The physical nature of the basic concepts of physics

Part 7: Potential Energy Fields (i)

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Abstract

'Potential' energy is 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 handbooks don't however tell us anything about the physical nature of this so-called 'potential' energy and how and where it is physically stored. The only thing that we know is that in the special case of conservative forces, the disappeared kinetic energy that is conserved as 'potential' energy, can be completely retransformed into kinetic energy.
In his paper part 3, the author has demonstrated that the kinetic energy of a particle system is a mathematical expression of its total amount of reversibly transferable translational motion.
In this paper, the author demonstrates that the present concepts of kinetic and potential energies are not different kinds of energy, but that it are just different mathematical equations for the work done by a force on a given mass over a given distance: the first expressed in function of the obtained speed, and the second in function of the covered distance.
This allows him to demonstrate that the present concept of gravitational 'potential' energy is an excellent mathematical tool to calculate the speed of falling objects in function of the covered distance, but that it creates a physical problem with the law of conservation of energy, because it supposes that both 'kinetic' and 'potential' energies arise out of nothing while the total amount of energy remains invariably zero!
This leads the author to demonstrate that the reversible transformation of 'kinetic' energy into 'potential' energy and vice versa, is in fact a mathematical expression for the reversible transformation of one kind of congruent motion into another, which allows him to demonstrate that the 'potential' energy of a perfectly elastic spring, is a mathematical expression of the amount of coherent, internal rotational-vibrational motion of its basic mass particles.

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

In the present handbooks of 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 on the motion and the mass of the particle system [ii] and the so-called 'potential' energy.

(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.

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 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 relative to another object, which is e.g. the case of the gravitation potential energy of a massive object relative to the Earth [4] or which is the case of the elastic potential energy of a stretched or compressed spring [5]
- 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) may be completely retransformed into ‘kinetic’ energy (when the ideal spring relaxes, or when 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 to apply a force to move it to a place with a higher potential energy or 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. According to Stanley Goldberg [7]: *“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 [8].
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 allowed 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 are 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 conception that all particles could be understood as the quanta of 'fields', elevating in that way the 'fields' to the status of truly independent entities and reducing particles to derivatives of a field.
Out of this arose the notion of the 'field' as a physical entity with intrinsic properties, such as energy and momentum. And this led to the so-called "Potential Energy Principle" [9] that asserts that all forces derive from a potential energy function ($F(x) = -dU(x)/dx$) which formed the basis for the Quantum Field Theory (QFT) that unifies general relativity and quantum physics.

2. The complementary character of '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 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 kinetic energy is just an alternative mathematical expression of the work, expressed in

function of the mass and the velocity, instead of its classic expression in function of the force the displacement): $W = \int F\,dx = \int (ma)\,dx = \int m\,dv\,dx/dt = \int m\,v\,dv = \Delta(mv^2/2) = \Delta K$

By introducing the concept of 'conservative' force, as a force that only depends on the starting and the end points (and not on the followed path), [10]: "*it is possible to construct a corresponding 'potential' energy U(P) by the following recipe: the change in the potential energy between points P_1 and P_2 equals the negative of the work done by the force between these two points*": $U(P) = -\int_{P0}^{P1} F.dr + U(P_0)$

$U(P_2) - U(P_1) = -\int_{P0}^{P2} F.dr - \int_{P1}^{P0} F.dr = -\int_{P1}^{P2} F.dr$

So that: $K_2 - K_1 = W = \int_{P1}^{P2} F.dr = U(P_1) - U(P_2)$

And: $K_2 + U(P_2) = K_1 + U(P_1)$

So that the sum of the kinetic and potential energies: $K + U = E$ = a constant

The force exerted by a spring on a mass in one-dimensional motion and the case of the gravitational force are the classic examples of such 'conservative' forces.

2.1 Elastic potential energy

The classic example of the concept of 'potential' energy is the case of an ideal mass-spring system, in which a frictionless mass 'm' slides horizontally with an initial velocity 'v_i' to an ideal massless spring (that obeys Hooke's law: $F = -kx$) that is fixed at the other side to a rigid wall [11].

When the mass with initial kinetic energy '$K_i = mv_i^2/2$' hits the spring, it compresses the spring while doing work on it: $W = \int F(x)\,dx = \int (-kx)\,dx = kx^2/2$

So that its speed and consequently its kinetic energy decrease, until the mass finally comes to a standstill ($v = K = 0$). From that moment on the compressed spring expands and pushes the block back until it fully regains its initial speed (in the opposite direction $v_f = -v_i$) and its initial kinetic energy ($K_f = K_i$).

Under these circumstances: [12] "*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: $\Delta K = -\Delta U$.*

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: $K + U = mv^2/2 + kx^2/2 = mv_i/2$ = constant

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 works in the downward direction and is represented with a negative sign: $F = -mg = -GMm/r^2$

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:

$K + U = mv^2/2 + (-GMm/r) = mv^2/2 - GMm/r$

So that: $(K =)\ mv^2/2 = GMm/r\ (= -U)$

2.3 The curvature of space-time

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 that velocity must is relative phenomenon.

The General Theory of Relativity is based on the fact that gravitational acceleration is independent of the physical composition of falling objects and concludes that it is therefore impossible to distinguish between an acceleration body and a body subjected to a gravitational field (the so-called equivalence principle).
This allowed Albert Einstein to conclude that gravitational acceleration must be a characteristic of the spacetime around celestial bodies. In Einstein's view, masses are not 'attracted' by a gravitational 'force', but accelerate along the geodesic path of the curvature of spacetime that is created by an heavy body, in exactly the same way that a heavy mass that is put on a rubber sheet will depress that sheet and make small balls on that sheet, accelerate to the heavy mass. It is as a consequence of this bending of spacetime that Einstein could demonstrate that heavy celestial bodies bend light rays and affect the rate at which clocks run. Both effects have later been proven experimentally!

3. The indistinct nature of gravitational 'potential' energy

3.1 The purely mathematical concept of 'potential' energy

When a thrown-up body comes to a standstill at a given height, its initial kinetic energy is said to be gradually transformed into 'potential' energy.
The present handbooks don't however tell us how and where the disappearing kinetic energy goes to: Is it stored in the thrown-up mass and in the Earth, in the configuration of both masses or in the vacuum space between both masses as a curvature of spacetime? The only thing we know for sure is that the kinetic energy must be conserved somehow, somewhere, because it can be completely regained when the body returns to its initial position.
This has led us to the concept of an energy 'field' that 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. ..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 this description that a field consist of a number of physical values (expressed as scalars, vectors or tensors) such as temperature or magnetic deflection, that are associated with given points in space. That doesn't however mean that the temperature, the magnetic deflection, the gravitational acceleration or the elastic force, are characteristics of those 'points', because a 'point' is not a physical concept.
These considerations oblige us to conclude that if we want to unveil the physical nature of the transformation of 'kinetic' into 'potential' energy, we must first have a correct understanding of the physical nature of 'kinetic' energy.
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 place, we keep

the lost kinetic energy 'potentially' in our equations (under the name of 'potential' energy) and take it back whenever the object returns to its initial position.

3.2 Two different mathematical expressions of work in conservative systems

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: $\int \mathbf{F}\, \mathbf{dr} = \mathbf{F} \int \mathbf{dr} = \mathbf{F}.\mathbf{r} = W(F,r)$

- That same work, done by a force 'F' on a mass 'm' over a distance 'r', can 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 a mathematical equation of the work, 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 'x' 'l', or 'h'):
$W(F,r) = \int F\, dr = \int (GMm/r^2)\, dr = GMm \int dr/r^2 = GMm/r = U(r)$.
These simple deductions demonstrate that the mathematical expressions: $mv^2/2$ and GMm/r are not different kinds of energy, but are both mathematical equations for the work done by a force 'F' over a distance 'r' on a free particle with mass 'm', to give it a velocity 'v':

- one expressed in function of the obtained velocity ($mv^2/2$)
- one is expressed in function of the covered distance (GMm/r)

Since both mathematical equations are equivalent ($K = mv^2/2 = GMm/r = U$), they can be represented by one and the same graph (Fig. 7.1).

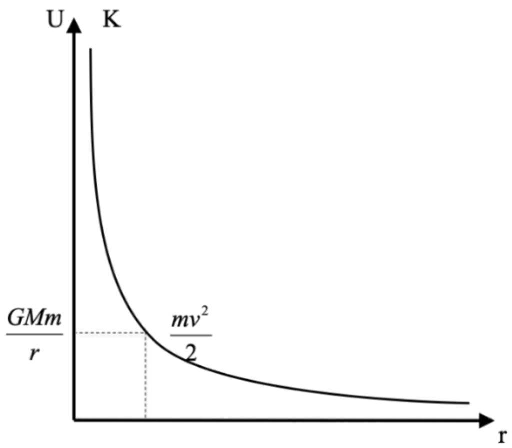

FIG. 7.1

3.3 Kinetic and potential energy out of nothing

Since I have demonstrated that kinetic and the gravitational potential energy are just different mathematical expressions of the same work done by a force 'F' over a distance 'r'(or 'h') on a mass 'm', 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 a mass 'm', the present textbooks introduce "the principle of the conservation of energy" as the sum of the kinetic and this so-called 'potential' energy, which is evidently zero at all points in space (Fig. 7.2):
$K + U = (mv^2/2) + (- GMm/r) = mv^2/2 - GMm/r = 0$. So that: $v = \sqrt{2GM/r}$
This means that the present concept of gravitational energy of 'configuration' is undeniably an excellent mathematical tool to express the speed of a falling object in function of its position ($v = \sqrt{2GM/r}$), but it creates a physical problem by supposing that the 'kinetic' as well as this so-called 'potential' energy' arise out of nothing, while the total amount of energy remains invariably zero in all points in space !

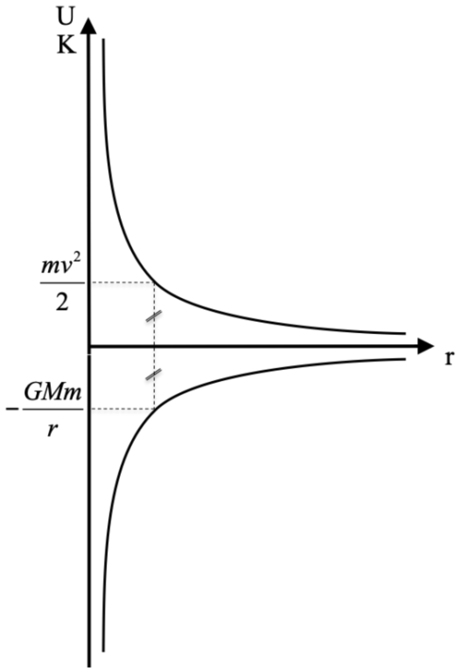

FIG. 7.2

This is demonstrated by the classic example [14] of a meteoroid that is initially at rest at a very large distance from the Sun (with $R_S = 6{,}96 \times 10^8$m) and that proceeds, under the influence of the Sun's mass ($M_S = 1{,}99 \times 10^{30}$kg) along a straight radial line.
The total energy of the meteoroid is: $E = mv^2/2 - GM_Sm/r$ = a constant
- Initially: $v = 0$ and $r \approx \infty$, so that the kinetic and the potential energies of the meteoroid are both zero, so that its total energy remains zero: $E = mv^2/2 - GM_Sm/r = 0$
- At the moment of impact with the Sun: $r = R_S$, so that: $E = mv^2/2 - GM_Sm/R_S = 0$
  So that the speed of the meteoroid at the moment of impact with the sun (with $G = 6{,}67 \times 10^{-11}$Nm/kg²) is $v_{imp} = \sqrt{2GM/R}$ = 618 km/s

This demonstrate that: "*The equations of the conservation of kinetic and potential energy are essentially bookkeeping statements about energy*" [15].
This is in full contrast with the case of the elastic potential energy of section 2.1 in which the sum of the kinetic (K) and the potential (U) energy remains in all points equal to the initial (kinetic) energy (K_i) of the moving mass: $K_x + U_x = K_i = E$ (Fig. 7.3).

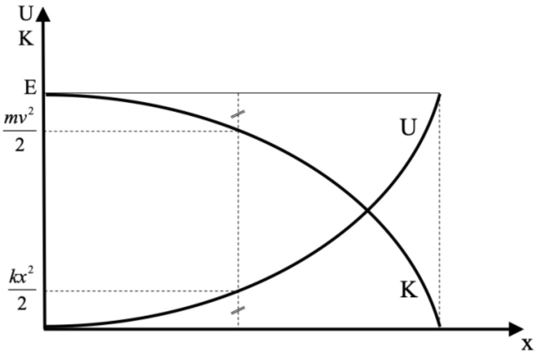

FIG. 7.3

3.4 The energy gap of General Relativity

Einstein based his General Theory of Relativity on his 'principle of equivalence' which stipulates that "it is impossible to distinguish between the effects of acceleration and of gravitational fields". This made Einstein conclude that everything that can be ascribed to a gravitational field, can as well be ascribed by an accelerated frame of reference. So, in General Relativity, masses are not considered to be 'attracted' by some force, but accelerate along 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*".
This is why General Relativity doesn't express itself with regard to the enormous amounts of kinetic energy that are generated in the process of celestial bodies accelerating towards each other. This gravitational acceleration is commonly illustrated by a heavy weight that is put in the middle of a trampoline and that makes small balls, that are put at the edge of the trampoline, roll effortlessly to the heavy weight along the curvature made by it in the trampoline. But this representation is based on a circular reasoning, because it works because of the gravitational pull of the Earth underneath the trampoline.
And this brings us to the energy gap of General Relativity: If gigantic heavenly bodies accelerate to each other due to a 'curvature of spacetime', then the increasing kinetic energy of these enormous masses must necessarily be supplied by spacetime. So the question is: how does the bending of spacetime generate these enormous amounts of energy?
This lack of knowledge is known as "the vacuum catastrophe", which indicates the catastrophic gap between the estimations of the vacuum energy of free space, which varies from 10^{-9} to 10^{113}J/cm^3 [17], which demonstrates that General Relativity hasn't solved its energy problem (iii).

4. The physical nature of potential energy

4.1 The dynamic natures of force and energy

In section 6 of my paper Part 2 on the physical nature of 'force', I have referred to the paper of Andrea diSessa "*Momentum flow as an alternative perspective in elementary mechanics*"

(iii) The physical nature of gravitational potential energy will be analyzed in my paper on the physical nature of gravitation.

[18]. In that paper, diSessa proposed to use the of ‘momentum flow’ instead of ‘force’, because momentum flow expresses ‘force’ as the result of repetitive collisions between the force particle system and the particle system of the body”.
And according to diSessa this is exactly what happens in 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 it is as a matter of fact also what happens between the molecules of a wall and the molecules of your body when you stretch yourself against it, or while hanging on the branch of a tree, or holding a weight stationary above the ground. Newton’s laws tells us that in those static cases no work is done, since nothing is accelerated or displaced, but you surely get exhausted by doing it! Momentum flow analysis clearly reveals the 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 my conclusions of my previous papers that the basic concepts related to force and energy are all related to motion:

- **Linear Momentum** is a mathematical expression of the total amount of congruent translational motion
- **Force** is a mathematical expression of the transfer rate of congruent translational motion from one body to another
- **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

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
- It was also discovered that heat phenomena are easily understandable from the laws of motion”
- It was also discovered that light is the motion of particles (photons).”

4.2 The fundamentally dynamic nature of elastic potential energy

In the light of the dynamic nature of ‘force’ and ‘energy’, the question: “*where has the kinetic energy gone to*” when a moving mass comes to a standstill against a compressed spring, must be replaced by the question “*where has the congruent translational motion gone to*”?
To answer this question, I return to the case of the ideal mass-spring system of section 2.1 which has the advantage that:

- the kinetic energy (the amount of congruent translational motion) is completely located in the mass and is expressed in function of the velocity of that mass: $K = mv^2/2$
- the ‘potential’ energy is completely located in the compressed spring and is expressed in function of the degree of compression ‘x’ of its free end:
  $U(x) = - \int F(x)\,dx = - \int (-kx)\,dx = kx^2/2$

This means that the amount of congruent translational motion of the mass is gradually transferred to the spring under the form of ‘potential’ energy.

According to Einstein's Special Theory of Relativity, an accelerating mass suffers a mass increase (iv) in its direction of motion: $m_v = \frac{m0}{\sqrt{1 - v^2/c^2}} = \gamma m_0$ so that: $\Delta m = m_0(\gamma - 1)$

This mass increase has been verified in 1914 by Bucherer and Neumann [20], by deflecting high speed electrons in magnetic fields and measuring the radii of the curvature of their path.

The close relation between mass and energy is expressed by Einstein's mass-energy equation: $E = mc^2$. On the basis of this equation it is demonstrated that the increase of the kinetic energy of a mass particle moving at a relatively low speed, corresponds exactly to the energy of its mass increase: $\Delta mc^2 = mv^2/2$.
This fact, that mass is equivalent to energy, can even be extended to energies other than kinetic energy [21]:

- "*When 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 U, its mass increases by an amount $\Delta m = \Delta U/c^2$*"

So that we can conclude that for every kind of energy ΔE supplied to a material body, the mass of that body increases by an amount $\Delta m = \Delta E/c^2$
Which means that in the case of the mass-spring system, the kinetic energy of the decelerating mass is gradually transformed in a velocity increase of the spring's basic mass particles !

5. The physical nature of elastic potential energy (v)

From the former section we can conclude that in an ideal mass-spring system, the decreasing kinetic energy of the mass is gradually transformed into congruent internal motion of the basic mass particles of the compressing spring.
This phenomenon is generally known as an 'endothermic' reaction, in which external kinetic energy is transformed into internal kinetic energy. In chemical reactions, this internal energy consists of the internal kinetic energy of the composing particles: their translational, rotational and vibrational energy. Which means that there is a lot of internal motion going on inside the basic particles of matter, in the way that this is expressed by Einstein's mass-energy equation $E = mc^2$.

This allows him to conclude that the 'potential' energy of a perfectly elastic spring, is a mathematical expression of the amount of coherent, internal rotational-vibrational motion of its basic mass particles.

This means that the so-called 'potential' energy (U) of a perfectly elastic spring, is in fact a mathematical expression of the amount of coherent, reversibly transferable motion, that is present in the spring under the form of internal, coherent, rotational/vibrational motion of its basic mass particles: $U = \sum I_i\omega_i^2/2$.
So that: $K + U = mv^2/2 + \sum I_i\omega_i^2/2 = \text{constant}$.
This formula has the same form as the equation of the internal energy of an ideal diatomic gas [22]: "*Diatomic gases store amounts of energy in the internal motions of the atoms within*

(iv) The nature of mass and mass increase will be analyzed in my paper on the physical nature of mass.
(v) The case of gravitational potential energy will be analyzed in my paper on the physical nature of gravitation

each molecule. .. If such a molecule collides with another molecule, it will usually start rotating about its center of mass", which simply means that the present (static) spring model for the storage of the so-called 'potential' energy, must be replaced by a dynamic 'flywheel model'.
It must thereby be pointed out that the present "spring-model" for the storage of the 'potential' energy, is as a matter of fact based on a circular reasoning, because it implicitly supposes that the atoms of the spring are on their turn interconnected by microscopically small springs.

My conclusion is thereby completely in line with the modern viewpoint of quantum mechanics, as expressed by Robert Adair, who already in 1987 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*"!

My dynamic flywheel model for the so-called 'potential' energy, is moreover in line with the press release of 29 July 2019 "Scientists film molecular rotation" [24].
The "Controlled Molecule Imaging" research group (CMI) of the Center for Free-Electron Laser Science (CFEL) [25] led by Jochen Küpper of the Coherent Imaging Division (DESY) and Arnoud Rouzée of the Max Born Institute of Berlin, has made a film of the ultrafast rotation of carbonyl sulphide (OCS) molecules spinning coherently (i.e.in unison).
The resulting "molecular movie" tracks one and a half revolutions taking place within 125 trillionths of a second. These images of the molecule's rotation show that the molecule does not simply point in one direction, but in various different directions at the same time. From the fact that these individual images start to repeat after about 82 picoseconds, one can deduce the period of rotation of this carbonyl sulphide molecule

My dynamic concept of 'potential energy', as internal rotational/vibrational motion, will in my next paper (vi) enable me to reveal the absolute, physical nature of 'velocity' and will automatically lead to the so-called 'relativistic' equations of the Special Theory of Relativity.

6. Conclusion

By making a clear distinction between the real physical data on one hand and the mathematical concepts on the other, 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 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 isotropic translational motion at the molecular level.
- Potential energy is a mathematical expression of the amount of internal, congruent rotational/vibrational motion at the quantum particle level.

This conclusion cannot be put aside as a purely didactic matter, because it makes us realize that energy is fundamentally a dynamic phenomenon so that the amount of motion that is

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

associated with e.g. the concept of “kinetic energy”, cannot an any way 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 kinds of motion into one another, while the total amount of motion is conserved.
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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