbol in the right form at the right place for understanding an equation and easily identifying the meaning of the symbol. *Mitchell's dream* is a symbol of form and function – form and function is the mitochondrial physiologist's dream.

1. Mitchell P (1961) Coupling of phosphorylation to electron and hydrogen transfer by a chemi-osmotic type of mechanism. Nature 191: 144-148.
2. Gnaiger E (1993) Nonequilibrium thermodynamics of energy transformations. Pure Appl Chem 65: 1983-2002.