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Are photons massless?

https://de.wikipedia.org/wiki/Impuls

Photon energy and momentum in the theory of relativity

A review by Dr. Manfred Pohl

This article is preliminary and will be further developed.
It contains texts from published sources – in black – and
my comments and observations – in red.

The starting point of this paper is the mass, which contains an equivalent energy that can be explained as the ability to do work, that is, to change its state of motion against its inertia, in other words, to accelerate it. **The ratio of energy to mass always remains constant.** Energy exists in various convertible forms. A distinction is made between kinetic, potential, chemical, electrical, and thermal energy. Further forms include radiation energy and nuclear energy, which manifests as the movement of elementary particles. **Energy is always the movement of mass.** The **overarching term for mass and energy is the matter**, the objective reality that cannot be created or destroyed. The state of motion of a mass is described by momentum, which is understood as the "amount" of motion it possesses, depending on its size and its relative velocity to other bodies (masses). The change in the state of motion over time is the force.

In response to the question about the momentum, Google's AI mode begins with:

In Newtonian physics, momentum is traditionally defined as the product of mass and velocity ($p = m \cdot v$),

and answers the question of its validity as follows:

Yes, that is correct. In classical Newtonian mechanics, the momentum ($\vec{p}$) of an object is traditionally defined as the product of its mass (m) and its velocity $\vec{p} = m \cdot \vec{v}$.

That is correct. Because velocity is a vector, meaning it has a direction and a magnitude, while mass is a scalar quantity, momentum is also a vector. However, it is not neccesary to emphasize that this is the case in classical Newtonian mechanics. According to the laws of relativity, momentum is also $\vec{p} = m \cdot \vec{v}$. The vague phrase "traditionally as the product..." is useless; it's a meaningless phrase, because momentum is always the product of mass and velocity.

This definition describes how much "amount of motion" an object possesses, and it's a fundamental quantity in describing collisions and forces (force is the rate of change of momentum, $\vec{F} = d\vec{p}/dt$)).

Further calculations then yield $\vec{F} = m \cdot \frac{d\vec{v}}{dt} = m \cdot \frac{d_2\vec{s}}{dt^2}$.

In this context, zero mass would also mean zero momentum.

This representation is correct. But what is the purpose of the expression "would be"? This suggests that momentum could exist even if the mass is zero. That's why I asked in AI mode.

To the question: "Is there momentum without mass?" AI answers:

Yes, there is momentum without mass. This statement is false. It contradicts the definition of impulse.
The most well-known example from physics is **photons**, the elementary particles of light:

- **Photons are massless:** They have no rest mass.
- **Photons have momentum:** Despite their masslessness, photons carry momentum and can therefore exert pressure (known as radiation pressure), which is used, for example, in solar sails.

Both explanations are incorrect.

- The first explanation is a contradiction in itself, as it assigns momentum to a photon despite its lack of mass. If it were massless, it would have no momentum.
- The second explanation is a misrepresentation of radiation pressure, which is always caused by mass.

These explanations attempt, on the one hand, to establish the existence of energy, which has no mass, and on the other hand, to declare a momentum that could exist without mass. However, neither is true; both contradict fundamental relationships and universal definitions that have been theoretically and experimentally verified in physics. According to the theory of relativity, a photon has a dynamic mass due to its motion. However, a dynamic mass arises only from the motion of a rest mass. I will show below that the postulate of momentum without mass is an error.

Momentum and energy are both functions of mass. Only the mass of a photon can be subject to motion and therefore have a "quantity of motion" (a momentum). If photons had no rest mass, it would mean they do not exist, because in that case they could possess neither energy nor momentum. The question of whether photons truly have no mass must be answered by negative at this point. If their rest mass were zero, their moving mass would also be zero, because $m´ = m \cdot \gamma$. Without moving mass, however, the photon cannot have momentum. Since the momentum of a photon is measurable, the moving mass must consequently be greater than zero, and therefore the rest mass cannot be zero either. It is, however, very small, immeasurably small, very close to zero. Its moving mass *m'* only reaches a detectable value at very high speeds because, due to the motion near the speed of light, the term γ, the Lorentz transformation, becomes very large. This results in a measurable momentum. On the other hand, if the rest mass of a body has a detectable finite value, it can only ever move at a lower speed, because very large forces are required to accelerate it to near the speed of light, forces that are not present in the body's vicinity. It is therefore a false claim that in classical mechanics momentum $\vec{p} = m \cdot \vec{v}$ depends on mass, while in moving systems, according to relativity, it is possible that momentum has no mass. It will be shown below that the photon represents a limiting case, which, as $v \to c$, would cause the mass $m \to 0$. This limiting case requires separate investigation.

The classical formula for momentum, $p=m \cdot v$, only applies to particles with mass that move slower than the speed of light.
This is correct insofar as there is no momentum without mass.

In special relativity, the relationship between energy (E), momentum (p), and mass (m) is described by the more general energy-momentum equation:

$E^2 = (mc^2)^2 + (pc)^2$.

What does this equation state and how is it derived? AI determines a derivation that proceeds as follows:

In the stationary frame of reference is

$$E = mc^2. \quad (1)$$

In the moving inertial frame of reference is

$$m' = m \cdot \gamma = m \cdot \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}, \quad \gamma \text{ - Lorentz transformation} \quad (2)$$

This means that the rest mass *m* increases by an amount that depends on the velocity of the moving system. If we correctly denote the rest mass as m_0, then the total mass *m* can be understood as $m = m_0 + m_{dyn}$. The mass *m* increases by the amount of the dynamic (moving) mass in the moving inertial frame. This dynamic mass is negligibly small at velocities $v \ll c$, but at high velocities *v* near the speed of light, it is non-zero: $m_{dyn} > 0$.

Thus, the following results for the moving system:

a) The energy:

$$E = m \cdot \frac{1}{\sqrt{1-\frac{v^2}{c^2}}} \cdot c^2 \text{ and further}$$

$$E^2 = m^2 \cdot c^4 \cdot \frac{1}{1-\frac{v^2}{c^2}}. \quad (3)$$

b) The momentum:

$$p = m \cdot v \cdot \frac{1}{\sqrt{1-\frac{v^2}{c^2}}} \text{ and further} \quad (4)$$

$$p^2 = (mv)^2 \cdot \frac{1}{1-\frac{v^2}{c^2}}$$

$$(pc)^2 = (mv)^2 \cdot \frac{c^2}{1-\frac{v^2}{c^2}} \quad (5)$$

Subtracting b) from a), results

$$E^2 - (pc)^2 = (m^2c^4 - m^2v^2c^2) \cdot \frac{1}{1-\frac{v^2}{c^2}} \text{ and further} \quad (6)$$

$$E^2 - (pc)^2 = (m^2c^4 - m^2v^2c^2) \cdot \frac{c^2}{c^2-v^2}$$

$$E^2 - p^2c^2 = m^2c^2 \cdot (c^2 - v^2) \cdot \frac{c^2}{c^2-v^2} = m^2c^4.$$

The reason for subtracting (5) from (3) here is not explained. This derivation step is suspicious. It cannot be explained physically. Ultimately, this results in:

$$\boldsymbol{E^2 = (mc^2)^2 + (pc)^2} \qquad (7)$$

Now the AI selects the following statement:

For massless particles (particles with rest mass m = 0), this formula simplifies to:

E = pc or *p = E/c*.

In this description, "massless" is incorrect, meaning the simplification is not precisely explained. The correct statement is that the rest mass *m* is close to *0.* Therefore, the first term is omitted as it is negligibly small; however, the rest mass is not zero, otherwise there would be no dynamic mass. But the dynamic mass $m_{dyn} > 0$. Therefore, it cannot be said that momentum has no mass. It is also said that momentum arises from moving energy. What is "moving energy"? Fundamentally, this energy has an equivalent mass, and only a mass can possess both energy and momentum, because $E = m \cdot c^2 \quad and \quad p = m_{dyn} \cdot v$.

Moving energy is always also moving mass. The momentum of a photon arises from the dynamic mass, which is greater than zero: $m_{dyn} > 0$. This is also evident in the expression *p = E/c*. If momentum would not have mass, then it could also no have energy, because "mass is the measure of the energy content of a body" – Einstein. And just as there is no massless energy because $E = m \cdot c^2$, there can also be no massless momentum, because *p = m · c* and therefore *E = p · c*.

Assuming that equation (7) is correct, we write it in the form

$$\sqrt{E^2 - (pc)^2} = mc^2. \qquad (8)$$

This shows that energy and momentum are invariant for all inertial frames of reference, and regardless of the inertial frame, both energy and momentum are functions of mass. Furthermore, the AI research provides several explanations that require further clarification:

Examples of momentum without mass – as we saw above, momentum without mass is impossible, as is also evident from the correct explanation of the following three photon descriptions.

The most prominent example is photons (light particles).

- Photons have no rest mass (*m = 0*). This is incorrect. It is essential to emphasize that the rest mass, although immeasurably small, cannot be zero; otherwise, no dynamic mass $m_{dyn} > 0$ could exist.
- Photons have energy ($E = hf$, where h is Planck's constant and f is the frequency). This wave description of the photon is correct. However, if they have energy, they must also have mass due to the equivalence of mass and energy.
- Photons have momentum ($p = E/c$). Correct. However, if they have energy, i.e., $E \neq 0$, then $p \neq 0$, as well, because $E = p \cdot c$, since *c* is a natural constant. Because of the equivalence of mass and energy, $m_{dyn} \neq 0$ as well.

The existence of a finite momentum of a photon implies that the velocity in the momentum equation $E = p \cdot c = m_{dyn} \cdot v \cdot c$ would approach infinity if the dynamic mass were reduced to zero. However, this is impossible due to the constancy of the speed of light.

$$p = m \cdot v \cdot \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}\,. \qquad (9)$$

The expression $v \cdot \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$ already approaches infinity when *v* reaches the speed of light.

Consequently, m_{dyn} cannot be zero at this point, because otherwise $p = 0$. For *p* to be finite, must be $m_{dyn} > 0$.

The fact that photons have momentum is confirmed experimentally, among other things by **radiation pressure**: When light hits a surface, it exerts a measurable force, which is used, for example, in practice for solar sails in space travel. This would not be possible without momentum transfer.

That's correct. And that's precisely why momentum cannot be massless. The experimentally detectable radiation pressure arises from the collision of its mass with the surface. In this collision, the dynamic mass is stopped, and its kinetic energy is transferred to the surface. The momentum is then a function of the rest mass, which is immeasurably small. Trivially speaking, the surface heats up or changes its velocity, or both.

Because of the ambiguities in the derivation above, I will outline a different approach to obtaining the energy-momentum relationship, taking into account the theory of relativity:

The energy of a body with mass m in a stationary inertial frame is
$E_0 = mc^2$.

In a moving inertial frame with velocity *v*, this energy increases by the kinetic energy of mass *m*:

$E_{kin} = \frac{m \cdot v^2}{2}$.

From the realization that energy is invariant for all reference frames, the total energy is thus

$$E = E_0 + E_{kin} = mc^2 + \frac{p \cdot v}{2} \qquad (10)$$

If we substitute the momentum *p* for the calculation of the kinetic energy, we obtain

$$E = E_0 + E_{kin} = mc^2 + \frac{p \cdot v}{2}. \qquad (11)$$

This statement is valid in the region of low velocities $v \ll c$. If the inertial frame moves at velocities close to the speed of light *c*, then the kinetic energy is given by

$$E_{kin} = \frac{(m' \cdot v^2)}{2} \text{ with} \qquad (12)$$

$m' = m \cdot \gamma$ und $\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$, Lorentz transformation.

The rest mass *m* is invariant for all inertial frames; it does not depend on *v*.
The kinetic energy depends on *v*, and therefore so does the momentum.

The total energy is then:

$$\boldsymbol{E = m \cdot c^2 + \frac{p \cdot v}{2 \cdot \sqrt{1-\frac{v^2}{c^2}}}} \qquad (13)$$

The value for $\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$ is imaginary for $v > c$, meaning there is no real representation of it in nature; consequently $v \leq c$.

The following thought experiment may clarify the explanation of dynamic mass.

$E = m \cdot c^2, \quad p = m \cdot v \cdot \gamma, \quad E = \frac{p}{v \cdot \gamma} \cdot c^2,$ p is a finite momentum. (14)

This momentum p is greater the larger v is. For a photon, a positive momentum $p > 0$ is measurable. Suppose a measured momentum $p = const$. Then, from $p = m_{dyn} \cdot v$, follows that the smaller m_{dyn}, the larger v is. For $m_{dyn} \rightarrow 0$, v would go $\longrightarrow \infty$. However, because $v \leq c$, i.e., v does not go $\longrightarrow \infty$, m_{dyn} cannot become zero. Conclusion: $m_{dyn} > 0$. As shown above, the dynamic mass can only be greater than zero if the rest mass is also greater than zero. It must differ from zero by a minimum amount so that a dynamic mass, and thus energy and momentum, can exist in the moving inertial frame. This means, however, that mass cannot be continuous in the range of small quantities.

At present, the nature of radiation is not yet definitively clarified in physics. However, one assumes a duality as corpuscular radiation and wave radiation. Therefore, its energy can plausibly be calculated in two ways, considering the dual nature of the radiation:

- as a corpuscular representation with energy $E = p \cdot c$. The corpuscular representation is the motion of a dynamic (moving) mass. Here, the momentum is $p = m \cdot v$.
- as a wave representation with energy $E = h \cdot f = h \cdot \frac{c}{\lambda}$, where
  h – Planck's constant [Js],
  f – the frequency [1/s],
  λ – wavelength [m].

Combining the two expressions leads to

$h \cdot f = p \cdot c \quad \rightarrow \quad p = \frac{h \cdot f}{c} \quad \rightarrow \quad p = \frac{h}{\lambda}$ (15)

Planck's constant is

$h = 6{,}62607015 \cdot 10^{-34}$ *Js*.

This is based on Max Planck's discovery in 1900 that energy in the microcosm is not a continuous quantity, but rather appears in quantized form .

The derivation of the magnitude of Planck's constant and its experimental confirmation as the smallest possible unit of energy can be found in several places online. To avoid extensive searches, I quote here a shortened explanation of Planck's constant from the internet, which, in my opinion, conveys the essential points:

Planck's constant (h) was not directly "derived" in its current form, but rather introduced in 1900 by Max Planck as a **fundamental constant** of nature to develop a formula for blackbody radiation that agreed with experimental data.

The derivation of Planck's radiation formula, and thus the introduction of h, was based on the following steps and assumptions:

1. **The problem of the "ultraviolet catastrophe"**: Classical physical theories (such as the Rayleigh-Jeans law) for describing blackbody radiation led to the paradoxical

result that the energy density becomes infinite at high frequencies, a phenomenon known as the "ultraviolet catastrophe." These laws only agreed with experimental results at low frequencies.

2. **Planck's assumption of energy quantization:** To solve this problem, Planck adopted a radical hypothesis: Electrically charged oscillators (conceived as atoms on the walls of a cavity that absorb and emit radiation) cannot absorb or emit energy continuously, but only in discrete packets called quanta.
3. **The energy formula:** The energy of these quanta is proportional to the frequency (ν) of the radiation. Planck postulated the formula:
   $E = h\nu$ ...
   Here, E is the energy of an energy packet and h is the newly introduced proportionality constant, Planck's constant.
4. **Statistical Mechanics:** Planck applied statistical mechanics to these quantized oscillators to calculate the average energy of an oscillator at a given temperature. In contrast to the classical assumption that each oscillator has an average energy of kT, he obtained an expression for the average energy that took quantization into account:
   $\langle E \rangle = \frac{h\nu}{e^{\frac{h\nu}{kT}}-1}$
5. **Planck's radiation formula:** By combining this average energy with the number of possible vibrational modes per unit volume in the cavity (determined by Rayleigh and Jeans), Planck derived the radiation formula now named after him, which correctly describes the entire experimental spectrum:
   $$u(\nu)d\nu = \frac{8\pi h\nu^3}{c^3} \cdot \frac{1}{e^{\frac{h\nu}{kT}}-1} \cdot d\nu \qquad (16)$$
   Here, $u(\nu)d\nu$ is the energy density in the frequency interval from ν to $\nu+d\nu$, is the speed of light and k the Boltzmann constant.

Planck himself initially viewed quantization merely as a mathematical device to derive the formula. It was Albert Einstein who later interpreted h as a universal constant and the actual existence of light quanta (photons) within the framework of his explanation of the photoelectric effect.

Following this development, it was then proven that energy is a quantized quantity, meaning there is a smallest quantum of energy whose size cannot be reduced. However, the question of what happens to its equivalent mass when it continuously decreases and reaches the size of the equivalent energy quantum was not addressed. The energy quantum has a minimum, not reducible size. But not the mass? If so, then the mass-energy equivalence equation $E=mc^2$ would no longer be valid. There is no consensus on this in official discourse. The Google's AI-mode reveals:

No, **mass itself is not considered a generally quantized quantity** in the same sense as, for example, electric charge or energy in bound states. **There is no universal "mass quantum."**

The vague phrase "generally" is not a definitive statement, as it leaves open the possibility that it might be quantized "in specific cases." Then again, it is stated definitively that there is no mass quantum. Such statements are unclear and require clarification.

The above explanations demonstrate that this view is incorrect. A fundamental conclusion follows from them:

The expression $p = m_{dyn} \cdot v = \frac{h}{\lambda}$ can only be meaningfully explained if it is assumed that, like energy, mass is not continuous but a quantized quantity. Consequently, in addition to the smallest possible energy *h · f*, the photon must also have a smallest possible mass *m* equivalent to this energy in order for a dynamic mass m_{dyn} to exist that can possess a momentum $p = m_{dyn} \cdot v$.

This assumption can also be derived from the equivalence of mass and energy. When considering small energies in the equation $E = m \cdot c^2$, one arrives at a quantity beyond which the energy cannot decrease further once it reaches Planck's constant. The mass-energy equivalence equation is only valid if the mass equivalent to this smallest energy quantity cannot be smaller. That is, mass must be quantized.

If one equates the energy in the corpuscular representation $E = m \cdot c^2$ with the energy in the wave representation $E = h \cdot f$, then we obtain:

$$\frac{m}{f} = \frac{h}{c^2} = const$$

$$\frac{h}{c^2} = \mathbf{7{,}37249732 \cdot 10^{-51} kg \cdot s} = const \qquad (17)$$

This is the mass quantum.

It necessarily follows that $m > 0$. That is, for any given amount of energy, the mass m cannot be zero. From this, it follows, on the one hand, that **energy without mass does not exist**. On the other hand, an energy quantum has a non-zero mass. Therefore, mass is a quantized quantity.

Analyzing the units of measurement now also confirms the statement that momentum cannot exist without mass.

The unit of measurement Joule [*J*] for energy in the SI system is [*kg·m²/s²*].

The unit of measurement for *p* is consequently, from $E = p \cdot c$:
[*J·s²/m*] = [*kg·m²/s²·s²/m*] = [*kg·m/s*]. (18)

This shows that momentum arises from a mass. This is the dynamic mass of the photon. If it were zero, momentum would not exist. From this, it follows: **Momentum without mass does not exist.**

The summary of this AI research is:

Summary

Momentum is a fundamental property of energy in motion, not just of matter. Even without mass at rest, an entity (like a photon) can possess momentum as long as it has energy and is moving at the speed of light.

This explanation is incomprehensible and flawed. The phrase "energy in motion, not just of matter" implies that energy is something different from matter. This is incorrect. Because of its equivalence to mass, moving energy is always also moving mass. Energy is matter and therefore always has a mass equivalent to it. **That is, momentum is not an entity that is free of mass.** Even if its rest mass is almost zero, because of its near-speed *c*, there is a dynamic mass that has a measurable momentum in a moving inertial frame of reference – and only in a moving inertial frame of reference.

It is true that the photon can only exist as a moving particle, because its rest mass is almost zero. Without movement, its dynamic mass would also be almost zero. The

photon would then have neither kinetic energy nor momentum, which is equivalent to it not existing.

Some further research

Regarding the equivalence of mass and energy, Wikipedia recently added entries whose contents were disputed until recently. However, this content is still misrepresented elsewhere on the site. It concerns the impossibility of converting mass into energy and vice versa:

https://de.wikipedia.org/wiki/%C3%84quivalenz_von_Masse_und_Energie#**:**

Correction:

Particularly in connection with nuclear fission and fusion, the term "conversion of mass into energy" is sometimes used, which is misleading. **Energy remains constant, and therefore so does mass**. When a system releases energy into its environment (e.g., through collisions of fission products with surrounding matter or as radiation), its remaining energy decreases, and therefore so does its mass. No "conversion" takes place.

And elsewhere:

Important caveat:

The common phrase "conversion of mass into energy" is misleading. There is no creation or annihilation, but rather a conversion between rest energy (mass) and other forms of energy, whereby the total energy (and thus the total mass) of a closed system remains constant.

That's correct. It also follows from the fact that mass is a conserved quantity. Mass, like energy, can neither be created nor destroyed. This demonstrates the impossibility of converting mass into energy and vice versa:

http://hauptplatz.unipohl.de/Wissenschaft/MasseEnergieFehler1.htm,
http://hauptplatz.unipohl.de/Wissenschaft/Masse_in_Energie.pdf,
http://hauptplatz.unipohl.de/Wissenschaft/MasseEnergieUmwandlung.pdf.

However, if you ask AI the question, "Can mass be converted into energy?" you get the answer:

Yes, **mass can be converted into energy** and vice versa, energy into mass. This principle is known as **mass-energy equivalence**, which is described by Albert Einstein's famous formula $E=mc^2$.

The error has therefore not yet been corrected. It remains unchanged in most sources. The possibility of converting mass into energy and vice versa is precisely not described by the mass-energy equivalence equation.

The so-called mass defect that occurs in nuclear reactions is incorrectly explained in the most sources. With the confirmation of the impossibility of converting mass into energy and vice versa, it can also be stated in the case of the "mass defect" that there is no "defect" – that is, no disappearance or creation of mass. Both mass and energy are present after the reaction, but their state of motion and their spatial position have changed.

For the same reason, the term "annihilation" is also misleading. It is supposed to explain the disappearance of mass when an electron combines with a positron, resulting

in two gamma quanta (one said the particles to "annihilate" into energy). Here, too, mass and energy remain unchanged after the reaction. There is no "annihilation."

The phrase "...to the surrounding matter or as radiation" is unclear. Once again, the previously mentioned error is present: that energy is not matter.

The correct statement is: radiation is energy, and energy is matter. If it were not considered as matter, it could not be equivalent to mass.

This misconception arises from a flawed definition of matter, in which energy is not considered as matter. This is the starting point for numerous further theoretical errors. Therefore, I have written a separate paper on the nature of matter, which can be found at:
http://hauptplatz.unipohl.de/Wissenschaft/EssenceMatter.pdf.

The correct statement is: mass and energy are two forms of matter that are equivalent to each other. That is, one form cannot exist without the other. The magnitudes of both forms are proportional to each other. Their ratio is constant. The proportionality factor is the square of the speed of light: $E/m = c^2 = const$. Incidentally, it is also evident here: if *E i*s quantized, then *m* must also be quantized.

The conservation of energy on Wikipedia at https://de.wikipedia.org/wiki/Energieerhaltungssatz. is described correctly, with some limitations.

However, one passage therein is fundamentally wrong. It attempts to cast doubt on the law of conservation of energy using nonsensical, unscientific pseudo-arguments:

The study of the universe using the methods of general relativity shows that the law of conservation of energy is not applicable to the universe as a whole. In particular, gravitational energy cannot always be unambiguously defined in a way that applies to the universe as a whole. Therefore, the total energy of the universe is neither conserved nor lost – it is undefined.

A “whole” universe cannot be neither described nor defined. There is no "whole" universe for two simple reasons:

- because it extends infinitely in all directions – a "whole" universe contradicts the axiom that a whole entity is always a finite entity, and
- because natural laws always apply – there are no natural laws that only apply sometimes.

Thus, the conservation of energy applies without restriction in the universe, provided one interprets a limited region as a closed system. If one defines several regions between which energy exchange can occur, the total energy of the regions remains constant; an energy balance can be determined between them. The total energy of the universe is infinite, like the universe itself; it cannot be determined or represented as a numerical value.

The formulation "...therefore neither remains nor is lost" has no physical meaning. It is confusing and illogical.

The reference to the theory of relativity in this passage is irrelevant due to the invariance of energy conservation.

The term "gravitational energy" is misleading; it is wrong. It is contradictory in itself and has no physical basis. Gravitation is a force, not energy. Only when the gravitational force accelerates a mass along a path is work done; this is the underlying energy.

Forces always act on masses; the fundamental relationship is force equals mass times acceleration: $F=m\cdot b$. The explanation of gravity as a curvature of spacetime, introduced in the theory of relativity, is a mathematical abstraction in which the motions of cosmic objects are linearized using geodesics. This provides the basis for computational methods that make the totality of gravitational fields between a multitude of considered cosmic objects mathematically manageable. The curvature of space, or rather of four-dimensional spacetime, has no equivalent in the real world. See also: http://hauptplatz.unipohl.de/Wissenschaft/Raumkruemmung_engl.pdf.

Attempts to explain the curvature of space as a real, existing entity inevitably lead down dead ends that cannot produce any scientifically valid results. Gravity, as a force, is not eliminated in such abstractions, as is often claimed. On the other hand, space is not a material object to which these and other motions can be attributed. The fundamental relationships between force and energy,

$F = m \cdot \frac{d^2s}{dt^2}$ and $E = \frac{m}{2} \cdot \left(\frac{ds}{dt}\right)^2$, where s is the path of mass m,

are fully valid for gravity.

All attempts to materialize mathematical abstractions, to ascribe to them an autonomous existence, to interpret space and time as material objects, as things, are invariably the starting point for unprovable speculations, untenable figments of the imagination, and pseudoscientific theories that misinterpret the results of natural observations and lead physics astray. Such misdevelopments can only be avoided if physics is returned to the consistent acceptance of the dialectical-materialist concept of matter, which has been dismantled beyond recognition in recent decades. In this way, most of the current misconceptions in physics and especially in cosmology can be eliminated and replaced by scientifically sound approaches. Only in this way the research efforts to find a theoretical unification of quantum physics with the macro world can to move forward.