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| **Why Maxwell Couldn’t Explain Gravity** |
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| It is also intuitively immediately apparent that without a stress tensor for the static gravitational field, the Newtonian forces cannot be derived from an energy tensor. Also, if the energy-momentum conservation concept is not applied to the metric field, it loses all physical value. |
| *A. Einstein to M. Besso, August 1918* |
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| From the earliest recorded thoughts about physics and philosophy, beginning in ancient times, theories about the constitution of nature have been divided into two opposing conceptual frameworks, one based on the idea of a continuum of substance permeating all space, and the other based on the idea of isolated entities moving through a void of empty space. (See [Continuity and the Void](https://www.mathpages.com/home/kmath526/kmath526.htm).) Although one view or the other has sometimes been predominant, neither view has ever won unanimous assent, and the “mainstream” view has alternated back and forth between the two frameworks many times throughout the history of science. At the beginning of the scientific revolution, Descartes adopted the philosophy of the continuum, insisting that space and matter are co-extant (indeed, that they are the same thing), so there is no such thing as empty space, and he asserted that objects affect each other only by direct contact. However, the swirling vortices of Descartes were soon discredited by Newton’s theories of dynamics and gravitation. Newton himself was equivocal, but his theories strongly tended to support the idea of isolated particles of matter moving in an empty void, capable of interacting with each other, via the force of gravity, over great distances. |
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| The early theories of electricity and magnetism developed by Coulomb, Ampere, and Oersted, were based on the Newtonian model of gravity, which is to say, they were based on the premise that isolated objects moving in the void of empty space exert forces on each other even when separated by some distance (rather than just when they are in direct contact). This theoretical approach proved very successful, and was developed to a high level, culminating in the work of Weber, Neumann, and others by around 1849. However, simultaneously with those developments, Faraday was investigating the same phenomena of electromagnetism from a completely different perspective, reverting to the idea of contact forces exerted through some kind of substance permeating all of space. This approach was taken up by Maxwell, who in 1855 published a paper, “On Faraday’s Lines of Force”, in which he sought to express Faraday’s ideas in mathematical form. Maxwell continued his investigations in a paper entitled “On Physical Lines of Force”, published in 1861, and then another, entitled “A Dynamical Theory of the Electrodynamic Field” in 1864. This work ultimately led to his great and highly influential “Treatise /triytıs/ on Electricity and Magnetism”, published in 1875, which is the basis for most treatments of the classical theory of electromagnetism to this day. |
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| Nevertheless, the tradition of Weber, et al, has continued, notably with the work of Lorenz, the retarded potentials of Lenard and Weichert, and the absorber theory of Wheeler and Feynman. It is generally conceded today that electrodynamics can be formulated either as a field theory or as a distant-action theory, although one may be more convenient than the other in any given circumstance. This ambiguity arises because, even in field theories, we never actually observe a field, we only observe the behavior of material entities. Based on this behavior, we find it convenient to hypothesize the existence of certain fields, partly as a computational aid, i.e., a simple way of encoding the rules that evidently govern the behavior of material entities. But it is also possible to formulate those laws without reference to any hypothetical fields in empty space, by allowing for distant action, provided we allow the forces to be retarded functions of the relative motions of particles (not just their relative positions). Maxwell was well aware of the viability of this “fieldless” approach, but was not satisfied with it. He wrote in his 1864 paper |
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| This theory, as developed by W. Weber and C. Neumann, is exceedingly ingenious, and wonderfully comprehensive in its application to the phenomena … The mechanical difficulties, however, which are involved in the assumption of particles acting at a distance with forces which depend on their velocities are such as to prevent me from considering this theory as an ultimate one… |
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| Ironically, the reason given here by Maxwell for being dissatisfied with the distant-action approach to electromagnetism was actually based on a misunderstanding, as Maxwell later acknowledged. He originally thought a velocity-dependent force law must automatically violate the conservation of energy. Indeed, the first such law to be proposed (by Gauss) was subject to this objection. However, the force law of Weber fully satisfies the conservation of energy, so Maxwell’s original stated motivation was unfounded. After realizing this, he amended his reasons for opposing distant action theories. In later treatments he emphasized the requirement (as he saw it) for the electromagnetic *energy* (and momentum) emitted by one body and absorbed some time later by another body to have some mode of existence *between* the emission and absorption events. Thus, his mature rationale /raşıneel/ for fields was that they provide the vehicle for spatially and temporally continuous conservation of energy and momentum during the intervals of communication – which he showed were non-zero, because of the finite speed of propagation of electromagnetic disturbances. Others have considered the sheer simplicity and clarity of the field formulation to be the strongest evidence for the “reality” of the fields. For example, this seems to have been Einstein’s view. |
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| In any case, Maxwell’s understanding of the electrical force that exists between charged particles was based on the idea that even the “empty space” of the vacuum is actually permeated with some kind of substance, called the ether, which consists of individual parts that can act as dielectrics. |
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| The theory I propose may therefore be called a theory of the Electromagnetic Field, because it has to do with the space in the neighbourhood of the electric or magnetic bodies, and it may be called a Dynamical Theory, because it assumes that in that space there is matter in motion, by which the observed electromagnetic phenomena are produced. |
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| The simplest component of this theory was the electrostatic field, which Maxwell envisaged as a displacement of the dielectric components at each point in the medium. In simple terms, he pictured ordinary empty space, when devoid of any electric field, as consisting of many small pairs of positive and negative charge elements, and in the absence of an electric field the two opposite charges in each pair are essentially co-located, so there is no net change or electric potential observable at any point. If an electric potential is established across some region of this medium (e.g., empty space), it tends to pull the components of each pair apart slightly. Maxwell termed this an electric displacement in the medium. Of course, the constituent parts of the dielectric pairs attract each other, so the electric displacement is somewhat like stretching a little spring at each point in space. |
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| As an aside, it’s interesting that this theory, which supposedly denies the intelligibility of distant action, nevertheless ends up invoking (albeit on a very small scale) what appears to be elementary attraction between distinct and separate entities. It’s clear that Maxwell recognized this aspect of his theory when he wrote |
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| I have therefore preferred to seek an explanation of the facts … without assuming the existence of forces capable of acting directly at *sensible* distances. |
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| The qualifier “sensible” is obviously intended to side-step the fact that his “explanation of the facts” does still assume the existence of forces capable of acting at a distance, but he excuses this on the grounds that it is not a “sensible” distance. This can certainly be criticized, since if the objection to action at a distance is based on principle, then it isn’t clear why it should be considered more acceptable over short distances than over long distances. Ironically, Maxwell himself even commented on this critically in an article on Attraction written for the 9th edition of the Encyclopedia Britannica in 1875. |
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| If, in order to get rid of the idea of action at a distance, we imagine a material medium through which the action is transmitted, all that we have done is to substitute for a single action at a great distance a series of actions at smaller distances between the parts of the medium, so that we cannot even thus get rid of action at a distance. |
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| and elsewhere he said even more pointedly |
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| …it is in questionable scientific taste, after using atoms so freely to get rid of forces acting at sensible distances, to make the whole function of the atoms an action at insensible distances. |
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| Despite these scruples, Maxwell’s theory of electrodynamics, based on forces acting over insensible distances, proved to be tremendously successful. The elaborate and complicated material mechanisms that Maxwell originally conceived to embody the mathematical relations of the field eventually receded in his thinking, as he came to focus more and more on purely abstract energy-based considerations. |
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| We may express the fact that there is attraction between the two bodies by saying that the energy of the system consisting of the two bodies increases when their distance increases. The question, therefore, Why do the two bodies attract each other? may be expressed in a different form. Why does the energy of the system increase when the distance increases? |
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| It’s easy to see that Maxwell’s conception of the electric field is quite consistent with this energy-based approach. First, recall that, according to standard electromagnetic theory, the energy density of an electric field in vacuum is (1/2)0E2, where E is the magnitude of the electric field at the given point and 0 is the permittivity of the vacuum. (For the spherical field around a stationary mass point, E drops off as the square of the distance, so the energy density drops off as the fourth power, so the total integrated energy is finite.) Now consider two particles with equal and opposite electric charges, and suppose they are initially co-located at a single position. Their electric fields cancel out, because the union of these oppositely charged particles is an electrically neutral particle. As a result, the dielectric medium surrounding these two particles is “un-stressed”, i.e., none of the tiny springs are displaced at all, so no energy is stored in those springs. Now suppose we separate the two oppositely charged particles by some distance. This displacement results in a net electric field in the surrounding medium. Much of the two fields still cancel out, but not all, so the dielectric elements are displaced, the “springs” are stretched slightly, and the medium now holds some energy. The energy came from the work done to separate the particles, so we see that these two oppositely charged particles exert a force of attraction on each other (through the intermediary of the dielectric medium). The further we separate the particles, the more energy we put into the field, and we approach the energy of two complete isolated fields when the particles are infinitely far apart. |
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| The other case to consider is two particles with the *same* electric charges, both positive or both negative. Again we start with the two particles co-located, but in this case the fields do not cancel each other, they combine to produce a spherical field of twice the strength (and hence four times the energy) of a single charged particle. Thus the surrounding dielectric medium is already significantly “displaced”, and it contains energy in all those stretched “springs”. If we now separate the two particles by some distance, some cancellation of the fields is introduced (most notably in the region between them, where the fields point in opposite directions), and the fields are less additive in other regions. As a result, the stress and displacement of the dielectric medium is reduced, as is the amount of energy stored in the field. The released energy as the particles move further apart corresponds to a force of repulsion between the two positively (or two negatively) charged particles. The further apart we move the particles, the more energy is removed from the field, and we again approach the energy of the fields of two individual isolated particles. (This is less than the energy of the original single field with twice the strength, because the energy is proportional to the square of the field strength.) |
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| Toward the end of his 1864 paper, Maxwell inserted a brief note regarding the force of gravitation. He had commented previously on the formal similarities between the electric, magnetic, and gravitational fields, but now, after describing his energy-based model for the electric (and magnetic) forces between charges, he faced an obvious difficulty when trying to account for the force of gravity in a similar way. |
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| Gravitation differs from magnetism and electricity in this ; that the bodies concerned are all of the same kind, instead of being of opposite signs, like magnetic poles and electrified bodies, and that the force between these bodies is an attraction and not a repulsion, as is the case between like electric and magnetic bodies. |
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| To be more explicit, suppose we regard the force of gravitation as arising from the actions of a field, and suppose the presence of a gravitational field represents a certain energy content. The stronger the field, the more energy it contains. Now if analyze a pair of massive particles, we find that when they are initially co-located, we have a field with twice the intensity of the field of either particle individually, and as we move the particles apart, the integral of the squared field strength (i.e., the total energy content of the field) drops, just as in the case of the electric field of two positively charged particles. Since the energy of the combined gravitational field drops as the particles are moved apart, it follows (by Maxwell’s reasoning) that there is a force of *repulsion*, not attraction, between the particles. The force of gravity predicted by this simple energy-based reasoning is in the wrong direction. Indeed this reasoning implies that it is impossible for “like” charges to attract each other – at least if their interaction can be represented as a continuous field. |
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| The only possibility that Maxwell could see for salvaging the field-based approach to gravity was if we suppose that a massive body contributes negatively to the energy of the gravitational field in its vicinity. It would then be the most negative when the two particles are co-located, and become somewhat less negative as they are moved apart. Since the change in energy as the particles are moved apart would be positive, so this would represent a force of attraction. However, Maxwell was not prepared to contemplate negative energy (notice that, since energy is proportional to the square of the field strength, a negative energy would imply an imaginary field strength), so he suggested that we could postulate a huge positive *background* energy content for empty space, and then we could suppose that the presence of matter somehow diminishes the energy of this background field in its vicinity. To ensure that the total energy density of the field at any point is never negative, he said the background field stress would need to be at least as great as that of the strongest gravitational field anywhere in the universe. (He apparently ruled out the possibility of point-like masses, which would require the background stress to be infinite.) |
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| The assumption, therefore, that gravitation arises from the action of the surrounding medium in the way pointed out, leads to the conclusion that every part of this medium possesses, when undisturbed, an enormous intrinsic energy, and that the presence of dense bodies influences the medium so as to diminish this energy wherever there is a resultant attraction. As I am unable to understand in what way a medium can possess such properties, I cannot go any further in this direction in searching for the cause of gravitation. |
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| This problem helps to explain why it took longer to devise a viable field theory for gravitation than it did for electromagnetism. Of course, in a sense, a field theory for gravity already existed in the form of the classical scalar potential, which satisfies the (Poisson) field equation |
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| https://www.mathpages.com/home/kmath613/kmath613_files/image001.gif |
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| in suitable units, where  is the potential energy and  is the mass density. This equation is identically satisfied by setting (r) = k/r + C for any constants k and C, positive or negative, but in order for the  field to give an attractive force, we must set k to a negative value. This is entirely consistent with Maxwell’s comments, i.e., the potential gravitational energy associated with a configuration of mass particles must decrease as the particles are brought closer together. The only way in this classical context to avoid actual negative energy (which Maxwell deemed necessary) is to set the “background” constant C to a value greater than the largest magnitude of k/r anywhere in the universe. In pre-relativistic physics, people worked with Poisson’s equation without worrying about the meaning of negative energy, they simply set C = 0, accepting the (apparent) fact that gravitational potential energy is negative. This “works” fine for most applications, but it doesn’t satisfy Maxwell’s desire to form an intelligible conception of the gravitational field in terms of ordinary classical dynamics. |
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| Remarkably, the expression corresponding to the “potential” in the weak field limit of general relativity actually does correspond to something like what Maxwell suggested. The effective classical “potential” for a spherically symmetrical field surrounding a mass M in the weak field limit is (half of) the time-time component of the metric tensor |
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| https://www.mathpages.com/home/kmath613/kmath613_files/image002.gif |
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| where G is Newton’s gravitational constant and c is the speed of light. The classical pre-relativistic expression for gravitational potential energy per unit mass is -GM/r, so a test particle of mass m is assigned the potential energy -GMm/r. Re-writing gtt in a form that isolates this expression, we have |
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| https://www.mathpages.com/home/kmath613/kmath613_files/image003.gif |
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| Thus when Maxwell said that the gravitational medium must possess enormous intrinsic energy, and the leading constant term must (to avoid negative energy) equal “the greatest possible value of the intensity of gravitating force in any part of the universe”, he could have been (as we see in retrospect) referring to the field intensity at the Schwarzschild radius of a black hole, where the gravitational “potential” is comparable to the intrinsic “rest” energy of a test particle. In a sense, the enormous background energy corresponds to the “rest” energy E = mc2 of the test particle, which in turn corresponds to the ratio of proper time to some suitable coordinate time at any location in the field. Of course, there need not always be a “suitable” coordinate time, and hence energy cannot always be unambiguously localized in general relativity. However, in special circumstances such as a spherically symmetric field going to flat Minkowski spacetime at infinity, we have a fairly unambiguous definition of energy. |
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| As an aside, the attractive nature of gravity is sometimes said to be closely related to (if not a direct consequence of) the equivalence principle, according to which the gravitational “charge” m of a given body is identical to the inertia of that body. In the case of electricity, reversing the sign of a particle’s electrical charge will reverse the direction of the applied force, but not of its inertia, so the resulting acceleration is reversed. In contrast, reversing the sign of the mass of a body would not only reverse the direction of the force, it would also reverse the direction of the resulting acceleration relative to the force, so the acceleration would be in the same direction, regardless of the sign of the mass. On the other hand, it could be argued that the gravitational interaction between two “like” particles involves *three* applications of the sign of mass: The mass producing the field (active charge), the mass responding to the field (passive charge), and the inertial mass of the responding particle. On this basis, reversing the sign of mass would reverse the direction of acceleration. This kind of superficial algebraic conundrum highlights the importance of energy-based reasoning. |
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| In his encyclopedia article on “Attraction” Maxwell did suggest one possible representation of the gravitational force in terms of a dynamical field that he hadn’t mentioned in 1864. After explaining how forces (such as electricity and magnetism) that are repulsive between “like” bodies may be represented in terms of a medium in a state of stress “consisting of tension along the lines of force and pressure in all directions at right angles to the lines of force”, he turns again to the vexing problem of gravity. |
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| To account for such a force [of attraction between like bodies] by means of stress in an intervening medium, on the plan adopted for electric and magnetic forces, we must assume a stress *of an opposite kind* from that already mentioned. We must suppose that there is a pressure in the direction of the lines of force, combined with a tension in all directions at right angles to the lines of force. Such a state of stress would, no doubt, account for the observed effects of gravitation. We have not, however, been able hitherto to imagine any physical cause for such a state of stress. |
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| This is interesting because his theory of electromagnetism is normally regarded as a vector field (corresponding to a spin-1 mediated force), and all such fields are known to yield repulsion for “like” charges, and yet Maxwell seems to be saying that he can conceive of an attractive force “on the [same] plan”, merely by exchanging tension and compression. On the other hand, his specification of both tension and compression in various directions at each point within the medium is more suggestive of a tensor field (i.e., a spin-2 mediated force) rather than a vector field. The usual textbook explanation is that even-order fields (e.g., scalars and tensors) are attractive for like particles, whereas odd-order field (e.g., vectors) are repulsive for like particles, all under the assumption of strict positivity of energy. This shows how prescient /preşiyınt, presiyınt/ was Maxwell in imposing this requirement on his field theories. |
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| However, there is one other important premise underlying the modern textbook answer, namely, that we are working in a relativistic context. We’ve already seen that the classical non-relativistic scalar field representation of gravity implies an attractive force only if we assume that the field energy is *reduced* when masses are brought together, and yet the magnitude of the field strength clearly increases in such circumstances, just as when two identical electric charges are brought together. So, the modern textbook explanation today is that the total mass-energy of a system is indeed reduced when the matter components are in closer proximity, just as Maxwell surmised. Furthermore, the total overall mass-energy of any system, including the “negative” contribution of gravitational potential energy, is always positive, which again is just as Maxwell surmised, when he suggested the existence of a very large “background” energy that is diminished when objects are close together. Of course, this is the very thing that Maxwell said he could not understand. It is perhaps slightly misleading to say the gravitational potential energy is negative. It might be better to say the absence of gravitational potential represents positive energy, except that even in the case of gravitation the energy of the field is said to be proportional to the square of the field strength, which (as noted above) would seem to imply imaginary field strength in order to give negative energy. In view of all this, is it fair to say that we’ve satisfactorily answered the question Maxwell was unable to answer – or have we simply decided to disregard it? Are we any more able than Maxwell to conceive of how bringing two objects together, increasing the magnitude of the field strength, whose square corresponds to field energy, results in a decrease of energy? Are there any alternative conceptual frameworks within which Maxwell’s question could be answered in a more satisfactory way? Part of his difficulty may be attributed to the fact that he didn’t have a unified concept of energy-momentum, but more fundamentally it could be argued that Maxwell couldn’t explain gravity because he didn’t know that *the signature of the spacetime metric is negative*. |
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| The effect of the negative signature of the spacetime metric is discussed in the note on [Path Lengths and Coordinates](https://www.mathpages.com/home/kmath412/kmath412.htm), and more specifically as it relates to the attractiveness of gravity in the note entitled [Accelerating in Place](https://www.mathpages.com/home/kmath409/kmath409.htm). The latter note explains in detail why, if the signature of the spacetime metric was positive, we would indeed expect gravity (for positive mass-energy) to be a repulsive force. The negative signature implies that geodesic worldlines of material particles actually maximize (rather than minimize) its absolute path length. The sign of the accelerations in the geodesic equations depends on the sign of the metric signature, i.e., on whether the time coefficient has the same or opposite sign as the space coefficients. An even more explicit demonstration of this is presented in the discussion of the Newtonian limit of general relativity in [Scholium](https://www.mathpages.com/rr/s8-05/8-05.htm). There it is shown that the direction of gravitational acceleration is determined by the sign of M/k where M is the mass of the gravitating body and k is the signature of the spacetime metric. If we assume a Euclidean, positive definite, spacetime metric, then k = 1 and the only way for gravity to be attractive is with negative mass-energy. Conversely, with a Minkowski metric we have k = -1, so attractive gravity corresponds to strictly positive mass-energy. (See also the note on [Potential Energy, Inertia, and Quantum Coherence](https://www.mathpages.com/home/kmath534/kmath534.htm) for thoughts on the energy implications of falling objects in different contexts, and how the energy is transported away.) |
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| It would be interesting to know if Maxwell’s reversal of stresses can be seen as corresponding to a negation of the signature of spacetime. Related to this is the question of how he derived the value of 37,000 tons per square inch for the pressure (and perpendicular tension) that would be required at the Earth’s surface to reproduce the effects of gravity. |
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VOCABULARY:

to record:/rikoord/ kaydetmek

record: /rekırd/ kayıt

ancient:kadim, eski

constitution:bünye, yapı,anayasa

framework: yapı, esas

continuum:bütün, bölünmemiş şey, süreç

substance:madde

to permeate:nüfuz etmek, geçmek, sızmak

permeating

isolated:yalıtılmış

entity:unsur, varlık

void:boşluk, boş yer,geçersiz, ıssız

predominant:üstün, baskın,hakim

unanimous:oy birliği, fikir birliği

assent:Kabul, rıza, onay

to assent Kabul etmek, razı olmak

mainstream:anaakım

to alternate: ardışıklı olarak değişmek (alternating current), birbirini takip etmek

revolution:devir, devrim

to adopt:benimsemek,evlat edinmek, sahip çıkmak

insisting: ısrar eden, ısrarcı

extant:/ekstınt/ hala var olan,

extinct :nesli tükenmiş, artık var olmayan

co-extant:

to assert:iddia etmek, ileri sürmek, öne sürmek

to assert oneself : otoritesini kullanmak

affect: etkilemek, etki etmek

to swirl girdap gibi dönmek, fırıl fırıl dönmek

swirling:

vortices: plural of vortex

vortex: girdap, anafor

to discredit:gözden düşürmek, itibarını sarsmak

equivocal:belirsiz, iki manalı,

capable of: -----yapmaya muktedir

via:yoluyla

viable: makul, geçerli

viability: makul olma, geçerlilik

which is to say: that is to say, yani

premise:önerme

to culminate:doruğa ulaşmak, sonuçlanmak

to revert: eski haline dönmek, (bakış) çevirmek

reverting:

ultimate: nihai, en son

ultimately:

led: past form of lead

influential:tesirli, nüfuzlu

treatise:/triytıs/ ilmi eser, bilimsel eser

nevertheless:yine de, buna ragmen, bununla beraber

to retard: geciktirmek,alıkoymak,yavailatmak

retarded:

absorb:soğurmak

concede: taviz vermek,kabullenmek:

circumstance:hal, vaziyet

ambiguity:belirsizlik, şüpheli oluş

aid:yardım

to encode: kodlamak, şifrelemek

encoding:

ingenious:becerikli,marifetli,hünerli

comprehensive:kapsamlı,etraflı,idrak edebilen

ironical alaylı,alaycı,ters anlamlı, umulanın aksine

ironically:

to acknowledge:tanımak, kabul etmek, alındığını bildirmek, teşekkür etmek

to propose:teklif etmek, tasarlamak, evlenme teklifi etmek

proposal

was subject to: maruz idi

objection: itiraz

unfounded:temelsiz

to amend: (kanun vs) değiştirmek:

amendment

mature:olgun, olgunlaşmış, tam

rationale:/raşıneel/ mantık, gerekçe, mantıklı açıklama

vehicle:/ viyhekıl /vasıta, araç, taşıt

spatial: uzaya ait, mesafeye ait

temporal:zamana ait

propagation: yayılma

disturbance:karışıklık, rahatsızlık, bozukluk,kargaşa

sheer:saf, karışıksız, tam,düpedüz

evidence:delil, ipucu

ether:esir maddesi

dielectric:yalıtkan, dielektrik

component:parça, öğe, bileşen

to envisage:tahayyül etmek, kafasında canlandırmak

to picture:resmetmek

devoid of:-----den yoksun, mahrum

absence:yokluk, eksiklik

to establish:kurmak, tesis etmek

aside:kenar notu

intelligible: anlaşılabilir, anlaşılır

intelligibility: anlaşılabilirlik

to invoke çağırmak, yalvarmak, yakarmak, yardıma iağırmak

invoking:

albeit: ---na ragmen, gerçi

aspect:hal, tavır,çehre, görünüş

to intend:niyet etmek

to comment:yorum yapmak, yorumlamak, (düşünce) açıklamak

pointed keskin, dokunaklı, anlamlı,

pointedly:

scruple: /skrupl/ endişe

to conceive:tasavvur etmek,kavramak,düşünmek

to embody:cisimleştirmek,somutlaştırmak,ihtiva etmek

to recede: geri çekilmek,vazgeçmek,gerilemek

permittivity: (dielektrik) geçirgenlik

to drop off:azalmak

to integrate:bütünlemek, tamamlamak,birleştirmek, toplamak

surrounding:civar, kuşatan, etrafını saran

intermediary:aracı, arabulucu

to insert:sokmak

brief:kısa

regarding: hakkında

explicit: sarih, belirgin, açık,aşikar

content:muhteviyat,kapsam

to salvage: kurtarmak,atık madde veya hurda toplamak

salvaging:

to contemplate:tasarlamak,düşünmek

to diminish:azalmak, eksilmek

to ensure:sağlamak, sağlama almak, garantiye almak, sigorta etmek

to possess:sahip olmak

resultant:sonuç, bileşke

to devise:tasarlamak,planlamak,

configuration:biçim, gruplaşma, dağılım,

to deem:farzetmek,saymak, inanmak

in retrospect:geçmişe bakıldığında, geçmişte

superficial:sathi, yüzeysel, üstünkörü

conundrum:muamma,bilmece

to vex: üzmek, gücendirmek,canını sıkmak,

vexing:

to account for:hesap vermek,sorumlu olmak,sebebi olmak

hitherto:şimdiye kadar, bugüne kadar

prescient:/preşiyınt, presiyınt/ ileriyi gören, geleceği gören, önsezileri güçlü

proximity: yakınlık, kan bağı

to surmise:tahmin etmek,sanmak

surmise: tahmin, şüphe

geodesic:jeodezik