The physical nature of the basic concepts of physics

Part 7: Potential Energy Fields [(i)]

Guido F. Nelissen

guido.nelissen@gmail.com

Abstract

'Potential' energy is generally defined as the energy that has to do with location relative to something else and therefore it is also called 'energy of configuration'.
The present physics doesn't however tell us anything about the physical nature of this so-called 'potential' energy is and how and where it is physically stored. The only thing that we know is that in the case of conservative forces, the disappeared kinetic energy that is conserved as 'potential' energy, can be completely retransformed into kinetic energy.
In my paper part 3 on the physical nature of kinetic energy, I have demonstrated that the kinetic energy of a particle system is a mathematical expression of its total amount of reversibly transferable translational motion.
In the present paper I demonstrate that the concept of gravitational 'potential' energy is an excellent mathematical tool to calculate the speed of a falling object, but it creates a physical problem with the law of conservation of energy, because it supposes that both, the 'kinetic energy' as well as the 'potential energy', arise out of nothing, while the total amount of energy remains zero throughout the whole process.
This allows me to demonstrate that the reversible transformation of 'kinetic' energy into 'potential' energy and vice versa, is a mathematical expression for the reversible transformation of one kind of congruent motion into another, which allows me to reveal the specific nature of the congruent motion that is associated with the mathematical concept of 'potential' energy.
This will allow me in my next paper on 'velocity' to reveal the physical nature of variable velocity, and it will in my next papers on 'mass' and on 'gravitation' lead allow me to reveal the physical nature of respectively propelled acceleration and of gravitational acceleration.

1. The historical development of the present concept of potential energy

In the present physics the concept of 'energy' is used in a large number of different forms [1]: kinetic energy, potential energy, thermal energy, chemical energy, gravitational energy, nuclear energy, etc. But all these forms can be brought back to two basic forms of energy: 'Kinetic' energy, which depends of the motion and the mass of the particle [ii] and 'potential' energy.
The term 'potential' comes from Aristotle's concept of 'potentiality', which refers to any possible property that a thing can have [2]. Depending on the context it could be translated as 'ability', 'capability', 'capacity', 'potency', or 'power', which remained very important in the

(i) Updated edition of the paper "Potential Energy" December 1991 by the same author.
(ii) See my paper on the physical nature of Work and Kinetic Energy.

middle ages, especially in the development of medieval theology.
Joseph Louis, Comte Lagrange (1736-1813), French mathematician, director of the Berlin Academy and professor at the Ecole Polytechnique (Paris) formulated Newtonian mechanics in the language of advanced calculus and introduced the general definition of the 'potential' energy function [3].
In modern physics, 'potential' energy (U) is defined in a general way as:

- the capacity of a particle to do work by virtue of its position in space [4], which is e.g. the case of gravitation potential energy of a massive object relative to the Earth
- the energy that an object possesses by virtue of its position relative to another object [5] which is e.g. the case of the elastic potential energy of a stretched or compressed spring
- the energy that an object possessed because of specific properties within itself, which is the case of electric potential energy e.g. of two point charges

Potential energy is expressed in Joule (J), which is the unit of 'work' that is defined as the force times the displacement (Nm).

It follows from these definitions that e.g. the gravitational potential energy of a mass particle above the Earth is a property of the configuration of the particle-Earth system. [6]. This 'energy of configuration' is said to be 'conservative', which means that the amount of 'kinetic' energy that is transformed into 'potential' energy (while e.g. compressing an ideal spring or throwing an object up in the air) can be completely retransformed into 'kinetic' energy (when the ideal spring relaxes, or the object falls back to its initial position).

Potential energy is closely linked to force. The concept of 'force', as the product of a mass times its acceleration, was developed by Isaac Newton (1642 – 1727), who demonstrated that the gravitational force is proportional to the masses of the attracting bodies and inversely proportional to the square of their mutual distance: $F_g = G(Mm/r^2)$
If a body is free to move, it will automatically proceed to the position with the lowest potential energy, and one needs a force to move it to a place with a higher potential energy and even to keep it in such a place. In that way, the potential energy is defined as the work that has to be performed by a force over a distance to move a given mass to a position with a higher 'potential' energy.

In the 18th century, when looking at the motion of a many bodies system, dealing with the gravitational force between each pair of bodies rapidly became computationally inconvenient. In order to simplify the calculations of all these gravitational forces, a new quantity was introduced, that gave to each point in space the total gravitational acceleration that would be felt by a unit mass at that point [7]. According to Stanley Goldberg [8]: *"Rather than dealing with forces* (*which are vectors*) *and their effects on masses directly, which can be difficult, the potential energy that a body acquires under the action of those forces can be calculated. Since energy is a scalar quantity, very often an analysis which had been difficult becomes relatively easy."*

In 1849, Michael Faraday introduced the strong visual concept of "field lines" in order to explain the properties of electricity and magnetism [9].
In a series of papers in 1861 and 1862, James Clerk Maxwell developed a unified theory of electricity and magnetism. Maxwell had first supposed that the electromagnetic field was a consequence of the deformation of some underlying 'ether'. The independent nature of the field became however apparent with his discovery that the waves in those fields propagated at the finite speed of light. By doing so, Maxwell had noticed that he could rearrange his set of equations in a way that took exactly the same form as the equations that describe sound or

water waves:

$$\frac{\delta^2 z}{\delta x^2} = \frac{1}{v^2}\frac{\delta^2 z}{\delta t^2}$$

which are periodic oscillations of the air or the water, while proceeding at a velocity 'v'. This led him to conclude that light (for which v = c) must be a wave that is produced by the oscillations of the electric and magnetic fields. By introducing these 'fields', Maxwell was able to write down a set of equations that described all the known electrical and magnetic phenomena. His equations showed that as an electric field changes, it creates a changing magnetic field, which on its turn creates a changing electric field, etc.

The problem of the invariability of the speed of light was later solved by Albert Einstein, with the introduction in 1905 of his Special Theory of Relativity, in which he demonstrated that the speed of electromagnetic waves is the same for all observers.

The fact that the gravitational acceleration of an 'attracted' object is independent of its mass ($g = F/m = - GM/r^2$), constituted the starting point of Einstein's General Theory of Relativity in 1916, in which he incorporated his Special Theory of Relativity and Newton's law of universal gravitation, in a geometric theory in which massive bodies accelerate effortlessly to one another. In that way, Einstein replaced the action at a distance implied in Newton's theory, by the acceleration of massive bodies in a "curved" space-time".
This led to the modern concept of the 'field' as a physical quantity that assigns a value to each point in space-time:

- The temperature or the energy at different points in a room are examples of such a "scalar field"
- The wind speed and direction that is described by assigning a vector to each point on a map, is an example of such a "vector field".
- Three-dimensional distortions of a rubber sheet is an example of a such a "tensor field"

In 1927 Paul Dirac used quantum fields to explain how the decay of an atom to a lower quantum state leads to the emission of a photon (which is the quantum particle of the electromagnetic field). This led to the general conception that all particles could be understood as the quanta of some 'quantum fields', elevating in that way 'fields' to the status of truly independent entities and reducing particles to derivatives of a field.
This then led to the notion of the 'field' as a physical entity with intrinsic properties, such as energy, momentum and force content, which led to the present Quantum Field Theory (QFT) that tries to unify Relativity with quantum physics.

2. The close relation between 'kinetic' and 'potential' energy

In the present textbooks of physics, the concept of kinetic' energy is introduced by means of the Work-Energy Theorem, that says that the work 'W' done by a force 'F' on a free particle with a mass 'm', is equal to the change in the kinetic energy of that particle.
In my papers Part 3 and 4 on the physical nature of 'kinetic' energy, I have demonstrated that the Work-Energy Theorem is a straight consequence of the mathematical definitions of 'work' and 'kinetic energy':
$W = \int F\,dx = \int (ma)\,dx = \int m\,dv\,dx/dt = \int m\,v\,dv = \Delta(mv^2/2) = \Delta K$

By introducing the work performed by a 'conservative' force, as a force that only depends on the starting and the end points (and not on the followed path, it is possible to define a

conservative force F(x) as: $F(x) = - dU(x)/dx$
The force exerted by a spring on a mass in one-dimensional motion and the case of Newton's gravitational force are two basic examples of such 'conservative' forces.

2.1 Elastic potential energy

The basic concept of 'potential' energy is the case of an ideal mass-spring system, in which a mass 'm' moves with an initial velocity 'v_i' frictionless against an ideal massless spring that obeys Hooke's law: $F = - kx$ and that is fixed at one end to a rigid wall [10].
The ideal mass-spring system has the advantage that the kinetic energy is completely located in the moving mass 'm' (as $K = mv^2/2$) and that the potential energy is completely located in the compressed/expanded spring and is expressed in function of the relative position 'x' of the free end of the spring: $U(x) = - \int F(x)\, dx = - \int (-kx)\, dx = kx^2/2$

When the mass with an initial kinetic energy '$K_i = mv_i^2/2$' hits the spring, its speed and consequently its kinetic energy decrease while compressing the spring, until the block finally comes to a standstill and $v = K = 0$).
From that moment on [11] "*the compressed spring expands and pushes the block back to its initial position, whereby its regains its initial speed (in the opposite direction $v_f = -v_i$) and its initial kinetic energy ($K_f = K_i$). Under these circumstances it makes sense to introduce the concept of 'energy of configuration' or 'potential' energy U, and to say that if the kinetic energy* (of the mass) *changes by ΔK then the 'potential' energy* (of the spring) *must change by an equal but opposite amount ΔU, so that the sum of the two changes remains zero during the whole process: $\Delta K + \Delta U = 0$*".
In that way, the sum of the kinetic energy (of the moving mass) and the potential energy (of the compressed/extended spring) remains equal to the initial kinetic energy throughout the whole process: $K + U = mv^2/2 + kx^2/2 = mv_i/2$

2.2 Newtonian gravitational potential energy

Another classic example of the concept of 'potential' energy is the case of Newtonian gravitational potential energy. In that case, the force of gravity in the downward direction, is introduced as a negative force: $F = -mg$.
In that way the gravitational potential energy at a position 'y' is then defined as:
$U(r) = -\int F\, dr = - \int (GMm/r^2)dr = - GMm/r$
And the conservation of the total energy gives us:
$K + U = mv^2/2 + (-GMm/r) = mv^2/2 – GMm/r = 0$
So that: $(K =)\ mv^2/2 = GMm/r\ (= -U)$

2.3 The curvature of space-time

The basic postulate of the Special Theory of Relativity is based on the fact that it is impossible to determine which frame is in motion and which not, and concludes therefore that velocity is a relative phenomenon.
The basic postulate of the General Theory of Relativity is based on the fact that the gravitational acceleration is independent of the physical characteristics of a falling object, and concludes therefore that it is impossible to distinguish between the effects of acceleration

and the effects of a gravitational field (the so-called principle of equivalence).
This led Albert Einstein to conclude that gravitational acceleration is a characteristic of the deformation of the spacetime around celestial bodies, that deforms under the influence of a heavy mass, in the same way that a heavy ball that is dropped on a rubber sheet, will depress the rubber sheet and curve the sheet around it. In that way, a celestial body will curve spacetime around it proportional to its mass.
This means that masses are not 'attracted' by a (gravitational) 'force', but they follow the geodesic path of the downward curvature of spacetime that is created by the celestial body.
In that way, there is no difference between an inertial frame of reference and a gravitational field so that the gravitational field must bent light rays and must affect the rate at which clocks run. Both effects predicted by Einstein's General Theory of Relativity have later been proven experimentally!

3. The indistinct nature of gravitational 'potential' energy fields

3.1 The mathematical nature of 'potential' energy fields

When a thrown up body comes to a standstill at a given height, the present physics doesn't really tell us where the disappeared kinetic energy has gone to: Is it in the thrown up mass, in the Earth's potential energy, in the configuration of both or in the vacuum space between both, as a curvature of spacetime? The only thing that we know for sure is that the kinetic energy must be conserved somehow, somewhere, because it can be completely regained when the body falls back to its initial position.
The mathematical solution of this problem is that, by attributing a 'potential' energy to each 'point' in space, that is exactly equal to the disappeared kinetic energy in that same place, we keep the lost kinetic energy 'potentially' in our equations (under the name of 'potential' energy) and can take it back whenever the object returns to its initial position.
This practical character of 'potential' energy as a mathematical tool is expressed by Hans Ohanian when he writes [12] "*Whenever the force acting on a particle is conservative, it is possible to construct a corresponding potential energy". … The change in the potential energy between two points equals the negative of the work done by the force between these points, so that the total mechanical energy K + U is conserved*".

The idea of an energy 'field' plays a central role in modern physics. According to Brian Cox and Andrew Cohen [13]: "*The concept of field is basically an array of numbers that are associated to each point of a surface or a volume. One example of a field is the temperature in a room. If you could measure the temperature at each point in a room, you obtain an array of numbers that describe how the temperature changes with the position in the room. This array of numbers is called the temperature field*."
And Cox and Cohen continue that "*In a similar way you can introduce the concept of a magnetic field by holding a compass at places around a wire carrying an electric current and noting down how much the needle deflects and in what direction. These numbers and directions are called the 'magnetic field'.*"
It follows from these descriptions that a field consist of a number of physical values (expressed as scalars, vectors or tensors) such as the temperature or the magnetic deflection, that are associated with given points in space.
That doesn't however mean that that the temperature, the magnetic deflection, the gravitational acceleration and the elastic force of a spring, are characteristics of these 'points' in space, because a 'point' is not a physical entity, but a purely mathematical concept.

These considerations oblige us to conclude that if we want to unveil the physical nature of the transformation of ‘kinetic energy’ into ‘potential energy’, we must first of all start with correct definitions of the physical nature of ‘kinetic’ energy.

3.2 Kinetic and potential energy as different expressions of work

In this section, I will use the concept of gravitational acceleration ‘$g = GM/r^2$’.

- The work ‘W’ done by a force ‘F’ on a mass ‘m’ over a distance ‘r’ is per definition the product of the force times the displacement: $\int F\, dr = W(F,r)$
So that for a constant force: $\int F\, dr = F \int dr = F.r = W(F,r)$

- That same work, done by a force ‘F’ on a mass ‘m’ over a distance ‘r’, can also be expressed in function of mass ‘m’ and the obtained speed ‘v’:
$W(F,r) = \int F\, dr = \int m\, a\, dr = \int m\, dv\, dr/dt = \int m\, v\, dv = mv^2/2 = W(m,v)$
This mathematical expression of the work done on a mass ‘m’ while accelerating it to a velocity ‘v’, is generally defined as the kinetic energy $K = mv^2/2$ of a mass ‘m’.
This simple deduction demonstrates that the concept of ‘kinetic energy’ is not a new physical quantity, but that it is just a mathematical expression of the done on a mass ‘m’, expressed in function of the mass ‘m’ and the obtained speed ‘v’ (instead of the force ‘F’ and the covered distance ‘r’). So that both mathematical expressions are equivalent:
$W(F,r) = \int F\, dr = mv^2/2 = K = W(m,v)$

- That same work done by a force F (= GMm/r^2) on a particle with a mass ‘m’, can also be expressed in function of the covered distance ‘r’ (or ‘l’, or ‘h’) as:
$W(F,r) = \int F\, dr = \int (GMm/r^2)\, dr = GMm \int dr/r^2 = GMm/r = K(r)$.

These simple deductions demonstrate that the mathematical equations ‘$mv^2/2$’ and ‘GMm/r’, are not different physical entities but that it are just different mathematical expressions of the work done by a force ‘F’ over a distance ‘r’ (or ‘h’ or ‘l’) on a free particle with mass ‘m’, that acquires a velocity ‘v’, one expressed in function of the obtained velocity ‘v’ and one expressed in function of the covered distance ‘r’(or ‘l’ or ‘h’): $K(m,v) = mv^2/2 = GMm/r$.
This means that the both mathematical equations can be represented by one graph (Fig. 7.1).

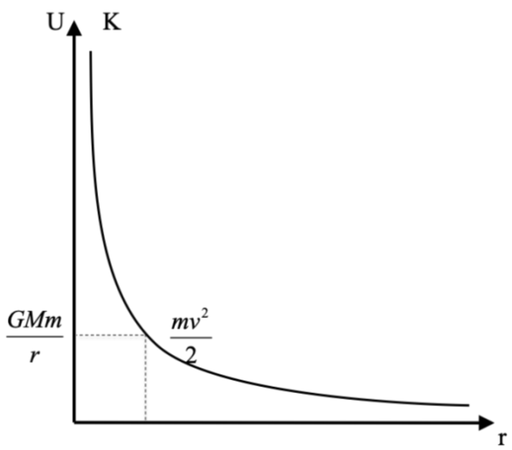

FIG. 7.1

And that the relation between both expressions is given by the equation of the velocity 'v' in function of the covered distance 'r' as: v = $\sqrt{2GM/r}$. In that way it becomes clear that: K(m,v) = $mv^2/2$ = m(2GM/r)/2 = GMm/r = K(m,r).

3.3 The conservation of kinetic and potential energy as bookkeeping statements

From the former deduction, it follows that $mv^2/2$ and GMm/r are not different kinds of energy, but that it are different mathematical expression of the work performed over a given distance 'r' (or h). Because both equations are just different expressions of one and the same work, the difference between both expressions is necessarily zero in all points of the graph: $(mv^2/2) - (GMm/r) = 0$

By defining '-GMm/r' as the 'potential' energy of the mass 'm', the present textbooks introduce the principle of the conservation of energy, as the sum of the kinetic ($mv^2/2$) and the potential (-GMm/r) energy: $(mv^2/2) + (-GMm/r) = 0$

This demonstrates that the mathematical concept of e.g. gravitational 'potential energy' as 'energy of configuration' is undeniably an excellent mathematical tool to calculate the speed of a falling object, but it creates a physical problem because it supposes that in the case of a falling mass both 'energies', the 'kinetic energy' as well as the 'potential energy', arise out of nothing, while the total amount of energy remains literally zero during the whole process so that [14] "*The equations of the conservation of kinetic and potential energy are essentially bookkeeping statements about energy.*" (Fig. 7.2)

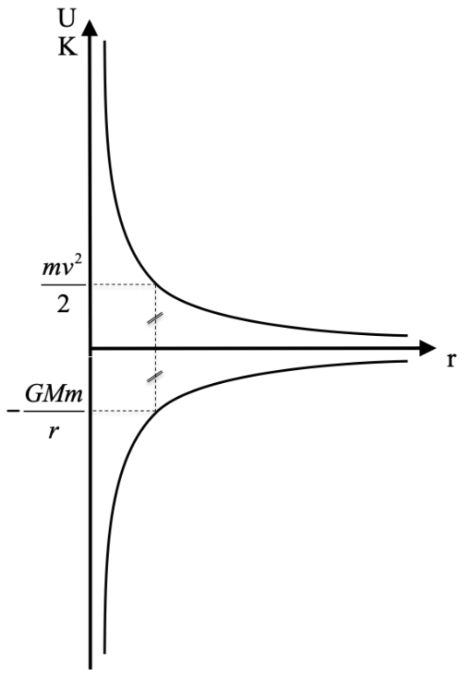

FIG. 7.2

This can be demonstrated by means of the case [15] of a meteoroid (of e.g. 1kg) that is initially at rest at a very large distance from the Earth (with $R_E = 6{,}38 \times 10^6$m) and that proceeds, under the influence of the Earth's gravity ($M_E = 5{,}98 \times 10^{24}$kg and $G = 6{,}67 \times 10^{-11}$Nm²/kg) to

the Earth along a straight radial line.
At a very large distance (r = ∞), the meteoroid is:

- at rest: $v = \sqrt{2GM/R} = 0$ and $K_\infty = mv^2/2 = 0$
- at a very large distance from the sun: $r = \infty$ and $U_\infty = -GM_E\, m/r = 0$

So that the total initial energy of the meteoroid is zero: $K_\infty + U_\infty = 0$

At the moment of impact with the Earth ($r = R_E$):

- the potential energy of the meteoroid is: $U_E = -GM_Em/R_E$
- the kinetic energy of the meteoroid is: $K_E = mv_E^2/2$

So that its total energy is: $mv_E^2/2 + (-GM_Em/R_E) = 0$
And the impact velocity v_E is given by: $v_E^2 = 2GM_E/R_E$ so that $v_E = 11{,}182x10$ m/s
Which gives us: $K_E = 62{,}518x10^6$ kgm²/s² and $U_E = -62{,}518x10^6$ kgm²/s²
So that the total energy of the meteoroid at the moment of impact is zero: $K_E + U_E = 0$

3.4 The energy gap of General Relativity

Einstein based his General Theory of Relativity on the equivalence principle which states that in an accelerated reference frame, an observer would experience exactly the same forces as those produced by gravity. In that way, everything that could be ascribed to a gravitational field could as well be ascribed to the acceleration of the frame of reference.
So, in General Relativity, masses are not considered to be attracted' by a force, but follow the curvature that is created by cosmic bodies in spacetime around them, or in the words of John Archibald Wheeler [16] "*Mass grips spacetime, telling it how to curve and spacetime grips mass, telling it how to move*". In that view, it is normal that General Relativity is less occupied with the forces (and the energies) involved in the increasing kinetic energies of bodies accelerating toward each other.
This view if commonly illustrated by a heavy mass that is put in the middle of a trampoline and that makes the balls at the edge of the trampoline accelerate along the curvature made by the weight. But this representation is a kind of circular reasoning, because it works because of Earth's gravity underneath the trampoline. Without it, the curvature in the trampoline would have no effect on the balls.
The general assumption is that the energy that is needed to accelerate masses toward each other is supplied by the vacuum energy of spacetime. The question is however how spacetime can generate this enormous amounts of energy. According to Jim Bagott [17] modest estimates based on some arbitrary assumptions predict a vacuum energy of 10^{105} J/cm³. On the other side "the mass density of 'empty' spacetime is 5.3 10^{-16}J/cm³, so the prediction is out by a factor 10^{121}. Another common assumption of the quantum field theory is that the quantum vacuum is equivalent to the cosmological constant. Which is on the order of 10^{-122}. The least we can say about this is that General Relativity has not really solved its energy problem (iii).

4. The physical nature of potential energy fields

4.1 The dynamic nature of kinetic energy

(iii) This will be analyzed in my paper on the physical nature of gravitation.

In section 6 "*The fundamentally dynamic nature of force*" of my paper Part 2 on the physical nature of 'force', I have referred to the paper "*Momentum flow as an alternative perspective in elementary mechanics*" [18] published in 1980 by Andrea A. diSessa of MIT. In that paper, diSessa proposed to use the notion of 'momentum flow' instead of 'force', because momentum flow expresses 'force' as a consequence of the repetitive collisions of the particle system of the force with the particle system of the body". In that paper diSessa demonstrates that this is exactly what happens e.g. the case of a pressure tank between the gas molecules and the walls of the tank, or between the jiggling molecules of an object lying on the floor and the surface of the floor. And this is as a matter of fact also what happens between the molecules of a wall and the molecules of our body when you stretch yourself against it, or while hanging on the branch of a tree, or while holding a weight stationary above the ground. Newton's laws tells us that in those cases no work is done, since nothing is accelerated or displaced, but we surely get exhausted by doing it! Momentum flow analysis clearly reveals the fundamentally dynamic character of all these so-called 'static' forces, which can have dynamic consequences, such as e.g. tension-corrosion.

This point of view of Andrea A. diSessa fits in with the conclusions of my previous papers on the physical nature of a number of basic concepts related to momentum and energy:

- **Linear Momentum** is a mathematical expression of the total amount of congruent translational motion (of its basic particles unit mass particles)
- **Force** is a mathematical expression of the rate at which momentum flows from one body to another, which expresses the transfer rate of congruent translational motion
- **Work** is a mathematical expression of the transferred amount of congruent translational motion
- **Kinetic Energy** (of bulk motion)' is a mathematical expression of the total amount of reversibly transferable congruent translational motion in regard to any free body that is at rest in the same reference frame
- **Temperature** is a mathematical expression of the average amount of the two-sided translational mass flow per unit number density of particles with isotropic motion.

These considerations demonstrate that over the years there has been a growing tendency in physics to associate more and more expressions related to 'energy' with motion.
This was already predicted by Richard Feynman, who wrote [19]: *"In the early days there were phenomena of motion and phenomena of heat; there were phenomena of sound, of light, and of gravity. But it was soon discovered, after Sir Isaac Newton explained the laws of motion, that some of these apparently different things were aspects of the same thing:*
- "The phenomena of sound could be completely understood as the motion of atoms in the air. So sound was no longer considered something in addition to motion.
- It was also discovered that heat phenomena are easily understandable from the laws of motion" and that light is the motion of particles (photons).

4.2 The dynamic nature of elastic potential energy

The former section lead us inevitably to the conclusion that the general principle of the conservation of "energy" must be a mathematical expression of the conservation of motion.
So the question: "where has the decreasing 'kinetic energy' gone to, when an object is thrown up in the air" must be replaced by the question "where has the congruent translational motion gone to, when an object is thrown up in the air"?
In the case of disappearing kinetic energy, no visible, macroscopic motion occurs. The only

thing that we perceive in that case is that we have to exert an increasing force to keep a body at a given place.

To analyse this, we return to the case of the ideal mass-spring system of section 2.1 because, this has the tremendous advantage that the potential energy is completely located in the spring and is expressed in function of the relative compression/expansion 'x' of the free end of the spring as: $U(x) = -\int F(x)\,dx = -\int (-kx)\,dx = kx^2/2$

According to Robert Resnick and David Halliday [20] "*Einstein's findings suggested that, if certain physic physical laws were to be retained, the mass of a particle had to be redefined as:* $m_v = \dfrac{m0}{\sqrt{1 - v^2/c^2}}$

Here m_0 is the mass of the particle when at rest with respect to the observer, called the rest mass; m is the mass of the particle measured as it moves at a speed 'v' relative to the observer." And they continue their analyses by stipulating that experimental checks of this equation made by Bucherer and Neumann in 1914 (by deflecting high speed electrons in magnetic fields and measuring the radii of the curvature of their path) confirm this equation.
They further demonstrate the close relation between mass and energy given by Einstein's famous equation: $E = mc^2$, by proving that the kinetic energy of a mass particle at relative low speeds is in fact nothing else than the energy of its mass increase: $mv^2/2 = \Delta mc^2$
According to Robert Resnick and David Halliday [21] "*The basic idea that energy is equivalent to mass can be extended to include energies other than kinetic*.
And they give two examples of this equivalence between mass and energy:

- "W*hen we add an amount 'ΔQ' of heat to an object, its mass increases by an amount* $\Delta m = \Delta Q/c^2$".
- "*When we compress a spring and give it an elastic potential energy ΔU, its mass increases by an amount* $\Delta m = \Delta U/c^2$"

From this, we can deduce that the motion that is associated with 'potential' energy must be located at the basic quantum level of the basic mass particles.

5. The quantum nature of elastic potential energy

Contrary to the case of 'kinetic energy' which is studied in particle systems in which the basic components are considered as individual particles that do not exert any influence on each other (except during collision), 'potential energy' exclusively occurs when the motions of the particles of the considered bodies are in some way entwined. The cases in which potential energy occurs are indeed always symmetric and synchronic and it reproduces congruent motion when it disappears.
In my paper "Part 4: The conservation of kinetic energy in elastic collisions" I have demonstrated that in a perfectly elastic collision (which is identical to the case of two rigid masses that are separated by a perfectly elastic spring), the 'forces', or in other words the momentum flows between the considered masses obey Newton's third law of motion and are at each moment equal and opposite. This means that the internal motion that must be associated with potential energy has to consist of some form of congruent motion!

When we take all these considerations into account, as well as the dynamic nature of the concept of energy, we must necessarily conclude that in the case of a perfect elastic spring as well as in the case of gravitational interaction, the most plausible explanation for the transformation of 'kinetic' energy into 'potential' energy is the synchronous transformation

of external congruent motion into internal congruent motion, and vice versa.
This leads us to the conclusion that 'potential energy' (U) is in fact a mathematical expression for the amount of reversibly transferable motion that is present in the particle system under the form of coherent, reversible rotational/vibrational motion of its basic, quantum components. This transformation is of the same nature as that of the internal kinetic energy of the atoms an ideal diatomic gas [22]: "*Diatomic gases store amounts of energy in the internal motions of the atoms within each molecule. If such a molecule collides with another molecule, it starts rotating about its center of mass.*" In that way the external translational kinetic energy is transformed in internal rotational/vibrational kinetic energy.

This conclusion is completely in line with the modern viewpoint of quantum mechanics, such as this is expressed by Robert Adair, who prophetically wrote [23]: "*In certain specific cases it is possible to show that the potential energy change is actually a change in the kinetic energy of microscopic particles … If we extent our notion of particles and kinetic energy to encompass the energies of quantum particles contributing to force fields, we may be able to consider all changes in potential energy as changes in the kinetic energies of particles.*"
It must thereby be pointed out that the present "spring-model" for potential energy in a classic mass-spring system, is in fact based on a circular reasoning, because it implicitly supposes that the atoms of the spring are on their turn connected by (microscopically small) springs! My dynamic model of subatomic 'flywheels' doesn't have this inconvenience and is in complete harmony with the fundamentally dynamic nature of "energy", as a mathematical equation that remains constant when the total amount of motion is conserved.
This dynamic concept of 'potential energy', as internal rotational/vibrational motion will enable me to reveal the absolute, physical nature of 'velocity' and will lead me in a self-evident way to the so-called 'relativistic' equations of Special Theory of Relativity (iv).

6. Conclusion

By making a clear distinction between the real physical data on the one hand and the mathematical concepts on the other hand, we have been able to reveal the physical nature of 'energy' in all its different forms:

- Kinetic energy of bulk motion is a mathematical expression of the amount of reversibly transferable congruent translational motion at a given velocity level.
- Kinetic energy of thermal motion (or shortly thermal energy, or heat), is a mathematical expression of the amount of transferable isotropic translational motion at the molecular level.
- Potential energy is a mathematical expression of the amount of congruent, reversibly transferable internal rotational/vibrational motion at the basic particle level.

This better understanding cannot be put aside as a purely didactic matter, because it has made us realize that the amount of motion that is associated with e.g. the concept of "kinetic energy", cannot by any means be generated from, or transformed in, a (static) energy of "configuration"!
It follows from this that the classical concept of the transformation of different kinds of "energy" into one another while the total amount of "energy" remains constant, means in really nothing else than the transformation of different types of motion into one another, while the total amount of motion is conserved.

(iv) This physical nature of velocity will be analysed in my paper "The physical nature of velocity".

This makes it clear that the general principle of “the conservation of energy” is in fact a mathematical expression of the fundamental principle of “the conservation of motion”.

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