Thermodynamics as a consequence of mechanics

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Abstract. In this paper the transition from the microscopic description to macroscopic one is considered. Transformation of Mechanics into Thermodynamics follows as its consequence. Retardation of interactions and their role in irreversibility of both theories are analyzed. The mechanical analogue of entropy is found.

1. Introduction
After creation of the classical mechanics (I.Newton, 1687) the motion of heaven bodies was understood, they obey the law of gravity. On our planet Earth mechanics is the same, but other laws apply.

According to atomic hypothesis macroscopic body consists of molecules moving after Newton’s law, therefore thermodynamics must flow from mechanics.

• But thermodynamics is irreversible as opposed to mechanics! What could be the way out of this situation? J.Maxwell (1859) and L.Boltzman (1866) found him in the averaged description, creating statistical mechanics. But this way led to an insoluble contradiction between the two theories.

• In this article I have shown that the source of irreversibility is retardation of interaction. As a result of the delay, part of the body's energy gone to the field, cannot return completely. This is irreversibility.

• Structure of article is following: 2nd and 3rd parts are devoted to the transition from microscopic description to macroscopic one. In 4th part they are compared and the role of the delay is clarified. The 5th part displays the First Principle of thermodynamics and the "special character" of heat. In the Conclusion, the issues requiring further analysis are considered.

2. Exclusion of the electromagnetic field
Let us consider the macroscopic body isolated from external forces. Each particle of this body moves under the action of internal electromagnetic field

\[
\frac{dp_\mu(x)}{dt} = F_{\mu \nu}(x) j_\nu(x),
\]

having the H.Lorentz force in her right part. All the quantities are taken at the same point according to principle of locality, action-at-distance is excluded.

• It appears at once the difference between descriptions of body and field: each particle is detailly described (the momentum \( p_\mu = mu_\mu \) and current \( j_\mu = eu_\mu \) are given with their mass \( m \) and charge \( e \)) but field is presente only by one variable, intensity \( F_{\mu \nu} \).

• The internal field is being created by all particles according to J. Maxwell equation.
\[ \partial_{\mu} F_{\mu\nu}(x) = I_{\nu}(x), \tag{2} \]

where the \( I_{\nu}(x) \) – current of all particles (the full current) stands. By the way, this is the first global characteristic of the body.

- Now our task is to solve Eq.(2) for \( F_{\mu\nu}(x) \). insert it into Eq.(1) and in this way to exclude it. We are going from intensity to potential \( F_{\mu\nu}(x) = \partial A_{\nu}(x)/\partial x_{\mu} - \partial A_{\mu}(x)/\partial x_{\nu} \), which is equal to

\[ A_{\nu}(x) = \int I_{\mu}(y)(x - y)^{-2} d^4 y, \tag{3} \]

This 4-dimensional expression was written by me [1]. In 3-dim form it belongs to L.V.Lorenz but usually named as "Lienard-Wiechert retarded potential" [2]. Also, the L.Lorenz condition \( \partial A_{\mu}/\partial x_{\mu} = 0 \) is attributed to H.A. Lorentz. What a strange habit, indeed.

Solution

\[ F_{\mu\nu}(x) = \left( \frac{\partial}{\partial x_{\mu}} \delta_{\nu\beta} - \frac{\partial}{\partial x_{\nu}} \delta_{\mu\beta} \right) \int I_{\beta}(y)(x - y)^{-2} d^4 y, \tag{4} \]

replace the field by his source

\[ \frac{dp_{\mu}(x)}{dt} = j_{\nu}(x) \left( \delta_{\mu\nu} \delta_{\rho\beta} - \delta_{\mu\rho} \delta_{\nu\beta} \right) \int I_{\beta}(y) \frac{\partial}{\partial x_{\nu}} (x - y)^{-2} d^4 y. \tag{5} \]

Summing this equation over all the particles, we are going over to concise description of the studied body. Now it is described by vector \( \mathcal{P}_{\mu} \), consisting of full energy \( E \) and momentum \( \vec{P} \).

\[ \frac{dp_{\mu}}{dt} = (\delta_{\mu\nu} \delta_{\rho\beta} - \delta_{\mu\rho} \delta_{\nu\beta}) \int I_{\nu}(x)I_{\beta}(y) \frac{\partial}{\partial x_{\nu}} (x - y)^{-2} d^4 y. \tag{6} \]

(the 3-dimensional analogue of this equation was obtained in [3]).

Tensor \( Q_{\mu\nu} = I_{\mu}(x)I_{\nu}(y) \) describes the macroscopic state of that body according to

\[ \frac{dp_{\mu}}{dt} = \int (Q_{\nu\nu} \delta_{\mu\nu} - Q_{\nu\mu}) \frac{\partial}{\partial x_{\nu}} \frac{d^4 y}{(x - y)^2}. \tag{7} \]

Being quite right and exact, this equation is unlikely useful because the full current \( I_{\nu}(x) \) cannot be calculated. Therefore, let us going to another approach which seems to be more practical.

3. Exclusion of the full current

It seems that the proposed alternative is simpler: we replace Eq. (1) by global one

\[ \frac{dp_{\mu}}{dt} = F_{\mu\nu} I_{\nu}, \tag{8} \]

and simply insert the current from Eq. (2), thus obtaining the Lorentz’s force as \( F_{\mu\nu} \partial_{\nu} F_{\alpha\gamma} \). A simple algebra shows that it is equal to \( \partial T_{\mu\nu}/\partial x_{\nu} \), where \( T_{\mu\nu} \) denotes the energy-momentum of electromagnetic field

\[ T_{\mu\nu}^{(field)} = F_{\mu\alpha} F_{\nu\beta} + \frac{1}{4} \delta_{\mu\nu} F_{\alpha\beta} F_{\alpha\beta}. \tag{9} \]

Indeed, taking the derivative, we obtain \( F_{\mu\alpha} F_{\nu\alpha} + F_{\mu\alpha\nu} F_{\alpha\alpha} + \frac{1}{2} F_{\alpha\beta} F_{\alpha\beta}, \mu \). The first term is equal to Lorentz force, the remaining compensate each other when \( F_{\mu\alpha\nu} \) is replaced by \( (F_{\mu\alpha\nu} - F_{\nu\alpha\mu})/2 \).

- The left hand part of Eq.(8) transforms into similar expression

\[ \frac{dp_{\mu}}{dt} = -\partial T_{\mu\nu}^{(body)}/\partial x_{\nu}, \text{ where } T_{\mu\nu}^{(body)} = \rho u_{\mu} u_{\nu}. \tag{10} \]

As a result, Eq.(8) is formulated as the law of energy conservation
\[
\frac{\partial}{\partial x_\nu} \left[ T^{(\text{field})}_{\mu \nu} + T^{(\text{body})}_{\mu \nu} \right] = 0. \tag{11}
\]

- The components of energy-momentum tensor (density of energy, energy/momentum flows etc.) are global characteristics of body. Each physical system makes its own meaning to them.
- A mysterious disappearance of retardation from (11) will be explained below.

4. Comparative analysis

The transition to a macroscopic description is inevitably associated with a reduction in the number of independent variables. In the part \(2^0\) it was energy and current. But it was not possible to completely exclude the field - the integral \(\int l_\beta(y)(x-y)^2\,dy\,dt\) is its "trace". Integration over volume \(\int d\mathbf{y}\,dt\) is limited by the size of the body, but the integral \(\int dt\) extends from minus to plus infinity - its value is determined by the pole at \((x-y)^2 = 0\). Consequently, the points \(x\) and \(y\) lie on a light cone tilted into the past, therefore the signal from the source is delaying.

- Because of this delay, the mechanical energy of the body is not conserved - part of his kinetic energy is transferred to the electromagnetic field (according to the virial theorem, the loss of energy \(\delta E = \epsilon\) is equal to \(\delta E_{\text{man}} = -\epsilon\)). But changing the form of energy does not affect its conservation - it just goes from \(T^{(\text{body})}_{\mu \nu}\) to \(T^{(\text{field})}_{\mu \nu}\). Thus, its inclusion into \(T^{(\text{field})}_{\mu \nu}\) explains his "mysterious" absence in the formula (11).

- Equation (11), perhaps, is the most general of all the equations of theoretical physics - for any system possessing the Lagrange function \(\mathcal{L}\), one can find the energy-momentum tensor by the formula \(T^{\mu \nu} = \partial\mathcal{L}/\partial g_{\mu \nu}\) (\(g_{\mu \nu}\) is the metric tensor). For example, in the General Theory of Relativity \(\mathcal{L} = \sqrt{-g}R\) (\(R\) is the Ricci tensor), in Electrodynamics \(\mathcal{L} = F_{\mu \nu}F^{\mu \nu}\) and in many other examples.

5. Thermodynamics

So, the main obstacle on the way of the transition from mechanics to thermodynamics - the reversibility of mechanics - has been eliminated. The unification of mechanics with electrodynamics into a single system in the form of Eq. (11) allows us to formulate the basis of thermodynamics.

Let us write retarded potential \(V(r - \partial \mathbf{r} / c)\) approximately as \(V(r) - \frac{\partial V}{\partial \mathbf{r}}\frac{\partial \mathbf{r}}{c}\). Its first part, potential energy, does not depend on time and leads to reversible mechanics. The second, as shown above, goes over to the electromagnetic field, losing energy \(\frac{\partial V}{\partial \mathbf{r}}\frac{\partial \mathbf{r}}{c}\). Expression \(\frac{d}{dt} \left[ r \frac{\partial V}{\partial \mathbf{r}} \frac{\partial \mathbf{r}}{mc} \right] dt\) is nothing more than heat.

So, we obtain \(\delta Q = TdS\), where

\[
\frac{dS}{dt} = k \frac{d}{mc} \frac{d}{dr} r \frac{\partial V}{\partial \mathbf{r}} \tag{12}
\]

is an increase in entropy (more precisely, its mechanical analogue).

Thus, we have received not only the mathematical definition of entropy, but also its main property - growth in time. Moreover, the above derivation demonstrates a close relationship between entropy and interaction delay.

With the help of entropy, we can formulate the First Principle of thermodynamics

\[
TdS = \left( \frac{\partial S}{\partial E} \right) dE + \left( \frac{\partial S}{\partial V} \right) dV = dU + pdV \tag{13}
\]

(by definition, the pressure \(p\) is equal to \(\left( \frac{\partial S}{\partial V} \right)\)).

Heat belongs to the entire system, it cannot be concentrated on one carrier – the property that distinguishes heat from other types of energy.
6. Conclusion
So, we have established that mechanics is reversible only when instant forces are acting in it. Real mechanics with locally acting forces is irreversible, and this property is transferred to thermodynamics. It is impossible to avoid statistics - even the main characteristic of the body, its temperature, is the result of averaging the molecular speeds. The statistical independence of coordinates and velocities is solved in quantum theory. It is also necessary to find out the simple reason why it is impossible 100% conversion of heat into work, its "second grade" (L. Brillouin).

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