VI

What is life?

http://sgoodwin.staff.shef.ac.uk/phy229.html
6.0 Introduction

If we are looking for 'life' we need to have as general a definition as possible of what we are looking for.

This is very problematic and is argued about by biologists, chemists, physicists, and philosophers...

(Later we will touch on the great problems of also defining 'intelligence' and 'technology' as well.)
Before we discuss a general definition of 'life' we should examine the basic properties of life on Earth. Biologists generally agree that life exhibits the following properties:

**HOMEOSTATIS**: being able to regulate its internal environment which is partially isolated from its surroundings (e.g. in a cell).

**METABOLISM**: using energy to build larger (biological) molecules from smaller molecules/elements (anabolism), or creating energy by decomposing (biological) molecules into simpler compounds (catabolism).

**RESPONSE TO STIMULI**: an ability to 'sense' the environment outside the organism and respond to changes in that environment.
6.1 The properties of life

**GROWTH**: maintaining a higher rate of the synthesis of biological material than simple just catabolism (ie. building complex molecules, rather than just decomposing them).

**REPRODUCTION**: the ability to create new organisms (sexually or asexually).

**ADAPTATION**: the ability to change in response to the environment. This is fundamental to Darwinian evolution.

Many biologists would also argue that the **cell** is a fundamental property of life as a container for the biochemistry required by life.
6.2 Problems

These properties seem to describe life fairly well, they appear to be applicable to humans, plants, bacteria...

However, there are problem cases:

Reproduction. If an organism is unable to reproduce then is it still alive? Worker ants are sterile, but work to ensure that the species (in the form of the queen) reproduces – so must this be applied species-wide, rather than individually?

Mules are sterile, and so the mule hybrid species (donkey + horse) can never reproduce or adapt, but are clearly alive. Individual cells within a mule do reproduce, so should this count?
6.3 Are viruses alive?

The problem of defining life is most keenly seen in viruses.

Viruses are complexes of organic molecules that can infect a cell and reproduce via this infection. A virus is basically some genetic material encased in a protective protein shell.

A virus will introduce its genetic material (DNA) into a cell. The genetic material contains the instructions for building a new virus and the cell machinery is co-opted into producing the constituent parts of the virus (proteins for the shell and copies of the genetic material) which then self-assemble within the cell.
6.3 Are viruses alive?

Pros:

- A virus does *respond* to external stimuli, seeking cells in which to reproduce.
- A virus can *reproduce* (although not on their own, however bacteria such as chlamydia also require a host cell in order to reproduce).
- A virus can *adapt* (it has genetic material in which copying errors may occur causing changes, some of which will be advantageous).

3/6 for life...
6.3 Are viruses alive?

Cons:
- Viruses *self-assemble* within the infected cell rather than by a 'deliberate' reproductive act (such as cell division).
- A virus *does not have an internal environment* (ie. within a cell) which is optimised (homeostasis).
- A virus *does not grow*, it is merely a container for transporting genetic material from one cell to another in which it can reproduce.

3/6 against life...

The general consensus is that viruses are *not alive*. However they focus attention on the exact definition of life (and possibly the spontaneous origin of life).
6.4 Thermodynamic definitions of life

In astrobiology we would like as broad a definition of life as possible to allow us to recognise life even if it does not conform to our (limited) terrestrial examples.

As physicists we can look at life as a thermodynamic process (see chapter 7 in Lunine). One property of life is that it is highly out of equilibrium with its surroundings. Physical systems will always try and place themselves in thermal, chemical and mechanical equilibrium. However life – in our earlier definition – is a system that, though homeostatis, attempts to regulate its internal environment to stay out of equilibrium.
In thermodynamics entropy is a measure of the degree of order (or information) in a system. The lower the entropy, the higher the degree of order.

For example: 'the cat sat on the mat' has a high information content (in English), and so low entropy. 'hostc tna e athate tm' has low information content (in English), and so high entropy (despite having exactly the same components).

Formally, entropy is a measure of the number of microscopic (quantum) states available to a system (from statistical mechanics - PHY203).
6.4 The 2nd law of thermodynamics

The second law of thermodynamics (often called the fundamental law of physics) states that the entropy of any isolated system will increase with time – that is it will become more disordered.

Possibly the defining feature of living organisms is that they increase their internal order (decrease their entropy): converting simple molecules into complex molecules, creating a highly ordered and structured system, and then keeping that system out of equilibrium with its environment.

(Death has been described as finally giving-in to the second law).
6.4 The 2nd law of thermodynamics

Life however is not in conflict with the second law, a living organism is not an isolated system. Living things are able to increase their internal order by making use of external energy sources (usually solar energy – directly through photosynthesis, or indirectly by consuming other organisms). So, whilst local entropy may decrease significantly, the entropy of the Universe increases.

Solar energy is of very low entropy – that is there are many possible states available to high-energy photons. They can be converted into thermal, mechanical or chemical energy, or into lower-energy photons (all of which life does with solar energy).
6.5 Viruses and entropy

Given a possible understanding of life in terms of increasing (local) entropy – is a virus alive?

A virus is not out of equilibrium with its surroundings (it is just some genetic material within a shell). Nor does it act to increase its internal order. A virus is constructed (i.e. the work is done) by a cell, and the virus self-assembles within the cell (actually increasing entropy). Therefore we would think it is not alive.

However, a virus cannot self-assemble without a cell having produced its components by lowering local entropy. So possibly a virus is alive as a parasite?
Entropy isn't everything – there are non-living systems that can decrease their local entropy (crystals etc.).

Life is also very complex – that is it is information-rich, and the whole is much more than a sum of the (biochemical) parts.

Developments in complexity theory and emergent behaviour show that large systems with a few very simple basic rules can develop very complex behaviour on a macro-scale. (Complex flocking behaviour can be reproduced by 3 very simple rules.)

It might be that simple physics + chemistry on micro-scales develops (rapidly?) to complex macro-scale behaviour that is biology.
At what point could humans be said to have produced artificial life? Clearly, if we were able to synthesise all of the components of a cell from non-life and assemble them into a working cell we would have created life.

It is also possible in theory to construct non-biological life. If we were able to construct a robot (or linked series of computers and robots) that were able to use sources of energy and matter to construct new components, and have the ability to vary the construction to adapt to their environment, then surely that would be life?

It would be complex, out-of-equilibrium and lower local entropy...
A working definition of life

Life utilises energy and material from an external source (metabolism) to (a) increase its internal order (growth), and (b) optimise its internal environment (homeostatis).

As a by-product, life will also tend to produce (imperfect) copies of itself (reproduction and adaptation) and have to find the optimum places to obtain energy and material (respond to stimuli).

In life based on (bio)chemistry this probably means some sort of cell structure in order to partially isolate itself from its surroundings.

From an astrobiologist's perspective the signatures of life are complexity and non-equilibrium conditions.