Thermo-Mechanical Energy

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Abstact:

Thermodynamics and mechanics are two highly developed disciplines, which have remained very independent. Some studies link them but they are restricted to very limited aspects, as if trying to maintain the independence between them. In Mechanics, energy is considered a single uniform property represented by a scalar magnitude has limited its study. On the contrary, Thermodynamics analyzes each magnitude separately and links them with already different definitions beforehand, this allows these to be given diverse properties often related to the reference systems and subsequently linked to each other a posteriori without losing their particularities. This can be seen in the definition of internal energy and kinetic energy of the volume of gases; In Mechanics, this separation is not made and therefore it is restricted to considering energy as a scalar. This study defines why energy should be subdivided, what advantage comes from analyzing it in this way, what cases it applies to, what answers are obtained that were not achievable before, and it eliminates contradictions that are generated if it is considered only a scalar. This reasoning also opens the way to the introduction of the concept of entropy in mechanics (more precisely in dynamics), which provides answers to the temporal direction of events and, in this way, the false idea of temporal symmetry in the equations is eliminated and it allows us to see that it is presented this way intentionally as a way to simplify problem-solving.

**Keywords:** energy, internal energy, entropy, dynamics.

I.   INTRODUCTION

In Lagrangian mechanics it is said that the shape of the equations of motion does not depend on the chosen reference system. This is true in cases in which the movement is subject to a fixed point which coincides with the reference system, for other cases this is not true and what is obtained is the movement seen from that particular system. Here we must say that each movement depends on the chosen reference system and that the easiest way to transfer or reference that movement to other systems is to place it at the center of mass of the interacting bodies. Due to the above, one must work with the internal energy of the problem, which is why it is logical that energy be taken as a scalar magnitude, see Annex No. 1. The fact that energy must be treated as a scalar in this process, added to how Newtonian mechanics is taught (especially in the first years of physics courses when that concept is introduced to the student), plus the fact of the large number of problems solved with the consideration of a scalar magnitude; has prevented any attempt at an analysis with a more complete vision that does not lead to errors..

Why then start this path? The answer is clear, there is evidence that indicates that energy does not accept a single interpretation, such as a scalar. Let us remember that physics is called an experimental science, because the results of laboratory tests are what confirm or nullify proposed hypotheses; and therefore what we question is: analyzing physical experiences by limiting the properties that the magnitudes present in the experience beforehand.

To begin with, the fact that a body with a certain kinetic energy can be changed direction without doing any work on it (under the action of a force at 90°) does not imply that the magnitude in question is a scalar. This characteristic, which does not correspond to that of scalars, is more noticeable if it is applied to a process with gravitational potential energy, given that this can be transformed into kinetic energy in a single direction, which cannot be altered. Which indicates that there is a magnitude (with energy units) of a vector nature, but it is not defined and is not mentioned anywhere.

A very common case in which students tend to question the scalar condition of energy is the oblique shot problem; In it, the projectile has a certain kinetic energy, which can be subdivided into two orthogonal components, which can be calculated directly from the projections of the velocity in each direction; This allows us to solve the problem through the concept of energy since the vertical component is the one to be transformed into gravitational potential energy, while the horizontal component will remain constant throughout the trajectory. Dividing energy into vertical and horizontal components; will lead the problem to be solved correctly in a faster and simpler way than by other methods generates doubts in the students, which are answered with a definition (a dogma) and not with logical reasoning as to why this is so.

Variable energy   ➡ Constant energy
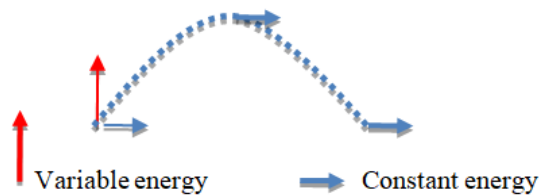
Following the same direction of introducing concepts of thermodynamics into mechanics, and taking into account that it is in this field where meaning can be given to the passage of time. The next point to consider arises, which is: Are the equations of mechanics symmetrical to the flow of time? This fact is known as "time reversal Invariance". The equations of mechanics are symmetrical if energy dissipation effects are ignored, which are normally not evaluated to simplify the problem. From here a question arises: Can the concept of entropy be introduced into mechanics?

II. BACKGROUND

Feynman [5] in "Six Easy Pieces" chapter 4 "The Conservation of Energy" assures that "**in physics today, we have no knowledge of what energy is**" and expresses it as there is a certain magnitude, which we call energy, which does not vary in the multiple changes that nature undergoes." It refers to energy as a magnitude that is conserved, alluding to the complexity of defining the concept of energy given the great variety of forms in which it occurs, in mechanics, electromagnetism, thermodynamics, chemistry, etc. This leads us to think that we are not only faced with different physical manifestations but also various mathematical ways of representing them.

We find some attempts to present these various mathematical expressions in A. Canero [1] who presents the vector characteristics that energy shows.

In stability, thermo-mechanical analysis is the study of the change in the properties of materials due to temperature variations. These studies are focused on static problems (in this study we are using it in dynamics and therefore all mechanics) to which the laws of thermodynamics are applied, as can be seen in Landau [4] "Theory of elasticity" Chapter 1 "Fundamental equations", § 3. Thermodynamics of deformations". Also here the concepts of internal energy and entropy are analyzed, although no attention is paid to the different characteristics presented by the different elements into which energy is decomposed, it is developed in the same direction of highlighting the need to deepen the application of the method of analysis of thermodynamics in mechanics.

III. BACKGROUND IN OTHER AREAS OF PHYSICS

In the theory of relativity, the existence of the energy-impulse tensor is defined, which is represented by a quadvector and relates the linear flow of energy and linear momentum. It can be found in Landau [3], "The Classical theory of fields", Chapter 1 "The Principle of Relativity", § 6 "Four-vectors" that one of the components is a three-dimensional scalar. This is understood given that the energy, analyzed from the point of view of coordinate systems is what we can decompose according to the directions of space. Therefore, it is shown that in other areas of physics there are clear indications that energy cannot be analyzed simply as a scalar magnitude; it requires being subdivided and analyzed in greater depth.

IV. ANALYSIS

From thermodynamics, we see that the energy of a particle system can be decomposed into internal energy [U] and kinetic energy of the fluid. The first is the energy that each of its particles has referred to the center of mass (kinetics and potential). Have in mind that we keep this definition unchanged from the one used in thermodynamics, see also that some authors express it in mechanics such as Landau [2] "Mechanics", first chapter "The equations of motion", § 8. "Center of mass". The second that we will call external energy [E] is that of the center of mass with respect to the chosen coordinate axis system. Under this concept, we not only have the translational kinetic energy $[E_t]$ but also the rotational energy $[E_r]$. Given what was mentioned above about the possibility of decomposing the translational kinetic energy E_t in the directions of the coordinate axes, there are seven linearly independent magnitudes, one for U, three for E_t and three others for E_r.

These seven magnitudes added arithmetically make up our traditional conception of kinetic energy. But they can be analyzed independently as seen in the oblique shot problem. This allows great simplifications and avoids entering into contradictions when decomposing according to the directions to a scalar magnitude.

From this approach, essential conditions arise for the interpretation of physical phenomena.

The first thing to highlight is that U is invariant when the coordinate system changes, and E is invariant in a collision. These effects are of significant importance to interpreting and solving this class of problems, given that the center of mass does not vary its direction, magnitude, or sense for any kind of collision and that U is the only one that varies in the collision, being completely lost when it is plastic. That is to say, the difference between an ideally elastic collision and a completely plastic one is the variation of its U. This shows that although we are

accustomed to adding the energy magnitudes as if they were a single magnitude, it can be seen that it has different degrees of independence, which cannot be exchanged arbitrarily. Although these divisions of the vector magnitudes can be considered as directions in the phase diagram, they do not comply with a sum corresponding to that of a Euclidean field, since it is arithmetic. Therefore, we are faced with a vector field of arithmetic sum.

Another element to take into account is that to vary the direction of movement of a body it is not necessary to apply on it, which at first glance makes us think that we are dealing with a scalar magnitude. When we analyze it carefully we see that for E_t we have to exert a force on it in a direction normal to its trajectory, on the other hand for E_r we have to exert a moment, also normal to the direction, but in this case of the rotation. Therefore, these two magnitudes, which can be decomposed on the coordinate axes, react differently to external actions implying that the energy must be decomposed to give a more precise interpretation to the events under study.

V.   PROPOSED MODEL

As the first element to highlight, it is mentioned that the U cannot be analyzed in vector form since its sum would be zero; this requires that when the sum of the U and E is studied, one must work with their module. On the other hand, the E has a vector character, it was presented with the example of the oblique shot, but it should be considered in this way given that the energy of the center of mass is a magnitude directly dependent on the chosen reference system and this is what defines its vector condition. That is, if we want to change from one coordinate system to another, the energy in the second system will have the same U (since it is invariant when changing coordinate systems) and the E or energy of the center of mass must be corrected according to the difference of speeds that occur between the different coordinate axis, the correction being for each axis independently, if the speed in that direction is maintained, the energy does not have to be corrected.

It should also be noted that in two-dimensional collision problems, in cases where the collision is elastic, we find four unknowns and a system of three equations to solve it, two of momentum and one of energy (because it is considered scalar), which does not allow us to solve the problem. If the energy equation of the center of mass is considered a vector and taking into account that it will not suffer any variation due to the collision. That is to say, the energy of the center of mass is conserved. We can interpret that the collision referred to a system that moves in solidarity with the center of mass is a collision that occurs perpendicular to the direction of movement and in this case, it is analyzed as a system of two equations with two unknowns. A conservation of momentum equation in a perpendicular direction to the motion of the center of mass and an energy equation (in this case U). It should be noted that to solve this problem, the energy must be decomposed according to its direction, that is, considered vector-wise, otherwise, this is not possible. Also during a plastic collision, the entire U is lost, since by definition it is given by the speed of the particles with respect to the center of mass and a plastic collision is defined when the bodies come out together after the impact, that is, without velocity with respect to the center of mass. Therefore, in a collision, the only energy at play is U, while E_r remains unchanged. From this analysis, it follows that a collision is elastic, partially elastic, or plastic does not depend on the direction or the speeds of the bodies before the impact (within a certain speed regime), but on the properties of the material; that is, whether it will produce permanent deformation or not.

If we pose another problem: that of a ruler which is hit from below by a projectile at a point that does not coincide with the center of mass; We see that the height reached by the center of mass of the system will be the same as if the impact is made at the center of mass. This suggests that part of the U has become E_r, which according to our model cannot be since E_r has vector properties and U has scalar properties.
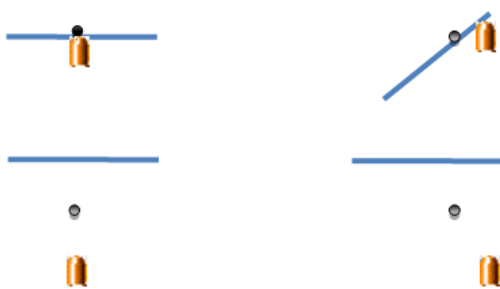
The figure shows the center of mass reaching the same height for both cases and although both systems initially have the same total energy, they do not reach the end with the same amount of energy since the one on the right has E_r.

This is understood by seeing that the system has E_r before the collision, and therefore is not part of the U. This problem shows that the E_r, the E_t and U have different properties and to understand the problem we must be able to separate them and understand the answers that each one of them gives. E_r remains constant because there is no external moment that varies the amount of angular momentum. E_t will vary as it goes up because the forces of gravity act. U becomes zero since the projectile is embedded in the ruler and therefore there is no velocity of the bodies with respect to the center of mass. Note that the U is not the same in both cases. The shock

is completely plastic whether the projectile hits the center of mass or another point on the ruler. This shows that U and E_r do not influence the conditions of the center of mass.

Note that the division of energy is a function of the distribution of mass of the problem and therefore allows us to analyze aspects that are lost as scalar.

Reversibility in physics: The introduction of entropy in mechanics is the subsequent step in considering the vector aspects of energy, since they are directly related. The energy equations are written symmetrical in the time phase for the sake of simplifying their resolution and not because they are really symmetrical.

By Nother's theorem, we know that any differentiable symmetry, representative of a physical system, involves a conservation law. It can be seen that when friction effects are not introduced, the equations maintain their temporal symmetry and therefore we have the principle of conservation of energy. Under these conditions we find that the variation of entropy is zero. Precisely the energy dissipated by friction effects can be considered as energy transformed into unusable heat or anergy of the system and therefore goes entirely to increase the entropy of the system.

$$1)\qquad \Delta S = S_b - S_a = \int_a^b \frac{dQ}{T} = \int_a^b \frac{f_{roce}(b-a)}{T}$$

Let us take into account that the work done by friction forces is converted into energy that is transferred from the body (or system) to the environment, that is, it is the heat that is dissipated in the environment which cannot be recovered and therefore It is an irreversible process that tells us the direction of time in our equations, separating the future from the past.

Keep in mind that this way of measuring time implies that it is not constant or uniform, that the flow of this magnitude increases at the times and places when the friction forces are greater, that is, when it undergoes greater accelerations.

The notion of time, independent of physical phenomena, and unalterable, is an idea that some authors attribute to Newton but that is not reflected in his equations. Although these work over time, they do so in a local way independent of the rest of the universe that surrounds it, unlike field theory which analyzes the context and relates it, this isolates it and individually links the components of the space that interests to its purposes. The concept of kinetic energy, for example, is not related to the rest of the universe, only to the reference system on which it has been calculated, as gravitational or elastic potential energy. Energy is a relationship between two objects, not a property of one of them. For these reasons, Newtonian mechanics is not contradicted by a particular time dependent on the location of the process under study. Mechanics combined with thermodynamics introduces through its formulas, more precisely entropy, the concept of temporal sequence, order of events, direction and meaning for the future of events, but being dependent on the process these cannot be neither uniform nor constant. Keep in mind that the statistical concept of thermodynamics is a result of an interpretation of classical mechanics interactions (collisions) and therefore complies with the rules that mechanics imposes.

We know that every process includes some friction, so time runs throughout space but at different speeds. Thermodynamics and mechanics are calculated in the equilibrium condition. This is because it allows an easy resolution of the equations and mainly because it gives a unique result of them. As we increase the degree of irreversibility we see that the results not only become more complex but also that by introducing a greater number of variables to the system we begin to have a multiplicity of results and therefore it stops being so predictable or unique. Let us keep in mind that assuming a linear response is valid in certain domains; when it goes beyond that the interactions between them generate unstable behaviors.

The dissipation of energy is produced by the friction between two bodies given its transformation into heat which cannot be used later. These two bodies must be considered part of the system and therefore what is dissipated is U, to which we give the scalar condition, it is the energy referred to as the center of mass. This must be so given that the E_r and E_t are energies that do not come into play in the interaction since they vary according to the system of coordinate axes selected. They are the energies that link the physical process with the reference system (which is not unique), and therefore, they cannot have any effect on the problem itself.

VI.   CONCLUSIONS

Energy is not a uniform property. It has specific characteristics depending on the class we are analyzing; not only can we divide it between scalar and vector, but we can again subdivide the vector between translational and rotational energy. Not differentiating it generates difficulties in solving the problems or directly prevents it, forcing the use of other paths that are usually longer and more complex or simply saying that Newtonian mechanics cannot solve it. As seen in problem No. 2 of the Annex, that statement is not true.

But the most important thing is that the idea is generated that elements are defined contrary to what our reasoning tells us. By saying that something that can be projected to be a scalar, we limit ourselves in the use of

that resource. It should be noted that accepting the division of energy is what allows a change of coordinate systems to be carried out in a manner consistent with the accepted theory.

From the above, it is concluded that energy must be subdivided and must be analyzed according to its characteristics: scalar and vector with conservation of linear momentum or angular momentum.

At this point, we want to emphasize that celestial mechanics based on Newtonian calculation is correct and that the orbit modification due to the effect of apsidal precession must be corrected with a term that incorporates the system rotation around the center of mass. This rotation is constant over time and should be interpreted as the E_r which was not evaluated through the Lagrange equations. In short, it is to add to the movement of the trajectory (ellipse) that Newton's equations give a rotational movement around the center of mass that Newton's same equations contemplate for rigid bodies. Keep in mind that in this case, not only the movement of the Earth is found but also that of the Sun. Einstein's solution gives the same answer in a single system of equations, therefore its resolution is more complex. With the proposed energy method, the same solution is reached as the sum of two simpler movements.

The measurement of time arises as something natural when energy is subdivided, since the U is the only one that intervenes in a physical process, its decrease is directly linked to the increase in entropy and therefore to the irreversibility that it possesses, note Keep in mind that the analysis is carried out on the system, that is, the surface against which the body rubs is part of the study.

VII.　ANNEX N°1

In Lagrangian mechanics, energy is treated as a scalar; normally no mention is made to which reference system it is being applied; but since the total energy is being taken and is expressed in a particular system, the equations found will be referred to that system.

As we will see in example No. 1, where the reference system coincides with that of the center of mass, which generates the false impression that an equation independent of the reference system is obtained. In example 2, given that the center of the Sun is taken as a reference, which differs very little from the center of mass and gives a result that is easy to find (and values very close to those that can be measured), it is assumed to be correct for any system. But it differs from what is assumed to be real, not because of a failure of Newton's equations, nor because of a poor application of Lagrange's equations, but because of having an erroneous vision of what the result should be.

To interpret this we refer to some examples:

1.– **Ideal pendulum**, the equations found through this method are: kinetic energy

2)　　$= \frac{1}{2}mv^2 = \frac{1}{2}ml^2\left(\frac{d\emptyset}{dt}\right)^2$

The potential energy:

3)　　$V = mgl\cos\emptyset$

Remaining the equation of the system

4)　　$\frac{d^2\emptyset}{dt^2} + \frac{g}{l}\sin\emptyset = 0$

It is the same equation found through Newton's laws. But why in this case do we say that the kinetic energy of the pendulum is a scalar and not a vector? The answer is that the movement of the concentrated mass of the pendulum has only one possibility of moving and that is following an arc of circumference, its trajectory. As indicated in the proposed model, for the E_t to be considered as scalar and not as vector must have its degrees of freedom restricted by forces that act normal to its trajectory, so they do not generate work. It is seen that the movement radially and parallel to the axis of rotation is prevented by the pendulum bar. Keep in mind that for modeling the body the bar and the fixation point must be included. So the forces are actually internal forces; The pendulum seen in this way moves around its center of mass given that the fixation point acts as CIR and therefore determines that for this movement it must be considered as an infinite mass, see example 2 for a more developed interpretation.

2.– **Movement of celestial bodies**, movement of the Earth around the Sun, if the center of coordinates is placed in the center of the Sun.

The kinetic energy

5)　　$T = \frac{1}{2}mv^2 = \frac{1}{2}m\left[\left(\frac{dr}{dt}\right)^2 + r^2\left(\frac{d\theta}{dt}\right)^2\right]$

The potential energy:

6) $\quad V = G\frac{Mm}{r}$

The two equations of motion are

7) $\quad \frac{d^2r}{dt^2} - r\left(\frac{d\theta}{dt}\right)^2 + G\frac{M}{r^2} = 0$

8) $\quad \frac{d}{dt}\left(r^2\frac{d\theta}{dt}\right) = 0$

Its simplest resolution is:

9) $\quad r(\theta) = \frac{a\left(1-\varepsilon^2\right)}{1+\varepsilon\cos\cos\theta}$

Where:

10) $\quad \varepsilon = \sqrt{1 - \frac{b^2}{a^2}}$

Where 'a' and 'b' are the semi-major and minor axes of the ellipse.

These two equations tell us, the first that the motion is an ellipse and the other that the angular momentum is conserved. Here we look at the one that expresses the trajectory, given that we have said that U is taken from the center of mass to be able to easily reference it to another system, the trajectory defined here is the one seen from the center of the Sun. This is very similar to what is seen from the center of mass, given the great difference between the mass of the Sun and the Earth. If we carry out the study placing the reference system at the center of mass, and, introducing the concept of reduced mass, to reference the movement to the center of gravity, we find the following equations.

11) $\quad M_{red} = \frac{Mm}{(m+M)}$

Where the reduced mass replaces the mass of the Sun in the Earth's motion equation and the mass of the Earth in the Sun's motion.

12) $\quad \frac{d^2r_t}{dt} - r_t\left(\frac{d\theta}{dt}\right)^2 + G\frac{Mm}{(m+M)r_t^2} = 0$

13) $\quad \frac{d}{dt}\left[r_s^2\frac{d\theta}{dt}\right] = 0$

14) $\quad \frac{d^2r_s}{dt} - r_s\left(\frac{d\theta}{dt}\right)^2 + G\frac{Mm}{(m+M)r_s^2} = 0$

15) $\quad \frac{d}{dt}\left[r_t^2\frac{d\theta}{dt}\right] = 0$

r_s is the distance from the Sun to the center of mass

r_t is the distance from Earth to center of mass.

Which are two independent systems of equations with a phase angle of 180 degrees. The solution is, two ellipses whose common focus is the center of mass of the set. To understand the movement of the Earth and understand that it is a cycloid and not an ellipse, it must be previously defined how the reference system is set. If the reference system is defined only by the bodies (sun-earth) the resulting equation is that of ellipses. If the system is fixed to the stars in the sky, the resulting equation is a cycloid, which is the previous ellipse plus the rotation of the previous reference system to the fixed system in the sky. The energy E_r put into play in the system depends on the reference system and not on the interaction of the bodies, which is why it does not appear for the reference system generated by Lagrange's equations. For the two cases presented, the energy is referred to the bodies of the system; this makes E_r equal to 0, that is, there is no rotation in this reference system and, therefore, there is no apsidal precession which does exist in another system of references such as being fixed to the stars. The calculation of E_r must be carried out by measuring the displacement that occurs in the lapse of one year between two aphelions. The system's momentum does not vary since there is no external moment, since the distance between the bodies is not constant, the moment of inertia varies, and, therefore, the rotation speed is variable to compensate for the variation in the moment of inertia. The rotation speed of the two bodies against a system considered fixed (the stars in the sky) is imposed by the amount of angular motion that the system must maintain to compensate for the centripetal force due to gravity, plus the amount of motion that the system must maintain to compensate for the centripetal force due to gravity has the above system against the fixed one. Since the two aforementioned quantities of motion are constant, the effects on the speed of the bodies are in phase and, therefore, the only visible result becomes the variation in angle that occurs when the cycle is completed.

This means that the cycle between one maximum and the next will be greater or less than 360°, generating the precession of the system. Therefore the correction factor has to be applied to the angle, so the equation is as follows.

16) $r(\theta) = \frac{a(1-\varepsilon^2)}{1+\varepsilon\cos\cos(\alpha\theta)}$

Where: R(θ) is the distance from the sun or the earth to the center of mass and ω is the angular velocity between the system fixed to the stars and that of the system calculated from Lagrange's equations. Keep in mind that the result through the Lagrange equations, being the one with the lowest energy, is calculated only with the internal energy of the system and does not take into account the external energy that is linked to the reference system, in this case, E_r.

VIII. REFERENCES

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