Thermodynamics of Elementary Particles

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Abstract

Classic thermodynamics studies and describes the thermal behavior of complex systems, in particular gaseous, reaching the definition of the three principles of thermodynamics and of the concept of entropy. In this paper we want to demonstrate also single charged massive elementary particles have a thermodynamic behavior that is related to the elementary structure and to the electrodynamic mass of particle. Thermodynamics of single elementary particles is defined by physical transformations and by energy exchanges that particles experience when the speed and the temperature change. These transformations allow to define for elementary particles an intrinsic temperature and an intrinsic entropy that have a different behavior with respect to the same physical quantities of complex classic systems and with respect to the collective behavior of particles inside a plasma.

1. Introduction

The transformation of a system is a physical process for which the system changes from an initial state to a final state because of the action of a cause. The reversible transformation is a physical process for which the system that has experienced the change can return always to the initial state. If it cannot happen the transformation is irreversible. In thermodynamics there are very numerous examples of reversible or irreversible transformations. In particle physics, for instance, forced acceleration and forced deceleration of a charged elementary particle into a force field are reversible processes. Spontaneous decays on the contrary aren't reversible processes because an unstable elementary particle that experiences a spontaneous process of decay toward a stability state never will return spontaneously to the preceding state of instability. Not all physical processes are therefore reversible and laws of physics and of thermodynamics that are valid for reversible processes could not be valid for irreversible processes. Let us study now the thermodynamic behavior of charged elementary particles and we will define an equivalence between those and particles (atoms or molecules) of a gaseous system.
This study and this paper are the fruit of a discussion into ResearchGate, proposed by Jhon Macken, relative to the question "Are all frames of reference truly equivalent?" and to which the following researchers took part, everyone with his own viewpoint:
V.T. Toth, Vikram Zaveri, Ilja Schmelzer, Alexander E Kaplan, Charles Francis, James Langworthy, Matts Roos, Stefano Quattrini, Eric Baird, Andy Biddulph, Robert J. low, Eric Lord, George E. Van Hoesen, Robin Spivry, Indranid Banik.

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2. Thermodynamic equivalence between gaseous particles and elementary particles

It is known that in thermodynamic different scales exist for the measurement of temperatures, as for example the Celsius scale [°C] and the Kelvin absolute scale [K]. The Kelvin scale uses only positive temperatures and it fixes a lower limit given by

$$T = -273.15°C = 0\ K \qquad (1)$$

where 0 K is the the absolute zero of the scale.
This lower limit is defined theoretically in classic thermodynamics by the Third Principle of Thermodynamics[1] that says:

"**It is impossible to reach the absolute zero by a finite number of transformations**".

An equivalent formulation of the third principle makes use of the concept of entropy of the zero point, that is the entropy of system at the Kelvin zero. Such formulation says:

" It is impossible that the entropy of a system can take on the value of the zero point by a finite number of transformations".

We know the dynamic behavior of elementary particles into force fields[2][3], let us propose now to examine thermodynamic characteristics of elementary particles into a thermal field and to that end, knowing the thermodynamic behavior of gaseous particles (atoms or molecules) of macroscopic systems, we can think to define a thermodynamic equivalence between gaseous particles and elementary particles. We know in a gaseous system, the kinetic energy of every single particle is given by

$$E_c = \frac{1}{2} m_o v^2 = \frac{3}{2} KT \qquad (2)$$

where $K = 1.38 \times 10^{-23}\ JK^{-1}$ is the Boltzmann constant and m_o is mass of gaseous particle.
From (2) we deduce

$$T = \frac{2}{3K} E_c = \frac{1}{3} \frac{m_o v^2}{K} \qquad (3)$$

We can chart the Kelvin absolute temperature of a gaseous particle when its velocity changes (fig.1).
From (3) we deduce the Kelvin temperature of particle is always positive. This result is in concordance with the third principle.
The graph of temperature is parabolic and theoretically it can take on any positive value in function of the speed. Negative values of the Kelvin temperature for gaseous particles therefore are not possible.

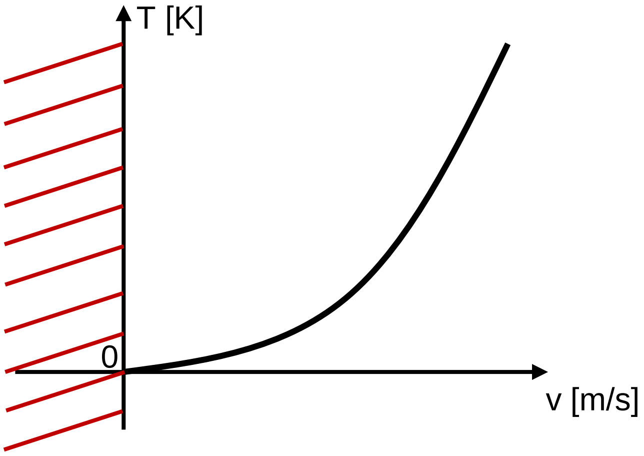

Fig.1 Graph of the Kelvin temperature of a gaseous particle at changing of the speed of particle

3. Electrodynamic behavior of elementary particles at changing of the speed

In concordance with the Theory of Reference Frames, we know electrodynamic mass of a charged massive elementary particle can be negative in conditions of instability of particle and consequently we can think, as per the (3), negative Kelvin temperatures are possible for elementary particles. In fact electrodynamic mass of a massive elementary particle, at changing of the speed, is given by[4][5][6]

$$m = m_o \left(1 - \frac{1}{2}\frac{v^2}{c^2}\right) \qquad (4)$$

where m_o is the resting electrodynamic mass and v is particle's speed.
The graph of electrodynamic mass of a massive elementary particle at changing of the speed is represented in fig.2.
Considering the equivalent kinetic energy of a massive elementary particle, given by $E_c=m_ov^2/2$, because electrodynamic mass, unlike mass of gaseous particles, can be negative for greater speeds than the critical speed, it is manifest again that negative Kelvin temperatures are possible for electrodynamic particles.
We know in particle physics, on a par with the kinetic energy, also the intrinsic energy that at rest is given by $E_{io}=m_oc^2$, plays an important part.
We will use this consideration in the next paragraph in order to specify better the equivalence that we have established between gaseous particles and elementary electrodynamic particles.
The study of the dynamic behavior of a charged massive elementary particle[3] into a force field F has allowed also to establish that into the inertial field, i.e. for reference frames in uniform relative motion, in order to have the invariance of physics laws and in particular of the Newton law (F=ma), acceleration of elementary electrodynamic particle has to change with the speed.

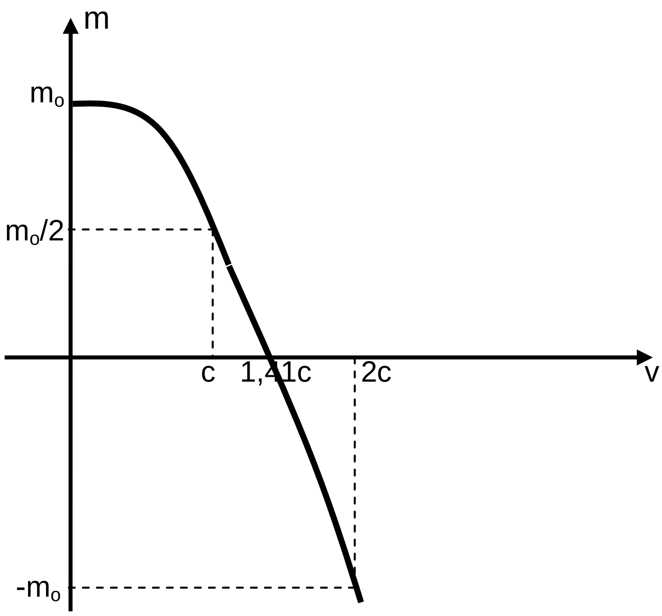

Fig.2 Diagram of electrodynamic mass of a massive elementary particle at changing of the speed

As per the (4), that variation is given by the following relation

$$a = \frac{a_o}{1 - \frac{1}{2}\frac{v^2}{c^2}} \qquad (5)$$

where a_o is the acceleration of particle with respect to the reference frame supposed at rest and a is the acceleration with respect to reference frame in relative motion.
The variation of the relativistic acceleration is graphed in fig.3

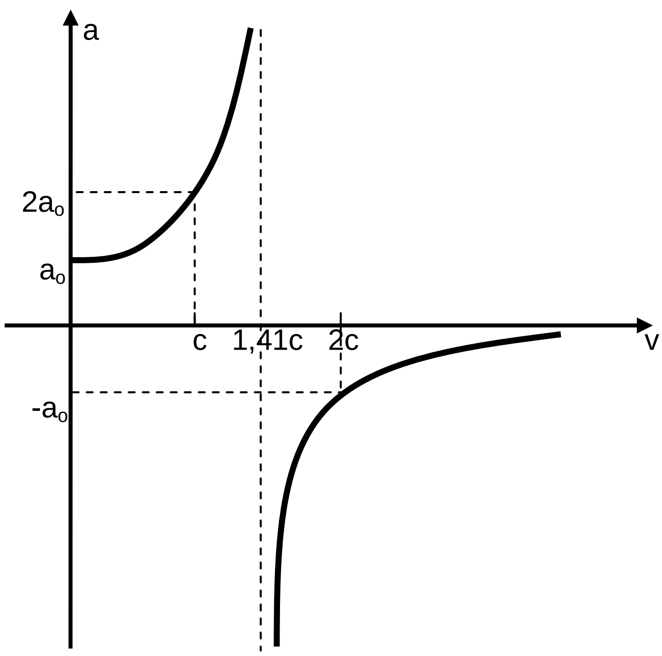

Fig.3 Variation of the relativistic acceleration of a charged massive elementary electrodynamic particle at the changing of the speed.

At the critical speed $v_c=\sqrt{2}\,c=1.41c$, the graph has a vertical asymptote, that is a mathematical singolarity that can be explained physically. In fact because electrodynamic mass of particle at the critical speed is null, in order to preserve the invariance of Newton's law, the acceleration must take on a tendentially infinite value. Then in order to preserve the invariance also for greater speeds than the critical speed, because electrodynamic mass tends always to decrease also for negative values, the acceleration must take on negative values, coming from the negative infinity, in order to continue to increase and to preserve the invariance of Newton's law.

4. Thermodynamic behavior of elementary particles at the changing of the speed

The type of energy that better defines and represents a charged massive elementary particle with resting electrodynamic mass m_o is the resting intrinsic energy $E_{io}=m_oc^2$.
At the speed v the particle has an electrodynamic mass m given by the (4) and an intrinsic energy

$$E_i = mc^2 = m_oc^2 \left(1 - \frac{v^2}{2c^2}\right) \qquad (6)$$

Because for every value of speed of elementary particle there is a different electrodynamic mass and a different intrinsic energy, in the thermodynamic equivalence between gaseous particles and charged massive elementary particles, we can assume without doubt that **"for every value of speed there is also a different internal Kelvin temperature of the same particle"**.
As per this principle of thermodynamic equivalence we can write from the (2), making use of the intrinsic energy in place of the kinetic energy,

$$E_i = mc^2 = \frac{3}{2} KT \qquad (7)$$

and considering the (6), we can still write

$$T = \frac{2}{3} \frac{m_oc^2}{K} \left(1 - \frac{v^2}{2c^2}\right) \qquad (8)$$

Placing as per the (7)

$$T_o = \frac{2}{3} \frac{E_{io}}{K} \qquad (9)$$

where T_o is the internal Kelvin temperature of resting elementary particle, we obtain still

$$T = T_o \left(1 - \frac{v^2}{2c^2}\right) \qquad (10)$$

The (10) describes the variation of the internal temperature of a charged massive elementary particle at the changing of the speed. From (9) we can derive the value of T_o. Because for the electron E_{io}=0.51MeV= 8.16×10^{-14} J, and considering the value of the Boltzmann constant, we have

$$T_o = 39.4 \times 10^8 \text{ K} \qquad (11)$$

The resting electron has therefore a highest internal temperature.
For the resting proton E_{io}=0.938GeV=1.5×10^{-10} J and therefore the internal temperature is still higher

$$T_o = 725 \times 10^{10} \text{ K} \qquad (12)$$

Those calculations prove elementary electrodynamic particles have at rest highest internal temperatures.
From (10) we deduce the temperature of electrodynamic particles decreases when the speed increases and this trend is graphed in fig.4.
This decrease of the temperature of electrodynamic particles with the speed happens because when particle is accelerated it radiates quantum electromagnetic energy at the expense of the intrinsic energy.

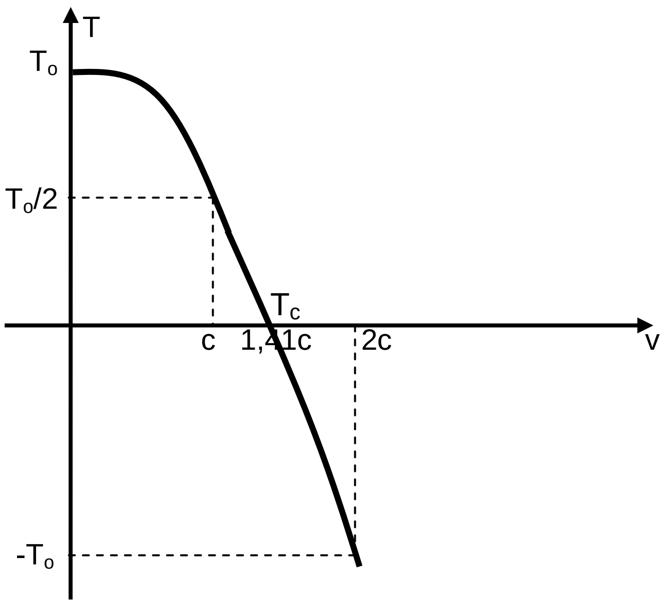

Fig.4 Diagram of the Kelvin temperature of an electrodynamic particle at the changing of the speed.

From the graph and from the study performed we deduce a few very interesting thermodynamic properties of electrodynamic particles:

a. Temperatures at resting state are highest for which electrodynamic particles command a greatest internal tank of intrinsic energy in spite of smallest masses.

b. The internal temperature of electrodynamic particles decreases when the speed increases, that is accelerated particles experience a cooling effect.

c. At the critical speed v_c=1.41c the Kelvin temperature of particles is null. If we call this temperature like "critical temperature T_c" we have T_c=0 for v=v_c.

d. Over the critical speed the Kelvin temperature becomes negative.

e. Because for greater speeds than the critical speed electrodynamic particle is unstable, we deduce negative Kelvin temperatures are associated in general with an instability state of particle.

5. Entropy of complex systems

Entropy S is a thermodynamic physical quantity that in the general formulation defines the direction according to which a physical transformation happens:

"any forced (non spontaneous) physical transformation happens according to the direction that produces an increase of entropy of any complex system".

The preceding sentence can be also considered a different formulation of the second principle of thermodynamics where for complex system we assume a non-elementary system that is made up of the functional aggregation of elementary components.
The difference between reversible transformation and irreversible transformation concerns only the entropy of the whole universe and not the entropy of the single system, i.e. in the event of a reversible transformation the entropy of the universe remains constant while in the event of an irreversible transformation the entropy of the universe increases. It is known then that the concept of entropy is associated also with the concept of disorder of system.
The variation of entropy dS in the transformation of a complex system is connected with the variation of heat dQ, emitted or absorbed, by the relation

$$dS = \frac{dQ}{T} \qquad (13)$$

where the variation of heat dQ is positive if the system absorbs heat or thermal energy and is negative if the system emits heat or energy.
Therefore for positive Kelvin temperatures an absorption of healt or of energy produces an increase of entropy and an increase of disorder while an emission of healt or of energy produces a decrease of entropy and a decrease of disorder.
The third principle of thermodynamics imposes for complex systems negative Kelvin temperatures cannot exist. In actuality many researchs and numerous experiments that have been performed in the last decades have proved negative Kelvin temperatures can be supposed also for complex systems in particular conditions and this conclusion has been the most important result of discussion in ResearchGate. In gaseous systems, as per (2) and (3), for positive temperatures we observe an increase of entropy when temperature and speed of gaseous particles increase.
The complex system, in particular gaseous, is a non-elementary system that is composed of a greatest number N of particles (atoms and molecules) that are composed of bound elementary particles. Entropy of these macroscopic systems is given by (13) where

$$dQ = M_o c_s dT \qquad (14)$$

M_o is mass of the complex system and c_s is the specific heat. Integrating the (13) and considering the (14), we have

$$S = S_o + M_o c_s \ln \frac{T}{T_o} \qquad (15)$$

where S_o is the system entropy at the temperature T_o.
The (15) gives the entropy variation of a macroscopic complex system when temperature changes. It can be graphed in fig.5 where we have considered only positive temperature in concordance with the (3).

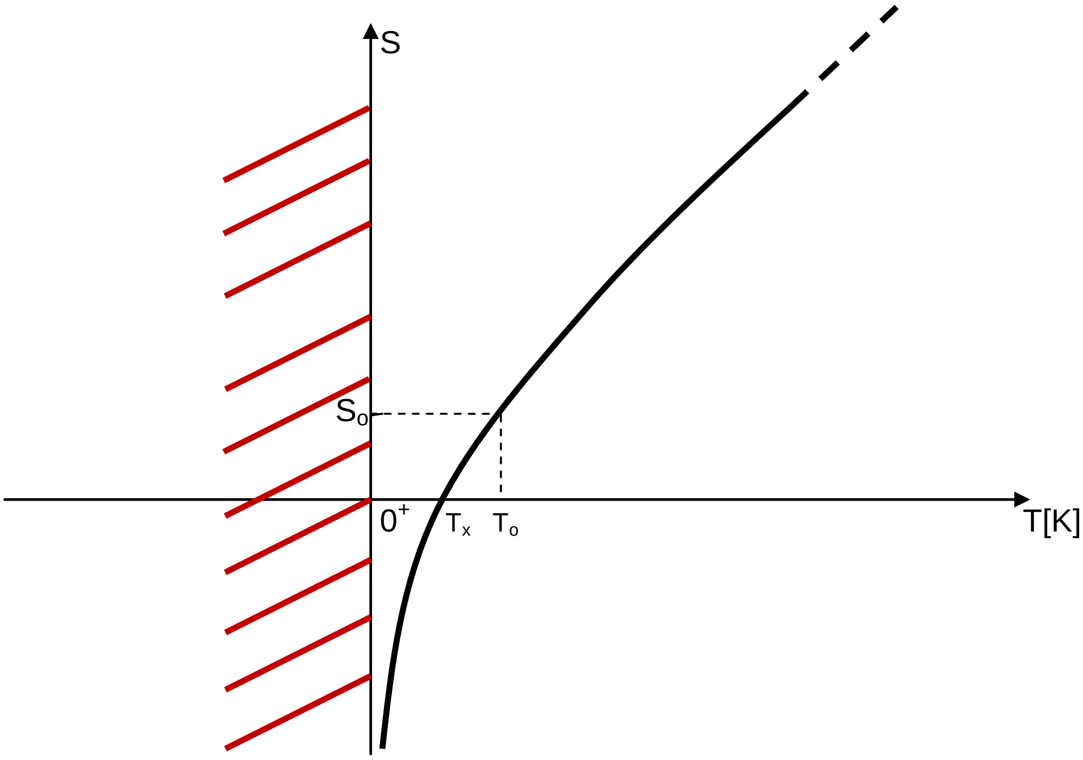

Fig.5 Trend of entropy of a gaseous complex system as function of the Kelvin temperature

From (15) we deduce zero entropy for the temperature T_x

$$T_x = T_o\, e^{-S_o/M_o c_s} \qquad (16)$$

Continuing we can calculate entropy as function of the speed.
At macroscopic level the absorbed positive heat $\Delta Q>0$ changes to kinetic energy E_c of single gaseous particles that is related to the temperature of system through the (2) $[E_c=m_o v^2/2=3KT/2]$. Supposing that the gaseous complex system is composed of N particles (molecules or atoms) that are equivalent from the kinetic and thermodynamic viewpoint , then all gaseous particles have the same average kinetic energy and the same average speed v. As per the (3) we can write

$$S = S_o + 2M_oc_s \ln \frac{v}{v_o} \qquad (17)$$

where v_o is the average speed of gaseous particles at the temperature T_o, given always for the (3) by

$$v_o = \sqrt{\frac{3KT_o}{m_o}} \qquad (18)$$

The (17) can be charted obtaining the graph of fig.6.

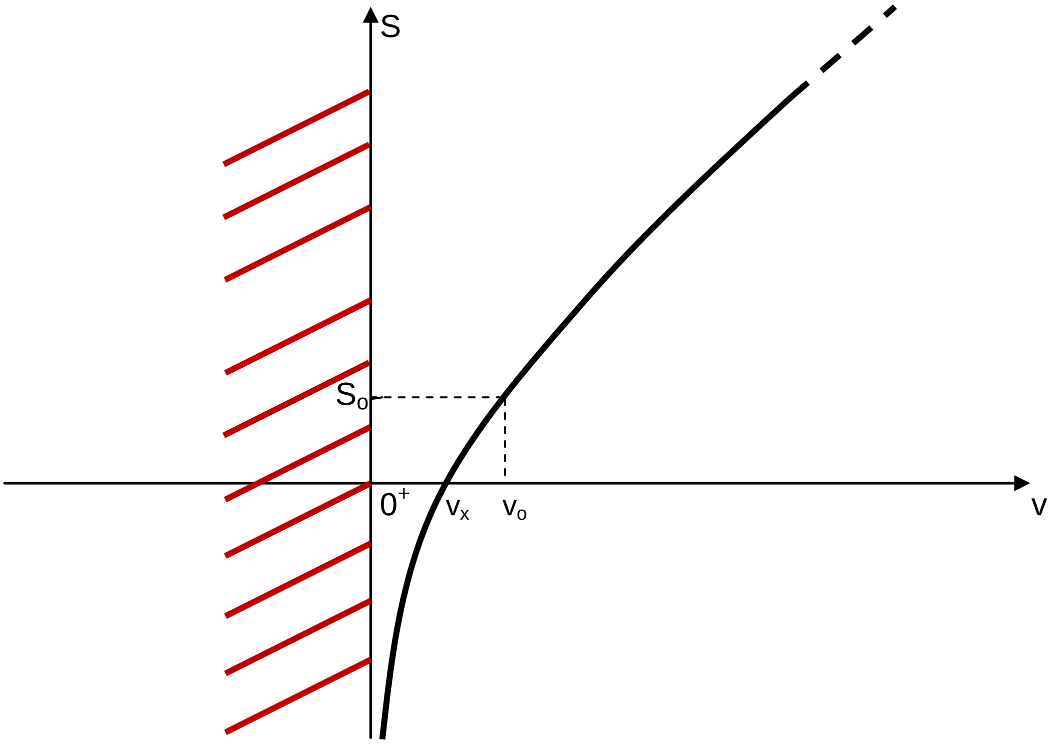

Fig.6 Variation of entropy of a gaseous complex system as function of the average speed of particles

Let us assume

$$S_o = \frac{Q_o}{T_o} = \frac{NE_{co}}{T_o} \qquad (19)$$

where Q_o is the total thermal energy of the complex system and E_{co} is the average kinetic energy of single particles at the temperature T_o. Because

$$Q_o = M_oc_sT_o \qquad (20)$$

we have from the (19)

$$S_o = M_oc_s \qquad (21)$$

and from the (18)

$$S_o = \frac{NE_{co}}{T_o} = \frac{3NK}{2} \qquad (22)$$

for which the (15) and (17) can be rewritten like this

$$S = S_o \left(1 + \ln \frac{T}{T_o}\right) \qquad (23)$$

$$S = S_o \left(1 + 2\ln \frac{v}{v_o}\right) \qquad (24)$$

From (21) and (16) we deduce also

$$T_o = eT_x \qquad (25)$$

and from (21) and from (17)

$$v_o = \sqrt{e}\, v_x \qquad (26)$$

6. Intrinsic entropy of electrodynamic elementary particles

We call "system entropy" the entropy of complex systems like gaseous systems while we call "intrinsic entropy" the entropy of single electrodynamic particles. As per (10) we know negative Kelvin temperatures are certainly possible relative to electrodynamic particles for greater speeds than the critical speed. Assuming that also for electrodynamic particles the relation (13) is valid, from this we deduce for positive Kelvin temperatures the behavior of particles is equivalent to complex systems, that is an absorption of heat produces an increase of entropy. For negative Kelvin temperatures instead, relative to only electrodynamic particles, an absorption of heat or of energy produces a decrease of entropy while an emission of heat or of energy produces an increase of entropy.
From that we deduce the thermodynamic behavior of electrodynamic particles for negative Kelvin temperatures is contrary to positive temperatures.
In fig.7 Feynman's dynamic graph is considered relative to the behavior of a charged massive electrodynamic particle that is accelerated (or decelerated) by a force field.
In the graph we observe in the accelerated direction (from left toward right hand), for smaller speeds than the critical speed ($v<v_c=\sqrt{2}\,c=1.41c$) electrodynamic mass of particle is positive, the Kelvin temperature is positive, particle is stable and there is emission of energy. For greater speeds than the critical speed electrodynamic mass is negative, the Kelvin temperature is negative, particle is unstable and there is absorption of energy. At the critical speed electrodynamic mass is null, the Kelvin temperature is zero and particle is on the margins of stability.
We know for electrodynamic particles the most representative sort of energy is the intrinsic energy E_i and emitted or absorbed energy by particle is electromagnetic. Besides this e.m. energy is equal to the variation of intrinsic energy of particle and it coincides with the equivalent kinetic energy that particle would have like an ordinary system.

In the event of electrodynamic particles, because $dQ = dE_i$, the relation (13) between entropy and energy has to be written in the following differential shape

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

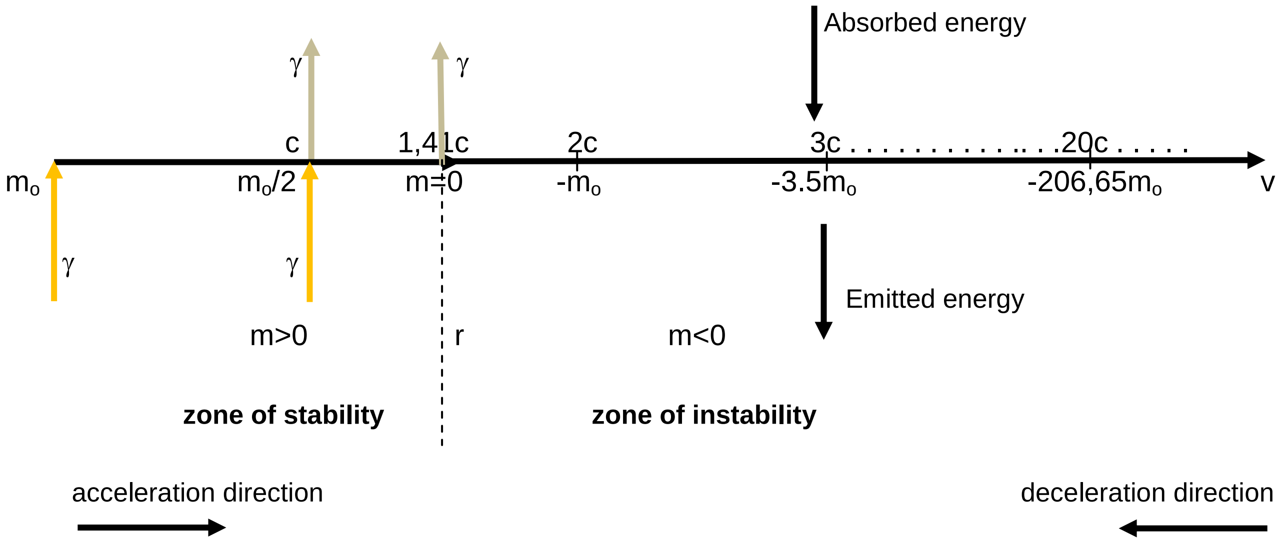

Fig.7 Feynman's diagram relative to the behavior of an accelerated or decelerated particle (in particular electron). The dotted line r separates the stable behavior of particle (left hand) from the unstable behavior (right hand). Besides the two arrows indicate the direction of acceleration or deceleration.

Let us integrate the (27) and let us assume the border condition that for $v=0$ and $T=T_o$ it is $S=S_{io}$ where

$$S_{io} = \frac{E_{io}}{T_o} = \frac{m_o c^2}{T_o} \qquad (28)$$

From (6) we deduce

$$dE_i = - m_o v dv \qquad (29)$$

Continuing in calculation and considering the (10), we have

$$dS = - \frac{m_o v dv}{T_o\left(1 - \frac{v^2}{2c^2}\right)} \qquad (30)$$

and because

$$d(2c^2 - v^2) = - 2vdv \qquad (31)$$

we have still

$$\int_{S_{io}}^{S} dS = \frac{m_o c^2}{T_o} \int_0^v \frac{d(2c^2 - v^2)}{2c^2 - v^2} \qquad (32)$$

Integrating the (32) we have at last

$$S = S_{io}\left(1 + \ln\left|1 - \frac{v^2}{2c^2}\right|\right) \qquad (33)$$

The (33) has been graphed in fig.8 in which we have considered that

a. for v=0 $S=S_{io}$
b. for $v=v_c= 1.41c$ $S= -\infty$
c. for $v= \infty$ $S=+\infty$

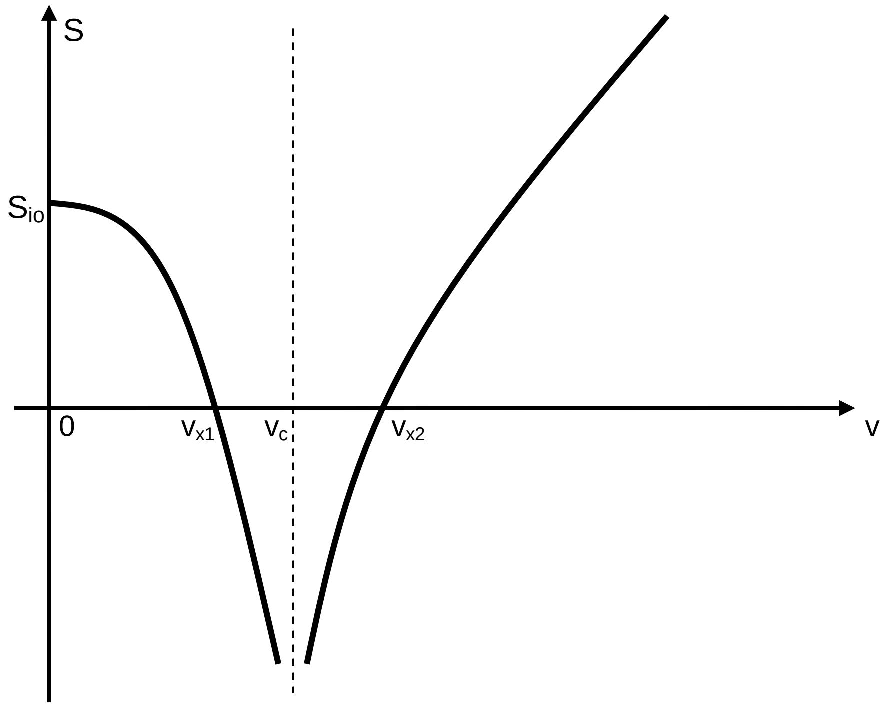

Fig.8 Entropy diagram of a charged elementary electrodynamic particle as function of the particle's speed in acceleration (from left toward right) and in deceleration (from right toward left).

From (28) and (9) then we deduce

$$S_{io} = \frac{3}{2}K \qquad (34)$$

that is the entropy at resting state is equal for all electrodynamic particles and it depends only on the Boltzmann constant.
Examining the graph we can do the following considerations:

a. The intrinsic entropy of an electrodynamic particle, when the speed increases, decreases for $v<v_c$ and increases for $v>v_c$. It is in concordance with the fact that for $v<v_c$ the Kelvin temperature is positive and the energy variation $dQ=dE_i$ is negative. For $v>v_c$ instead the temperature is negative and the variation of energy is negative.

b. Because in classic thermodynamics the entropy increase with the speed is associated with an increase of disorder of complex system, for electrodynamic particles we have to deduce the increase of the speed produces a decrease of the internal disorder of particle in the zone of stability for $v<v_c$ and it produces an increase of the disorder in the zone of instability for $v>v_c$.

c. The reading of the graph from right hand toward left gives the variation of the intrinsic entropy of decelerated particle

We can calculate the values v_x of speed for which the particle's intrinsic entropy is null solving the equation

$$1 + \ln\left|1 - \frac{v^2}{2c^2}\right| = 0 \qquad (35)$$

and we obtain the two values

$$v_{x1} = 0.79v_c \qquad (36)$$

$$v_{x2} = 1.17v_c \qquad (37)$$

that are independent of the particular elementary particle.
Let us calculate now the particle' s intrinsic entropy as function of the temperature. From the (19) we have

$$1 - \frac{v^2}{2c^2} = \frac{T}{T_o} \qquad (38)$$

and from the (33)

$$S = S_{io}\left(1 + \ln\frac{|T|}{T_o}\right) \qquad (39)$$

The (39) gives the variation of the intrinsic entropy of an elementary electrodynamic particle as function of the Kelvin temperature. In fig.9 the (39) is graphed considering that

a. for $T=T_o$ $S=S_{io}$
b. for $T=0$ $S=-\infty$
c. for $T=-\infty$ $S=+\infty$

The behavior of the intrinsic entropy relative to electrodynamic particles, when temperature changes, is therefore different from gaseous complex systems. In fact:

1. For gaseous systems there isn't a superior theoretical limit for the positive Kelvin temperature, while for electrodynamic particles there is a superior limit represented by T_o, it is given by (9) [$T_o=2m_oc^2/3K$] and depends on the electrodynamic mass m_o of particle.

2. For gaseous systems negative Kelvin temperatures aren' t possible while for electrodynamic particles the entropy decreases when the Kelvin temperature increases for negative values. Like this they show for negative temperature an opposite behavior with respect to positive temperatures.

3. At the Kelvin temperature T_c=0 (critical temperature) the entropy is $-\infty$ and therefore electrodynamic particle is theoretically in a state of maximum order.

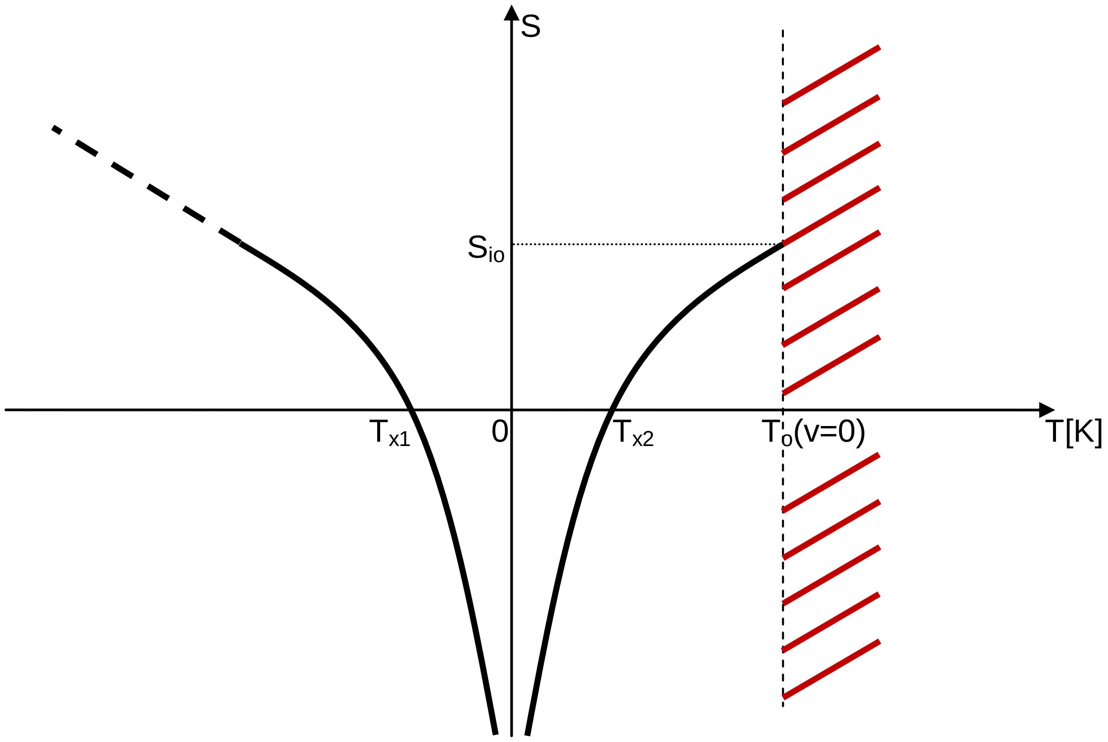

Fig.9 Graph of the entropy of a charged elementary electrodynamic particle as function of the Kelvin temperature

We can calculate temperatures where the entropy is null. From the (39) we have

$$1 + \ln \frac{|T|}{T_o} = 0 \qquad (40)$$

from which

$$T_{x1} = -\frac{T_o}{e} \qquad (41)$$

$$T_{x2} = +\frac{T_o}{e} \qquad (42)$$

Besides from the (10) we can calculate the speed v_{300} and from the (39) the intrinsic entropy S_{300} of the particle at the internal temperature 300K. Whether for free electron or for free proton we have

$$v_{e300} \approx v_c \qquad (43)$$

$$S_{e300} = -\infty \qquad (44)$$

7. From complex systems to plasma

Let us want briefly to list physical processes that a gaseous system experiences when, initially at ambient temperature, it absorbs heat:

a. Temperature and entropy of system increase and simultaneously the kinetic energy of single non-elementary (atoms and molecules) particles increases. The system in these conditions is governed by laws of gaseous systems.
b. When the temperature reaches a threshod value T_p (plasma temperature) gaseous particles ionize almost totally and the plasma is composed of protons and electrons that constitute matter at the plasma state.
c. The almost total ionization of gaseous particles with formation of plasma happens at the temperature $T_p \approx 10^4 K$ that is very inferior to the intrinsic maximum temperature T_o of both electrons and protons.
d. The system is now in a state of thermodynamic equilibrium and its behavior is governed now by physical laws of plasma.
e. The thermodynamic study of preceding paragraphs concerns single separated elementary particles that aren't in a plasma state.
f. When the system is in the physical state of plasma, charged elementary particles are free and in the presence of other particles. In that case forces act because of the presence of electric and magnetic fields and those forces act over great distances (collective effects) and they override Coulombian forces that act over small distances.
g. The predominance of ordered collective physical effects over great distances in the plasma with respect to physical effects over small distances, due to both the electrostatic energy of single charged particles and the casual motion of thermal agitation, is defined by the Debye length λ_D for which for distances $d< \lambda_D$ effects of single charged elementary particles predominate while for $d>\lambda_D$ plasma collective effects predominate.
h. The interesting question is now in what way the behavior of single charged elementary particles affects the collective behavior of plasma.

References

[1] M.W. Zemansky, Heat and Thermodynamics, MacGraw-Hill Book Company, New York, 1968, Italian translation by E. Verondini, Zanichelli, Bologna, 1968
[2] D. Sasso, On Physical Behavior of Elementary Particles in Force Fields, viXra.org, 2014, id: 1409.0013.
[3] D. Sasso, Relativistic Physics of Force Fields in the Space-Time-Mass Domain, viXra.org, 2014, id: 1403.0024
[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, On Primary Physical Transformations of Elementary Particles: the Origin of Electric Charge, 2012, viXra.org, id: 1202.0053
[6] D. Sasso, On the Stability of Electrodynamic Particles: the Delta Radiation, viXra.org, 2012, id: 1210.0002