Specific Entropy of Physical Systems

Daniele Sasso*

Abstract

The concept of entropy is generally defined for systems in which there is a heat exchange and it is connected with concepts of temperature and of internal disorder of system. This paper has the aim of examining the possibility of extending entropy to the generality of physical systems through the concept of specific entropy in which not necessarily heat is the only shape of energy that has to be considered. The outcome is that the concept of entropy can be extended from thermodynamic systems to other physical systems, including mechanical, gravitational and elementary electrodynamic systems. While all physical systems show the same behaviour with respect to the specific entropy, only mass electrodynamic particles show a different behaviour in instability conditions.

1. Introduction

The thermodynamic physicist E. A. Mendoza wrote "In Clapeyron's, Kelvin's and Clausius' hands thermodynamics began to progress only when they freed thermodynamics from the designing of machines"[1].

Similarly today we can say the concept of entropy will be clearer and it will can progress only when we will be able to free it from thermodynamics and to define it for all systems. In thermodynamics the concept of entropy of a physical system is connected with heat and with Kelvin temperature through the relation

$$dS = \frac{dQ}{T} \qquad (1)$$

in which dQ represents the heat exchange between the physical system and the surrounding ambient and T is the Kelvin temperature of the system, assumed practically constant.

A general definition of entropy for all physical systems, besides for thermodynamics, could make use of the more general concept of energy in place of heat:

$$dS = \frac{dE}{T} \qquad (2)$$

in which dE represents the energy exchange between the system and the surrounding ambient.

***e_mail: dgsasso@alice.it**

The temperature is the physical quantity that is connected strictly with heat (thermal energy) and it represents the parameter that measures the heat quantity of the system. Generally the temperature of a system is connected also with the velocity, for instance for gaseous thermodinamic systems and for elementay particles[2]. For mechanical systems energy is directly connected with the concept of velocity, for instance through the kinetic energy, and the temperature in that case doesn't seem an indispensable parameter. A general definition of energy is:

" Energy in various shapes is produced relative to a system, when a work is performed on the system, "

Work is generally the result of the action of a cause on the system. For mechanical and gravitational systems (ordinary bodies) the produced energy, because of a work due to a force, is generally kinetic energy. For thermodynamic systems the produced energy is heat. For electrodynamic systems, represented above all by mass elementary particles, the produced energy is a variation of intrinsic energy: this type of energy is characteristic of mass elementary particles that have a different physical behaviour with respect to ordinary bodies.

2. Physical systems

The physical system is a set of more components or parts that are interconnected in logical way in order to perform a function or to reach an outcome. Any conjunction of more components doesn't represent necessarily a system. For instance a monitor, a keyboard and a central unity constitute a computer system. Similarly the Earth, Jupiter, other planets and the Sun constitute an astronomical system. But a planet and a keyboard don't constitute a system because they are not interconnected in logical and functional way.
The physical process is a transformation or a change that happens into a system under the action of an external cause but it can happen also spontaneously when the system is into an instability state.
Three types of physical systems exist:

1. open systems: they exchange energy and mass with the surrounding ambient
2. closed systems: they exchange only energy and no mass with the surrounding ambient
3. insulated system: they exchange neither energy nor mass with the surrounding ambient.

A physical system and the surrounding ambient constitute the local universe U_L.
The total universe U represents instead the whole of the physical reality. U is therefore an insulated system like thermodynamic insulated systems, called also adiabatic systems.
There are then particular systems that are used in control of physical variables: in this context open systems represent those systems that are unable to control output variables (fig.1). Closed systems instead are called also reaction systems and they have a reaction line that allows to perform a control of output variables (fig.2).

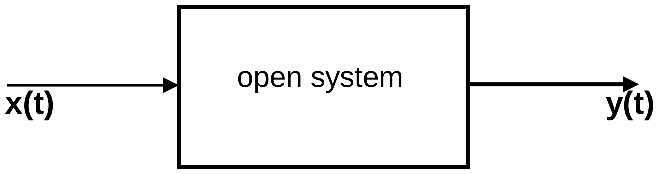

Fig.1 Graphic representation of an open system, x(t) is the input signal and y(t) is the output signal.

In the event of open systems the physical process is defined by the equation that connects the output signal y(t) with the input signal x(t). This relation is represented normally in the time domain by a differential equation, that represents the mathematical model of the system

$$a_n\frac{dy^n(t)}{dt^n} + a_{n-1}\frac{dy^{n-1}}{dt^{n-1}}(t) + \ldots + a_1\frac{dy(t)}{dt} + a_0y(t) = b_m\frac{dx^m(t)}{dt^m} + b_{m-1}\frac{dx^{m-1}}{dt^{m-1}}x(t) + \ldots + b_1\frac{dx(t)}{dt} + b_0x(t) \quad (3)$$

where t is the time variable, x(t) is the input signal, y(t) is the output signal, $dx^m(t)/dt^m$ is the derivative of order m of x(t), $dy^n(t)/dt^n$ is the derivative of order n of y(t).
If coefficients a_i (i=1,...n) and b_j (j=1,...m) are constant the system is linear and the Principle of Superposition is valid.
The closed system presents a reaction signal f(t) that compared with the input signal x(t) allows to control the output signal y(t) through the control signal d(t)=x(t)-f(t).

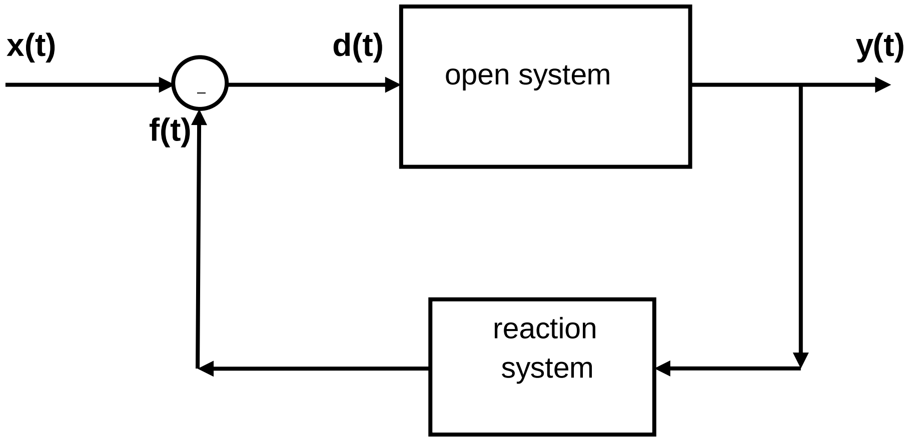

Fig.2 Graphic representation of a closed system, f(t) is the reaction signal and d(t) is the control signal

Control systems are also studied, for advantage of calculation into the domain of Laplace's complex variable s besides into the domain of the time real variable t.

Every single block of system into the domain s is defined by the transfer function that connects in algebraic shape, and therefore non differential, the output signal with the input signal and in the event of closed systems (fig.3) we have

$$G(s) = \frac{Y(s)}{D(s)} \qquad H(s) = \frac{F(s)}{Y(s)} \qquad D(s) = X(s) - F(s) \qquad (4)$$

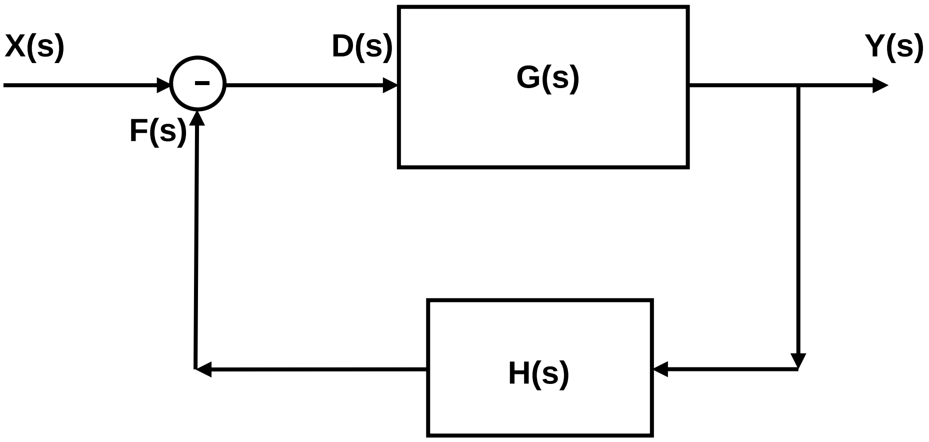

Fig.3 Graphic representation of a closed system into Laplace's domain

System Theory[3] proves the closed system is equivalent to an open system (fig.4) with equivalent transfer function given by

$$G_{eq}(s) = \frac{G(s)}{1 - G(s)H(s)} \qquad (5)$$

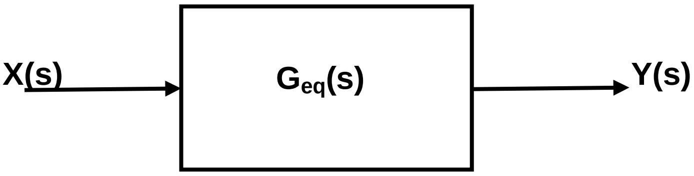

Fig.4 Graphic representation of a closed system through the transfer function of the equivalent open system

In the System Theory the input signal represents the action that produces work in any shape into the system and therefore a variation of energy into system. Because in the closed system the output Y(s), connected with the produced work, is generally smaller than the signal in the open system (i.e. without the block H(s)), we are able to deduce in the closed system entropy is smaller than the entropy in the open system.

3. A few considerations on classical thermodynamics

3.1 Reversible transformations and irreversible transformations

A reversible process is a transformation experienced by a system in which the energy exchange with the ambient depends only on the initial state and on the final state of a function that represents the internal energy of system. The transformation therefore is independent of the path for passing from the initial state to the final state. In reversible processes it is possible therefore to define a state function, that is called potential function in the theory of force conservative fields.

An irreversible process is a transformation experienced by a system in which it isn't possible to define a state function and therefore the energy exchange with the ambient depends whether on initial and final states or on the path. That is in an irreversible transformation the system cannot return to the initial state and a state function cannot be defined.

Physical processes in nature are generally irreversible. Artificial physical processes can be reversible under suitable physical conditions. It follows that the nature generates generally only irreversible physical processes while human activity can produce also physical processes that are practically reversible.

3.2. Principles of Thermodynamics

The concept of entropy has been defined historically for thermodynamic systems in which energy is largely in the form of heat and the characteristic physical quantity is the temperature. Two important properties of thermodinamic systems are:

a. a thermodynamic system is in thermal equilibrium when its temperature is constant

b. the transitive property that says:

" if the physical system X is in thermal equilibrium with the system Y and Y is in thermal equilibrium with the system Z, then X and Z are in thermal equilibrium (i.e. they have the same temperature).

Thermodynamics is characterized by three basic principles:

1° Principle: when a closed system is supplied with a heat Q, a part is converted into a variation of internal energy ΔU and the remaining part into work L performed by the system on the ambient, i.e. $Q = \Delta U + L$

2° Principle: It is impossible in nature a transformation whose only outcome is the transfer of heat from a colder body to a warmer body without external work (Clausius' definition) or it is impossible in nature a cyclic transformation whose only outcome is the transformation into work of all heat supplied by a source at constant temperature (Kelvin-Planck's definition).

3° Principle: It is impossible that the entropy assumes the value of the point zero (i.e. at 0K) with a finite number of transformations.

4. Classical entropy

The concept of classical entropy S was defined in function of the heat exchange between the physical system and the surrounding ambient

$$dS = \frac{dQ}{T} \qquad (6)$$

where T is the temperature of system.

In the event of gaseous systems the classical entropy, defined by (6), is given by the relation[2]

$$S = S_o\left(1 + \ln\frac{T}{T_o}\right) \qquad (7)$$

in function of the temperature, where S_o=M_oc_s is the entropy at the temperature of reference T_o , M_o is the mass of the gaseous system and c_s is its specific heat.

In function of the speed the same entropy is given by

$$S = S_o\left(1 + 2\ln\frac{v}{v_o}\right) \qquad (8)$$

in which v_o is the average speed of gaseous particles at the temperature T_o.

Indicating with F the physical system and with A the surrounding ambient we have

$$U_L = F + A \qquad (9)$$

that is the local universe is given by the combination of both, the physical system and the surrounding ambient. From (9) for infinitesimal variations we have

$$dS(U_L) = dS(F) + dS(A) \qquad (10)$$

and for finite variations

$$\Delta S(U_L) = \Delta S(F) + \Delta S(A) \qquad (11)$$

i.e. the variation of entropy of the local universe is given by the sum of variations of entropy of the physical system and of the surrounding ambient.

It is known that for reversible transformations[1] it is

$$dS(U_L) = 0 \qquad (12)$$

that is the entropy of the local universe is constant and consequently also the desorder is constant. From (10) and (11) we deduce

$$dS(A) = - dS(F) \qquad (13)$$

$$\Delta S(A) = - \Delta S(F) \qquad (14)$$

i.e. for reversible transformations the variation of entropy of the surrounding ambient is equal and opposite to the variation of entropy of the physical system.
For irreversible transformations[1] it is instead

$$dS(U_L) > 0 \qquad (15)$$

i.e. the entropy of the local universe increases and consequently also the associated disorder increases.
For irreversible transformations we deduce therefore

$$dS(U_L) = dS(F) + dS(A) > 0 \qquad (16)$$

$$\Delta S(U_L) = \Delta S(F) + \Delta S(A) >0 \qquad (17)$$

from which

$$dS(F) > - dS(A) \qquad (18)$$

$$\Delta S(F) > - \Delta S(A) \qquad (19)$$

From (18) and (19) we deduce for irreversible transformations the variation of entropy of the physical system is always greater than the variation of entropy of the surrounding ambient.
In an insulated physical system F (adiabatic system) there isn't heat exchange with the surrounding ambient (dQ=0) and therefore it is always

$$dS(F) = 0 \qquad (20)$$

i.e. the entropy of an insulated physical system is constant in time.
The total Universe (U) is an insulated system and consequently its entropy and the associated desorder are constant in time.
The definition (6) is appropriate for thermodynamic systems in which physical processes are characterized largely by heat exchanges but it isn't appropriate for all other physical systems. Considering anyway heat is a shape of energy it could be more suitable then to define entropy in function of energy E, in any shape, that is echanged between the system and the surrounding ambient,

$$dS = \frac{dE}{T} \qquad (21)$$

4. Specific entropy of physical systems

In the introduction we have pointed out the classical definition of entropy given by the (1) is valid exclusively for particular systems in which the heat exchange between the physical system and the surrounding ambient is the prevailing physical aspect. In that context we have proposed the extension of the entropy concept from thermodynamic systems to all physical systems and to that end we proposed to consider the relation (21), that here we write again

$$dS = \frac{dE}{T} \qquad (22)$$

where S represents the **specific entropy**, dS represents the infinitesimal variation of specific entropy and dE represents the infinitesimal exchange of energy, in place of the usual heat exchange, between the physical system and the surrounding ambient.
It is manifest also that in order to define the specific entropy for any physical system it would be suitable to consider a convenient physical quantity in place of the usual temperature that in effect regards more properly thermodynamic systems. It seems evident that the subsequent step consists in identifying the most convenient shape of energy and the most convenient physical quantity for defining the specific entropy for any physical system. To that end we can assume the following general definition of specific entropy:

$$dS = \frac{dE}{P} \qquad (23)$$

where dE is the shape of energy that is implicated into the physical process and P is the physical quantity that characterizes that shape.

1. For thermodynamic systems let us assume in the (23), as usual, dE=dQ, P=T.
S represents therefore the thermal specific entropy for which

$$dS = \frac{dQ}{T} \qquad (24)$$

and consequently the specific entropy of a thermodinamic system coincides with the classical entropy.

2. For mechanical systems let us assume in the (23) $dE=dW=dE_c$ where W is the work performed by the surrounding ambient on the physical system, that in physical particular conditions coincides completely with the kinetic energy and P=v is the velocity. S is the specific mechanical entropy for which

$$dS = \frac{dW}{v} \qquad (25)$$

3. For gravitational systems the study proves it is suitable to assume also for these systems $dE=dE_c$ where E_c is the kinetic energy, and $P=v$ is the system velocity. S represents then the gravitational specific entropy for which

$$dS = \frac{dE_c}{v} \qquad (26)$$

4. For elementary particles, in the (23), we assume $dE=dE_i$ where E_i is the intrinsic energy and $P=T$. S represents the intrinsic specific entropy of mass electrodynamic systems for which

$$dS = \frac{dE_i}{T} \qquad (27)$$

5. Specific entropy of thermodynamic systems

Let us distinguish between ideal reversible transformations and and real irreversible transformations.

- Let us consider a reversible transformation in which the heat dQ, coming from the surrounding ambient, is absorbed by the physical system at the temperature T.
In this ideal situation the variation of specific entropy of the physical system is given by

$$dS(F) = \frac{dQ}{T} \qquad (28)$$

in which $dQ>0$ represents the heat that is absorbed by the system.
Consequently the heat that is supplied by the surrounding ambient is -dQ and hence the variation of specific entropy of the surrounding ambient is

$$dS(A) = -\frac{dQ}{T} \qquad (29)$$

It follows that the variation of entropy of the local universe is

$$dS(U_L) = dS(F) + dS(A) = \frac{dQ}{T} - \frac{dQ}{T} = 0 \qquad (30)$$

If instead the physical system furnishes heat -dQ to the surrounding ambient, the variation of specific entropy of the system is

$$dS(F) = -\frac{dQ}{T} \qquad (31)$$

The variation of specific entropy of the surrounding ambient is therefore

$$dS(A) = \frac{dQ}{T} \qquad (32)$$

in which dQ>0 is now the heat that is absorbed by the surrounding ambient. The variation of specific entropy of the local universe (F+A) is always zero in both cases, and this result confirms the (12): $dS(U_L) = 0$.

If Q is the total heat exchanged between the thermodynamic system and the surrounding ambient at constant temperature, from preceding relations we have

$$S(F) = \pm \frac{Q}{T} + S_i(F) \qquad (33)$$

$$S(A) = \mp \frac{Q}{T} + S_i(A) \qquad (34)$$

where $S_i(F)$ is the initial specific entropy of the thermodynamic system and $S_i(A)$ is the initial specific entropy of the surrounding ambient.

In the two equations (33) and (34) the sign depends on the fact if the physical system absorbs or supplies heat to the surrounding ambient. Anyway we have in both cases

$$S(U_L) = S_i(F) + S_i(A) = S_i(U_L) \qquad (35)$$

in which $S_i(U_L)$ is the constant initial specific entropy of the local universe. Hence in a reversible thermodynamic transformation the variation of specific entropy of the local universe is always zero and the specific entropy is constant and equal to the sum of the initial entropy of the system and of the surrounding ambient. As we wrote frequently, this type of reversible transformation doesn't happen in a real natural physical process.

- Let us consider now an irreversible thermodynamic transformation, in which the heat dQ>0 is absorbed by a physical system at temperature T_F and supplied by the surrounding ambient at temperature $T_A>T_F$. In that case the variation of specific entropy of the system is

$$dS(F) = \frac{dQ}{T_F} \qquad (36)$$

and the variation of specific entropy of the surrounding ambient is

$$dS(A) = - \frac{dQ}{T_A} \qquad (37)$$

In these conditions the specific entropy of the thermodynamic system increases when the absorbed heat increases while the specific entropy of the surrounding ambient decreases.

The specific entropy of the local universe is given by

$$dS(U_L) = dS(F) + dS(A) = \frac{dQ}{T_F} - \frac{dQ}{T_A} > 0 \qquad (38)$$

and at practically constant temperatures

$$S(U_L) = S_i(U_L) + Q \frac{T_A - T_F}{T_F T_A} \qquad (39)$$

It follows that the variation of specific entropy of the local universe in an irreversible thermodynamic transformation in which the system absorbs heat from the surrounding ambient is always positive and hence entropy and disorder increase. The (38) and the (39) confirm the (16).

Let us consider now a thermodynamic process in which the physical system at temperature T_F furnishes heat to the surrounding ambient that is at temperature $T_A<T_F$. In that case the variation of specific entropy of the physical system is

$$dS(F) = - \frac{dQ}{T_F} \qquad (40)$$

and then variation of specific entropy of the surrounding ambient is

$$dS(A) = \frac{dQ}{T_A} \qquad (41)$$

In these conditions the specific entropy of the thermodynamic system decreases when the quantity of heat, that it supplies, increases while the specific entropy of the surrounding ambient increases. The specific entropy of the local universe is given by

$$dS(U_L) = dS(F) + dS(A) = \frac{dQ}{T_A} - \frac{dQ}{T_F} > 0 \qquad (42)$$

and at practically constant temperatures

$$S(U_L) = S_i(U_L) + Q \frac{T_F - T_A}{T_F T_A} \qquad (43)$$

We observe that also in this second case the variation of specific entropy of the local universe is always positive and consequently entropy and disorder increase, while entropy and disorder of the physical system decrease.

Hence in natural physical processes, that are generally irreversible, the entropy of the physical system increases when the energy of the system increases while the entropy of the local universe tends always to increase independently of the direction of heat.

6. Specific entropy of mechanical systems

Let us consider an ordinary system with inertial mass m and a force F applied that causes the motion of the mass m. The external system that generates the force F represents the surrounding ambient. The motion law[4] in ideal conditions, i.e. in the absence of external resistances to motion, is given by Newton's law

$$F = m\frac{dv}{dt} \qquad (44)$$

The elementary work dW performed by the surrounding ambient on the mass m is given by

$$dW = Fds = mvdv \qquad (45)$$

and the total work for leading the mass m from zero initial velocity to final velocity v is

$$W = m\int_0^v vdv = \frac{mv^2}{2} = E_c \qquad (46)$$

in which E_c is the kinetic energy of the mechanical system m.
The variation of specific entropy of the mechanical system in ideal conditions, as per the (25) and (45), is

$$dS = \frac{dW}{v} = mdv \qquad (47)$$

and the specific entropy at the speed v is

$$S = mv + S_i \qquad (48)$$

where S_i is the initial entropy of the mechanical system. The (47) and (48) prove the specific entropy and the disorder of the mechanical system with mass m increase when the velocity and the kinetic energy increase.

7. Specific entropy of gravitational systems

The motion of an ordinary body with inertial mass m in free fall into a gravitational field generated by the mass M, supposing the body falls from greatest distance with respect to the centre of gravity of M, is given, in ideal conditions, by the relation[5]

$$v(r) = \sqrt{\frac{2GM}{r}} \qquad (49)$$

The kinetic energy of the body into the gravitational field is given by

$$E_c(r) = \frac{GMm}{r} \qquad (50)$$

and consequently, as per the (26), the variation of specific entropy is

$$dS = \frac{dE_c}{v} = - m\sqrt{\frac{GM}{2}}\ r^{-3/2}\, dr \qquad (51)$$

The specific entropy of a body in free fall from $r=\infty$ to r is therefore

$$S(r) = S_i + m\sqrt{\frac{GM}{2r}} \qquad (52)$$

in which S_i is the entropy at greatest distance from the centre of gravity.
From the (52) we deduce the specific entropy and the disorder of a body in free fall increase when the velocity and the kinetic energy increase and the body approaches to the centre of gravity.

8. Specific entropy of electrodynamic elementary systems

In the event of mass elementary particles, their physical behaviour is defined by electrodynamic mass that, unlike constant inertial mass, under the action of a force field F changes with the speed according to the relation

$$m = m_o\left(1 - \frac{v^2}{2c^2}\right) \qquad (53)$$

In Thermodynamics of Elementary Particles[2] we have demonstrated particle's internal temperature is connected with the speed by the following relation

$$T = T_o\left(1 - \frac{v^2}{2c^2}\right) \qquad (54)$$

From (54) we deduce the internal temperature of electrodynamic particles decreases when the speed increases in concordance with the graph of fig.4. This behaviour is different from gaseous systems in which the average speed increases when the temperature increases. Besides the graph shows at the critical speed $v=1.41c=\sqrt{2}\,c$ the critical Kelvin temperature T_c of particles is zero and above the critical speed the Kelvin temperature becomes negative.
Because for greater speeds than the critical speed the electrodynamic particle is unstable, we deduce negative Kelvin temperatures are associated with an instability state of the particle[2].

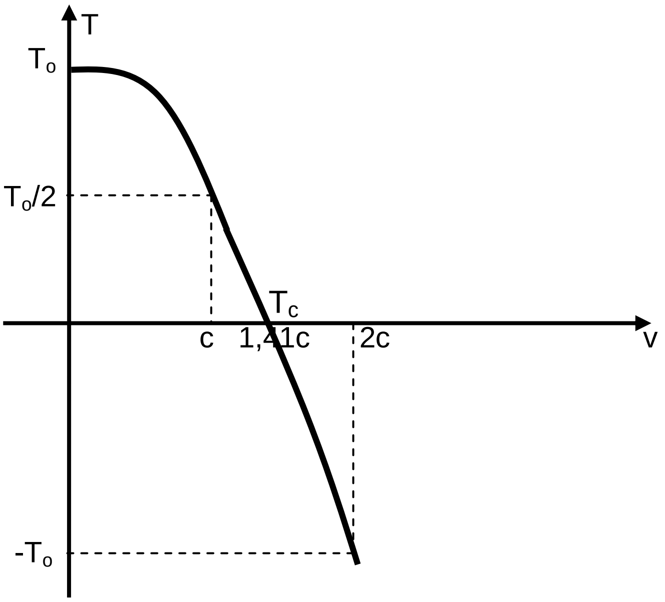

Fig.4 Diagram of the Kelvin temperature of an electrodynamic particle at the changing of the speed.

Let us assume for the specific entropy of mass elementary particles the definition (27)

$$dS = \frac{dE_i}{T} \qquad (27)$$

In "Thermodynamics of Elementary Particles"[2] we have calculated the following relations for the specific entropy of the particle (there called "intrinsic entropy")

$$S = S_o\left(1 + \ln\left|1 - \frac{v^2}{2c^2}\right|\right) \qquad (55)$$

in function of the speed v of the particle and

$$S = S_o\left(1 + \ln\left|\frac{T}{T_o}\right|\right) \qquad (56)$$

in function of the internal temperature of the particle.
From (55) and (56) we deduce the following properties of the intrinsic specific entropy of electrodynamic elementary particles:

1. A decrease of the internal positive Kelvin temperature ($T>0$) produces an increase of the speed and a decrease of the internal entropy and of disorder of the particle
2. A decrease of the internal negative Kelvin temperature ($T<0$) produces an increase of the speed and an increase of the internal entropy and of disorder of the particle

On the other hand the intrinsic energy $E_i=mc^2$ of the particle decreases when the speed increases according to the graph of fig.5. These considerations prove electrodynamic particles behave otherwise than mechanical physical systems in which an increase of the speed involves always an increase of the kinetic energy and of the specific entropy.

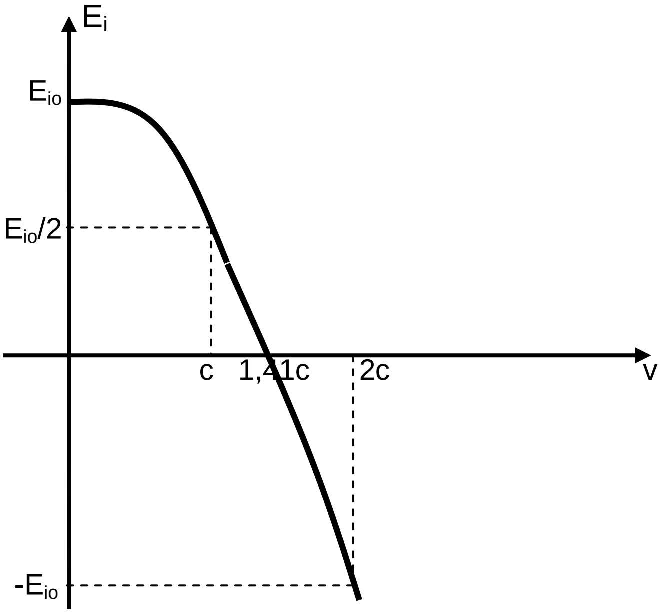

Fig.5 Diagram of intrinsic energy of a mass electrodynamic elementary particle at changing of the speed

9. General Principle of Entropy

In classical thermodynamics the following principle of entropy is valid:
" For any transformation concerning heat exchanges the entropy of the local universe tends to increase for irreversible transformations and it tends to be constant for reversible transformations". That is

$$\Delta S(U_L) \geq 0 \qquad (57)$$

Physical transformations in nature are generally irreversible and consequently the interesting part of the principle regards just irreversible transformations, i.e.

$$\Delta S(U_L)>0 \qquad (58)$$

With regard to the total universe it needs to specify in that case there isn't a surrounding ambient and therefore there aren't energy exchanges (dE=0). It follows that the entropy of the total universe is constant, i.e.

$$\Delta S(U) = 0 \qquad (59)$$

In this paper we have demonstrated the concept of specific entropy can be applied to all physical systems and therefore it is possible to define a principle of entropy that regards any energy exchange and not only heat exchanges.
We observe all physical systems have a similar behaviour with respect to the specific entropy: i.e. the specific entropy of any physical system increases when the energy

associated with the system increases. The only exception is represented by electrodynamic particles that behave like all other physical systems in stability conditions[2], while they behave differently in instability conditions. In fact for smaller speeds than the critical speed (i..e. $v<v_c=\sqrt{2}\,c$), the particle is stable and when the speed increases the intrinsic energy decreases (fig.5) and similarly the specific entropy decreases (fig.6), like other physical systems. Instead for greater speeds than the critical speed (i.e. $v>v_c$), the particle is unstable and when the speed increases the intrinsic energy decreases too but the specific entropy increases. We can define therefore the following

General Principle of Entropy

" The specific entropy of any physical system increases when its energy increases. Only elementary electrodynamic systems represented by mass elementary particles have a different behaviour in instability conditions where when the intrinsic energy decreases the specific entropy increases".

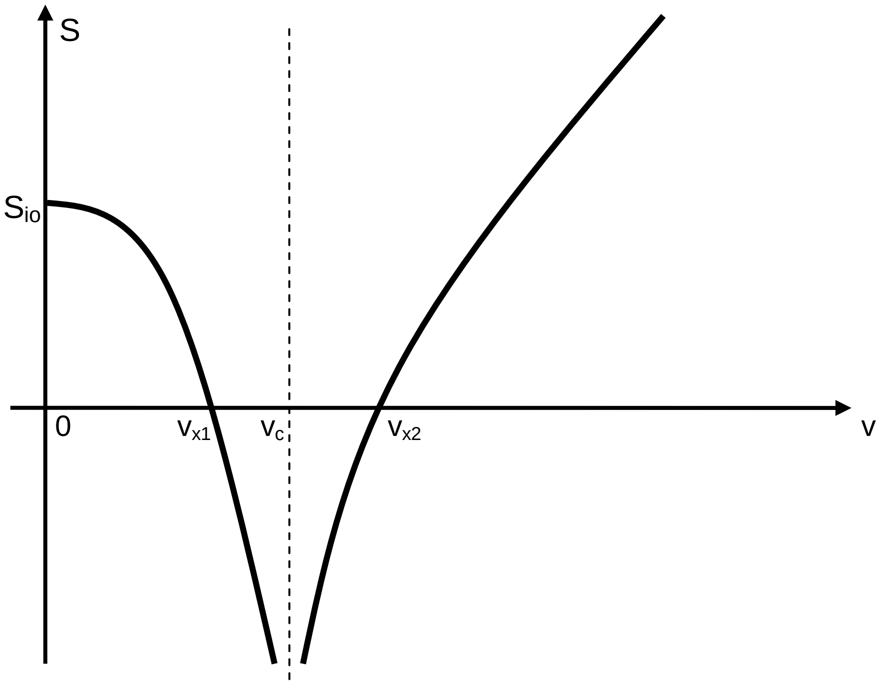

Fig.6 Graph of the specific entropy of an electrodynamic particle in function of the speed

References

[1] M.W. Zemansky, Heat and Thermodynamics, Translation by E. Verondini, Zanichelli Editor, 1970, Bologna
[2] D. Sasso, Thermodynamics of Elementary Particles, viXra.org, 2015, id: 1502.0009
[3] D. Sasso, On the Stability of Linear Systems, viXra.org, 2011, id: 1102.0009
[4] D. Sasso, Dynamics and Electrodynamics of Moving Real Systems in the Theory of Reference Frames, arXiv.org, 2010, id: 1001.2382
[5] D. Sasso, Physics of Gravitational Fields, viXra.org, 2014, id: 1405.0028
[6] D. Sasso, On the Stability of Electrodynamic Particles: the Delta Radiation, viXra.org, 2012, id: 1210.0025