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**1.**

**Energetics** is the scientific study of energy flows and storages under transformation. Because energy flows at all scales, from the quantum level, to the biosphere and cosmos, energetics is therefore a very broad discipline, encompassing for example thermodynamics, chemistry, [biological energetics](http://www.bionity.com/en/encyclopedia/Biological_thermodynamics.html), [biochemistry](http://www.bionity.com/en/encyclopedia/Biochemistry.html) and ecological energetics. Where each branch of energetics begins and ends is a topic of constant debate. For example, Lehninger (1973, p.21) contended that when the science of thermodynamics deals with energy exchanges of all types, it can be called energetics.

## 2.

In general, energetics is concerned with seeking principles that accurately describe the useful and non-useful tendencies of energy flows and storages under transformation. 'Principles' are understood here as phenomena which behave like historical invariants under multiple observations. When some critical number of people have observed such invariance, such a principle is usually then given the status of a 'fundamental law' of science. Like in all science, whether or not a theorem or principle is considered a fundamental law appears to depend on how many people agree to such a proposition. The ultimate aim of energetics therefore is the description of fundamental laws. Philosophers of science have held that the fundamental laws of thermodynamics can be treated as the laws of energetics, (Reiser 1926, p.432). Through the clarification of these laws energetics aims to produce reliable predictions about energy flow and storage transformations at any scale; nano to macro.

## 3.

Energetics has a controversial history. Some authors maintain that the origins of energetics can be found in the work of the ancient Greeks, but that the mathematical formalisation began with the work of Leibniz. Liet.-Col. Richard de Villamil (1928) said that Rankine formulated the Science of Energetics in his paper *Outlines of the Science of Energetics* published in the Proceedings of the Philosophical Society of Glasgow in 1855. W. Ostwald and E. Mach subsequently developed the study and in the late 1800s energetics was understood to be incompatible with the atomic view of the atom forwarded by Boltzmann's gas theory. Proof of the atom settled the dispute but not without significant damage. In the 1920's Lotka then attempted to build on Boltzmann's views through a mathematical synthesis of energetics with biological evolutionary theory. Lotka proposed that the selective principle of evolution was one which favoured the maximum useful energy flow transformation. This view subsequently influenced the further development of ecological energetics, especially the work of [Howard T. Odum](http://www.bionity.com/en/encyclopedia/Howard_T._Odum.html).

De Villamil attempted to clarify the scope of energetics with respects to other branches of physics by contriving a system that divides mechanics into two branches; energetics (the science of energy) and "pure", "abstract" or "rigid" dynamics (the science of momentum). According to Villamil energetics can be mathematically characterised by scalar equations, and rigid dynamics by vectorial equations. In this division the dimensions for dynamics are *space*, time and mass, and for energetics, *length*, time and mass (Villamil 1928, p.9). This division is made according to fundamental pressuppositions about the properties of bodies which can be expressed according to how one answers to following two questions:

1. Are particles rigidly fixed to together?

2. Is there any machinery for stopping moving bodies?

In Villamil's classification system, dynamics says yes to 1 and no to 2, whereas energetics says no to 1 and yes to 2. Therefore, Villamil's in system, dynamics assumes that particles are rigidly fixed together and cannot vibrate, and consequently must all be at zero temperature. The conservation of momentum is a consequence of this view, however it is considered valid only in logic and not to be a true representation of the facts (Villamil, p. 96). In contrast energetics does not assume that particles are rigidly fixed together, particles are therefore free to vibrate, and consequently can be at non-zero temperatures.

## 4.

As a general statement of energy flows under transformation, the principles of energetics include the first four laws of thermodynamics which seek a rigorous description. However the precise place of the laws of thermodynamics within the principles of energetics is a topic currently under debate. If the ecologist [Howard T. Odum](http://www.bionity.com/en/encyclopedia/Howard_T._Odum.html) was right, then the principles of energetics take into consideration a hierarchical ordering of energy forms, which aims to account for the concept of energy quality, and the evolution of the universe. Albert Lehninger (1973, p. 2) called these hierarchical orderings the

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| **“** | ... successive stages in the flow of energy through the biological macrocosm | **”** |

Odum proposed 3 further energetic principles and one corollary that take energy hierarchy into account. The first four principles of energetics are related to the same numbered laws of thermodynamics, and are expanded upon in that article. The final four principles are taken from the ecological energetics of H.T. Odum.

* **Zeroth principle of energetics**

If two thermodynamic systems A and B are in thermal equilibrium, and B and C are also in thermal equilibrium, then A and C are in thermal equilibrium.

* **First principle of energetics**

The increase in the internal energy of a system is equal to the amount of energy added to the system by heating, minus the amount lost in the form of work done by the system on its surroundings.

* **Second principle of energetics**

The total entropy of any isolated thermodynamic system tends to increase over time, approaching a maximum value.

* **Third principle of energetics**

As a system approaches absolute zero of temperature all processes cease and the entropy of the system approaches a minimum value or zero for the case of a perfect crystalline substance.

* **Fourth principle of energetics**

There seem to be two opinions on the fourth principle of energetics:

The Onsager reciprocal relations are sometimes called the fourth law of thermodynamics. As the fourth law of thermodynamics Onsager reciprocal relations would constitute the fourth principle of energetics.

In the field of ecological energetics H.T. Odum considered maximum power, the fourth principle of energetics. Odum also proposed the Maximum empower principle as a corollary of the maximum power principle, and considered it to describe the propensities of evolutionary self-organization.

* **Fifth principle of energetics**

The [energy quality factor](http://www.bionity.com/en/encyclopedia/Transformity.html) increases hierarchically. From studies of ecological food chains, Odum proposed that energy transformations form a hierarchical series measured by [Transformity](http://www.bionity.com/en/encyclopedia/Transformity.html" \o "Transformity) increase (Odum 2000, p. 246). Flows of energy develop hierarchical webs in which inflowing energies interact and are transformed by work processes into energy forms of higher quality that feedback amplifier actions, helping to maximise the power of the system" — (Odum 1994, p. 251)

* **Sixth principle of energetics**

Material cycles have hierarchical patterns measured by the [emergy](http://www.bionity.com/en/encyclopedia/Emergy.html" \o "Emergy)/mass ratio that determines its zone and pulse frequency in the energy hierarchy. (Odum 2000, p. 246). M.T. Brown and V. Buranakarn write, "Generally, emergy per mass is a good indicator of recycle-ability, where materials with high emergy per mass are more recyclable" (2003, p. 1).

http://www.bionity.com/en/encyclopedia/Energetics.html