

# "The rainbow and the worm"

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# Outline

The full title of this book, which Mae-Wan Ho described as 'the most exciting thing I have ever written'<sup>p.xix</sup> is

- ▶ 'The rainbow and the worm : the physics of organisms'.

The book was motivated by a question posed by the physicist Erwin Schroedinger<sup>†</sup> :

- ▶ 'How can the events that take place within a living organism be accounted for by physics and chemistry?'

The book ranges over an enormous variety of topics arising out of this question. The ones that seem to me most important are :

- ▶ I. Looking at living matter with polarized light
- ▶ II. Liquid crystals
- ▶ III. Water
- ▶ IV. Coherence
- ▶ V. Thermodynamics of organized complexity
- ▶ VI. Consciousness, time and Free Will

<sup>†</sup> Schroedinger, E, *What is life?* (Cambridge 1943, Dover reprint circa 1960)

# I. Looking at living matter with polarized light

- ▶ Pictures showing embryos of *drosophila* (a kind of fruit fly) under a polarizing microscope p 207 were shown in the talk. Examples of such pictures are on the outside cover of the book.
- ▶ What is polarized light?
- ▶ How it informs us about micro-structure, *i.e.* about the degree of coherent order.

## II. Liquid crystals

- ▶ A liquid crystal is a state of matter in which the molecules (often needle-shaped) are to some extent ordered in a way similar to a solid crystal, but move around much more than in a solid crystal, so that the substance can flow like a liquid
- ▶ It can affect polarized light (showing interference colours in a suitable microscope<sub>p 219</sub>) in a way that enables the principal direction along which the molecules are ordered to be observed
- ▶ In a growing organism, direction of the liquid crystals agrees with the "head-to-tail" direction of the organism<sub>p 221, 233</sub>
- ▶ Liquid crystals may be involved in registering the long-term memory that enables developing organisms to make specific structures and organs later on in development <sub>p 225</sub>

### III. Water

- ▶ About 75 % per cent of your body is water p 120
- ▶ Shape of the water molecule: like a regular tetrahedron with an oxygen atom in the middle, (positively charged) hydrogen atoms at two of the corners and concentrations of negative charge, called hydrogen bonds, at the other two corners
- ▶ Water molecules can be linked together in many ways, each hydrogen atom pairing up with a hydrogen bond on another molecule
- ▶ For example, they can form a chain along which positive electric current can flow very quickly p 256
- ▶ There is some evidence for the formation of some kind of liquid crystal water, possibly such a chain, in fibres of collagen in living matter p 262

## IV. Coherence

- ▶ Coherence = large-scale orderly motion in a system of particles
- ▶ Liquid crystals can be thought of as an example of coherence
- ▶ Herbert Froehlich (1968) considered (theoretically) waves in a system of movable electric charges. If energy is supplied quickly enough a steady state is reached where a single mode of oscillation is strongly, i.e. coherently, excited. The energy going into this mode is stored there rather than being dissipated frictionally into random motions (i.e. heat). He suggested that this possibility might have far-reaching biological consequences.

Froehlich, H. *Long-range coherence and energy storage in living systems*  
Int. J. Quantum Chemistry **2** (1968) 641-649 (a frequently cited paper)

## IVa Quantum coherence

Mae-Wan's poetic vision of the complex molecular motions in living matter, a vision inspired by some of the mysterious features of quantum physics, is described below. She calls this "quantum coherence":

- ▶ 'Imagine an immensely huge super-orchestra playing with instruments spanning an incredible spectrum of sizes from a molecular or atomic piccolo of less than  $10^{-9}$  metre up to a bassoon or bass viol of metre dimensions, and a musical range of perhaps 72 *octaves*. The amazing thing about this super-orchestra is that it never ceases to play out our individual song lines, with a certain recurring rhythm and beat, but in endless variations that never repeat exactly. . . . Furthermore, each and every player, however small, can enjoy maximum freedom of expression, improvising from moment to moment, while maintaining in step and in tune with the whole.' p283

## V Thermodynamics of organized complexity

- ▶ Classical thermodynamics is a theory of energy transformations originally developed with the object of making steam engines more efficient. It applies to equilibrium states and quasi-static processes (i.e. ones which can be approximated as a succession of equilibrium states). But living organisms are not in equilibrium
- ▶ Thermodynamics, if it is to describe living systems adequately, needs to be generalized so that it is not restricted to equilibrium and approximately equilibrium states.
- ▶ The processes in a living system consist of (i) reversible cyclic processes (to which classical thermodynamics would apply) and (ii) irreversible (dissipative) processes outside the scope of classical equilibrium thermodynamics.
- ▶ The living system is effectively partitioned into subsystems, each with its own time scale for coming to local equilibrium.



## VI Consciousness, time and free will

- ▶ The hallmarks of consciousness are sentience (responsiveness), intercommunication and memory<sub>p237</sub>
- ▶ Body consciousness (a different thing from brain consciousness) is not localized in brain or heart but is spread throughout the liquid crystalline continuum of the body<sub>p229</sub>
- ▶ The mechanistic picture of time as a succession of discrete instants, which all Western scientific theories are still based upon<sub>p314</sub>, does not match our experience, in which every moment contains memories of the past and expectations about the future (as argued by Henri Bergson<sup>†</sup>)<sub>p318</sub>
- ▶ The problem of free will versus determinism comes from a mechanistic picture of the world. But in reality, the self does not pass like an automaton from one frozen instant to the next; instead it 'lives and develops by means of its very hesitations, until the free action drops from it like an over-ripe fruit'.<sup>†</sup><sub>p332</sub>

<sup>†</sup>H Bergson *Time and free will, an essay on the immediate data of consciousness* George Allen and Unwin 1916