

FIELD PROCESSES IN SPACE

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More than two thousand years ago Democritus said, "In reality there are atoms and the void." Philosophers from that day to the present have been inclined to follow his lead; they have usually denied to space any semblance of physical properties, any attributes beyond a mere emptiness, a mere "void."

Such a philosophy has never proved adequate. We may refrain from assigning physical properties to space, but it has still been necessary to assign to it abstract mathematical properties, in increasing number and complexity. The geometry of Euclid presupposes a measure of length, valid beyond the boundaries of solid matter, capable of extension to the space outside. More general geometries require a similar supposition if they are to have useful physical application.

We assign coordinates, measures of length and of time, but this is still not enough. In addition we have found it necessary to associate various potentials with these coordinates, the gravitational potentials of Laplace and Poisson, the electromagnetic potentials of Maxwell. These potentials are quantities whose significance is localized, quantities associated with the region of the space and time coordinates to which they are assigned. We can hardly avoid the implication that they are associated with some aspects of a physical process in space.

An important step away from the concept of space as a void was the development of the traditional "ether" concept. This concept sought to describe field phenomena in essentially static terms, in terms of strains and stresses bearing some analogy to the familiar properties of matter. Quantum theory has made it obvious that such a picture is inadequate, that the fundamental structure of nature must be formulated in dynamic terms, in terms of energy, action, and waves. It is quantum theory which provides a clue to the next step.

If we are to apply a quantum viewpoint consistently, we must certainly assign quantum attributes, not only to the structure of matter, but also to processes in space outside of matter. Dirac was perhaps among the first to recognize that space must possess properties beyond those of the traditional ether, basing his inference on profound mathematical considerations. Such an approach unfortunately does not encourage attempts at interpretation; we need a more physical approach if we are to break the grip of ancient philosophies.

Field phenomena can be regarded as representing aspects of an energy pattern in space. Such a view follows naturally from ideas of Maxwell, Poincare, Planck, and many others. It is the one view which assigns a simple, understandable physical significance to field processes; there appear to be no specific objections to it.

The usual descriptions of field phenomena require us to assign quantities whose significance is localized. Still, nothing in the manner of derivation and definition of these quantities demands that they retain significance for regions indefinitely small. Potentials are mathematically continuous functions, but there is no need to regard them as associated with a physically continuous structure.

Field quantities serve to express resultant energy differences directly, without requiring a formulation of small scale structure. Field phenomena at the ordinary scale of magnitude are concerned only with such resultant energy differences and energy changes. These phenomena can give no indication of the presence of any uniformly distributed energy in space; they give no information regarding the density or small scale structure of such energy.

The energy densities associated with field quantities are small. It is usually tacitly assumed that apart from observable fields space is quite empty; the energy density is zero. Such an assumption is entirely arbitrary; we cannot infer the

actual energy density from these observable fields. Rather, we are free to assign to so-called empty space an energy density which fits in best with quantum processes; this is our only clue to the actual energy density in space. Densities traditionally associated with the "ether" concept are totally inadequate here.

Discontinuity factors form an intrinsic part of this energy background, playing as vital a role there as in the structure of matter. Such factors should not be thought of as a contradiction of classical theories; they are the expression of an essential limitation. The quantum and the Compton wave length determine an energy pattern of high density.

The interaction of this energy background with small scale processes provides a physical basis for the familiar "uncertainty principle," while small modifications in the field background account for the usual field phenomena. Gravitation and electromagnetism represent modifications of one basic field structure. These concepts serve to express energy differences at the ordinary scale of magnitude, but they do not provide a description of the small scale structure of nature; small scale forces are more potent.

We have ample reason to abandon the concept of an empty space, and substitute a space filled with such an energy background. In regions where this structure is completely uniform, it will show no observable effects at the ordinary scale of magnitude; its net interaction is zero. Observable field effects imply resultant energy differences, which are associated with small modifications of this uniform structure. Where the uniformity of the field background is disturbed, resultant forces appear which tend to restore the normal uniformity and symmetry of this background.

Energy differences associated with field processes in space fall into three simple categories. An interaction with the structure of matter along radial lines may modify the energy of linear motion along one line in space. This field pattern is represented by the gradient of a scalar potential, and constitutes an electric field; the "sources" are referred to as electric "charges."

Similarly, we may have modifications of the field energy around some line in space. This modification of the energy of rotational motion, represented by the curl of a vector potential, constitutes a magnetic field. Its origin may be associated with the motion of electric charges, or with "spin" energy at any order of magnitude. A magnetic field is *not* a vector field; it is a tensor of the second rank. The use of a vector to represent such a field is a practical simplification which may suggest false analogies with electric field structure, a point often overlooked in textbooks.

The third type of field effect is associated with differences in total density of our field pattern; such differences constitute gravitation. A gravitational field is usually represented adequately in terms of a simple scalar potential, but the small scale processes are here more complex, and a more detailed interpretation may be needed to correlate associated phenomena.

In the electromagnetic field there is in general no specific relation between the source "charges" and their intrinsic energy or mass, so the value of "charge" is assigned without reference to any associated mass. In the gravitational field, on the other hand, no measurable difference in the gravitational acceleration of different substances has been established experimentally, so it has been customary to assume a complete equivalence of gravitational and inertial mass. We can maintain a correlation with electromagnetic field structure if we use a formulation which does not depend on such an assumption. This is easily done.

We can simply start out as with other field processes. For the interaction of two entities we write $F = Q_1 Q_2 / r^2$. As in the electromagnetic field, this is regarded as strictly applicable only to stationary states, but its purpose is to assign to each entity a quantity, Q , characteristic of that entity; this quantity serves as a measure of its interaction with the surrounding region. Though it is usually referred to

as a "gravitational mass," this quantity is *not* in mass units. Rather, it corresponds dimensionally to electrostatic charge and magnetic pole strength. Such assigned quantities provide us with a means of describing the gravitational field in essentially the same way as the electromagnetic field.

Newton's law in its usual form implies the additional assumption that these assigned quantities, Q , are exactly proportional to the masses, m ; i.e., $Q = Km$, where K is a dimensional constant determined experimentally. The expression $F = Q_1Q_2/r^2$ becomes identical with Newton's law by taking $g = K^2$.

More generally, we express our distribution pattern by assigning potentials distributed in space and time. The source quantities then serve simply as labels which determine these potentials. For gravitation, as for other field processes, we may define our potential as a summation of (Q/r) , and determine the force acting on any entity by multiplying its assigned value of Q by the potential gradient in its region. No constant appears in this relation; a constant appears only in the relation between Q and m . To the extent that this constant is uniform for all accumulations of matter, the formulation remains equivalent to Newton's law.

The potential so defined has the dimensional status (force)^{1/2}, the same as the basic potentials of the electromagnetic field (Holm, 1959). We thus parallel the usual formulation of electrostatic and magnetic fields. Even though the physical pattern of our field energy is different in all three cases, we can still use units which are the same dimensionally and in magnitude. This is possible because we are in no way describing the detailed small scale structure of field processes; our field quantities simply express resultant energy differences directly. They have no more basic significance.

In describing gravitational interaction, one application of K is concerned with the interaction between the source masses and the surrounding field while the second is concerned with the interaction between the field and the entity acted upon. These are distinct physical processes, separated in space and time. If we assume a uniform value of K , the two constants can of course be combined without affecting the mathematical results, but we must recognize that this is not in accord with an objective interpretation of gravitation as a sequence of physical processes. Any deviation from a uniform value of K at once requires us to split the constant, g , and assign a proper constant to each entity. We are prepared for this eventuality if we parallel the formulation of the electromagnetic field; we can pave the way for a closer coordination of all field processes.

Such a formulation is not too unfamiliar though its basis is usually not stated explicitly. The gravitational Q associated with a one-gram mass is equal to $K = g^{1/2}$, so we require a mass of about 3872 grams to produce unit potential gradient at unit radius. This is the unit of Q commonly referred to as a "gravitational unit of mass." The exact relation between Q and m is the value of K for the substance considered.

Actually only one element, hydrogen, with its atomic weight of 1.008, can be expected to show a significant deviation in its gravitational acceleration. Since hydrogen appears in combination with a variety of elements, it is entirely feasible to make gravitational experiments comparing such substances with others. Apparently no such experiments have ever been made. We need a higher order of precision to compare substances which do not contain hydrogen.

The presence of a basic field structure in space implies one very important consequence. It obviously restricts the generality of any "relativity" principle, making it necessary to assign a more specific interpretation to the Lorentz transformation. This transformation law has a direct and vital physical significance entirely apart from the abstract and mystical philosophy which has come to surround it.

The mathematical basis of the law is no mystery. It can be correlated with understandable physical factors. This means that we must coordinate our mathematical reasoning with attributes of specific physical meaning.

Mathematical methods of reasoning have proved so useful that we may fail to recognize the limitations which surround such methods. Modern physics has largely substituted a mysticism of equations for the mysticism of numbers of the ancient Pythagoreans. It behooves us to examine the reasons for the success of such a philosophy, so we may remain equally aware of its limitations.

We are able to set up physical laws and physical equations only because there exists in nature a degree of uniformity, a degree of consistency. If this were not so, if nature were completely haphazard and unpredictable, there would be no such things as physical laws.

Sometimes the degree of uniformity and consistency is only approximate, as in the biological sciences, and we must rely largely on descriptive names and classifications to express our knowledge. In other areas, the degree of consistency may exceed the degree of accuracy of our observations and measurements, so we are able to set up valid general physical laws. Some such laws may be valid far beyond the order of accuracy of our observations, so we tend to overlook the fact that we are still dealing with a degree of uniformity, a degree of consistency. The fundamental things in physics are not equations, but are rather the uniformities and consistencies which underlie them. Equations are a brief and convenient way of expressing these consistencies, but in the ultimate the equations may not be described as "true," only as adequate or inadequate to any given situation.

The inverse square law serves as an excellent example here; it leads in simple steps to more general laws. This law is in essence simply a geometrical distribution pattern, aptly symbolized by the traditional "lines of force" concept. Physical processes in space conform to this law subject to various limitations. This becomes understandable if we recognize the law, not just as an equation, but rather as a specific type of uniformity.

Field phenomena at the ordinary scale of magnitude all show this simple symmetrical distribution for stationary states. The law represents a distribution pattern in space alone, so it obviously is not adequate for rapidly changing situations where time derivatives become important. Thus, in electromagnetic theory we substitute a more general "equation of propagation."

The electromagnetic field is the domain of a scalar and a vector potential, both of which satisfy equations of propagation. These equations may be regarded as the fundamental equations of the electromagnetic field. Thus, in place of $\nabla^2 P = 0$, we have $\nabla^2 P - \partial^2 P / \partial (ct)^2 = 0$; in place of a simple spatial symmetry we have a specific type of space-time symmetry, a symmetry deriving directly from the propagation process.

It is this type of symmetry which appears in the Lorentz transformation. This transformation law was derived by Lorentz initially on the basis of the electromagnetic field equations; Einstein gave it a more general application. The law takes its form from the equations of propagation of the electromagnetic field, the familiar "wave equations." The denominator of these equations forms the invariant function of the coordinates which is the basis of the Lorentz transformation.

The Lorentz transformation implies the presence of propagation in physical processes in general. We in effect apply the pattern of the equation of propagation to internal mass-energy structure. The fundamental physical fact is the presence of an intrinsic velocity, c , associated, not only with all forms of energy in space, but also with the internal energy of matter. This is the physical basis for the mass-energy relationship $\text{Energy} = mc^2$.

Relativity theory takes the velocity of light specifically as a fundamental thing which does not change, and then without apparent logical connection proceeds to incorporate this velocity in equations that have nothing to do with the propagation of light. We bridge this gap if we regard the velocity, c , as a basic velocity associated with energy in general, an intrinsic velocity in physical processes. This

gives us a more fundamental basis for the continuum of special relativity than the mere transmission of a light signal. We can accept the usefulness of the equations of relativity and still recognize the existence of limits to the relativity principle.

The relativity viewpoint is one of the type of assumptions known as negative postulates, or "postulates of impotence." Such postulates form a necessary and useful part of physics though they are not always stated in the most appropriate language. In abstract mathematics we may be entitled to say, "It is impossible to . . ."; physics calls for more modest statements. Postulates of this type are essentially a simplifying procedure, a process of omitting factors which do not play a measurable part in the experiments considered. We can always conceive the possibility that such factors will play a measurable part in other future experiments, so we can never regard such postulates as ultimate or final truths.

We cannot of course return to Newton's concepts of "absolute space" and "absolute time"; the actual situation is far more complex. A single primary coordinate system cannot form an adequate background for all purposes. We must recognize local variations and restrictions. The general field pattern is modified by the presence and motion of matter. Our choice of coordinates must reflect this; it cannot be made completely arbitrary.

Relativity speaks of observers moving with different velocities. All *actual* observers are effectively limited to one velocity, that of the earth's surface; we have no cognizance of observers moving with a substantially different velocity. For experiments at the earth's surface, we choose a primary coordinate system moving with the earth's surface and apply transformed coordinates to a rapidly moving entity. We will need experimental data under a wide variety of conditions, at high velocities and at a distance from the earth's surface, before we can develop more complete rules for choosing our coordinate systems and specifying their limitations. Detailed mathematical interpretation must await further knowledge, but the concept of "lines of symmetry" can serve as a useful descriptive basis (Holm, 1953).

It is not possible to maintain relativity as a *principle* since it leads to a variety of paradoxes and contradictions. Such paradoxes seem too abstract to be generally convincing; we need a more direct and satisfying proof of the limitations of the relativity principle. Space rocket experiments should soon make this possible.

Newton's laws of motion implied a simple relativity, valid for low velocities but not strictly true. To deal with high velocities we need the Lorentz transformation. It remains a fundamental physical law, but its exact range of validity is still to be determined.

The Lorentz transformation is inherently coordinated with the electromagnetic field equations; it is the gravitational field which requires further consideration. Changes in gravitational fields usually take place much too slowly to make time derivatives of the potentials directly significant; this aspect of propagation becomes important only at very great distances. We are dealing with energy densities, so a scalar potential is generally adequate. There remains one situation where we find it necessary to go beyond Newton's law.

Mass was traditionally regarded as a simple scalar constant assigned to any particular portion of matter. Today we know that such a concept is valid only at low velocities. For a rapidly moving entity, mass becomes a tensor subject to the Lorentz transformation.

The Lorentz transformation can be applied directly to determine the precession of a planet, as Birkhoff (1950) has shown. We need not assume the general validity of the relativity principle; we can avoid the even more abstract assumptions of the general relativity theory.

The general relativity theory still reduces its conclusions to the concept of an orbit and its precession. The word "orbit" in itself defines a coordinate system since it implies the attributes of size, shape, and position. When we speak of the

precession of an orbit we necessarily infer a precisely specified coordinate system. In contradistinction to the relativity viewpoint, such a specific coordinate system seems peculiarly suited to the description of planetary motion; the orbit appears as a path through the field.

The concept of a basic field structure in space permits us to interpret photons as simply small increments of energy superimposed on this structure, much as signals are superimposed on a carrier wave. The field structure can transmit such individual pulses of energy, or more complex superimposed wave forms. We reconcile at once the "wave" and "particle" attributes of radiation; light manifests wave attributes simply because it is superimposed on an existing wave pattern. The physical property which distinguishes the individual photon is its energy or momentum. Wave length is *not* an intrinsic property of the individual photon; it appears only as a statistical distribution of photons in space. The field background plays an essential role in creating such a probability pattern. There is no directly associated frequency; the time of emission of the photons may be quite random.

The most elementary property of such a statistical distribution is the inverse relation between the size of these energy increments and the resultant wave length. If we compare these wave lengths with the basic Compton wave length, we see that visible light consists of very small energy increments, only a few parts per million. Small as these increments are, they still produce some specific effects. The eye, for example, responds directly to the energy impact of the photons. It has no mechanism for forming or recognizing wave lengths; the same is true of the photographic plate.

With larger increments, individual effects are more readily identifiable, "particle" attributes become more prominent. Smaller increments are less likely to show identifiable individual effects, but they can form part of a larger scale pattern. When we produce waves by electromagnetic means, the quantum discontinuity of the field becomes quite unimportant. The source introduces regularity in both time and space; frequency has a direct physical significance. We deal directly with this larger scale wave pattern.

Only the transverse aspect of radiation appears experimentally; the absence of an accompanying longitudinal wave has no adequate explanation in classical wave theory. We face no such problem here; the longitudinal wave pattern simply remains uniform in any region of space. Our field structure can transmit small energy increments for enormous distances without substantial attenuation.

An attenuation, a gradual loss of energy by individual photons, is certainly conceivable; the remarkable aspect is its smallness. We surely need not picture field processes as taking place in a structure of infinite rigidity. We have no very positive means of distinguishing such a factor from a possible expansion, but it can explain Olber's paradox and Hubble's limit without the need for assuming an expansion. The existence of a basic field structure in space requires a radical modification of expansion ideas.

The designation of h , rather than hc as the quantum constant, is probably a serious error. No experiment measures a frequency associated with visible light, or radiation of higher energy content. We have good reason to believe that such a frequency does not exist. Where we introduce a frequency directly, as in waves produced by electromagnetic means, the quantum constant loses its significance. The measured quantity associated with visible light is a statistical distribution of photons in space, a length, not a frequency; it is related to hc , not to h .

The distinction becomes increasingly important when we examine its more fundamental implications. To use hc consistently in place of h will generally necessitate multiplying momentum by c also, giving us a directed or vector energy, expressed in energy units. Conservation of momentum then appears as a special aspect of the principle of conservation of energy, just as the conservation of mass is a special aspect of the same principle.

Using values given by the Lorentz transformation, we see that the momentum-energy of a "particle" is related to its mass-energy through its relative velocity, $B = v/c$; i.e.,

$$\text{Momentum} \times c = \text{Energy} \times B.$$

In the case of a photon, energy and momentum are related by the constant factor, c :

$$\text{Momentum} \times c = mc^2 = \text{Energy}.$$

There is thus no essential physical distinction between the two concepts for a photon, or for field energy in the fundamental sense. Energy and momentum merge in one basic concept of field energy. The customary scalar energy function is one aspect of this concept; momentum is another aspect, the directional aspect or component of our energy pattern.

The three concepts mass, energy, and momentum differ in pattern and context but are united in their fundamental significance. Their reduction to a unified common basis is a necessary prerequisite to a consistent interpretation of physics. Such a simplification in our fundamental concepts permits one conservation law to serve as a basis for all of physics.

Fundamental Constants

The basic field structure depends on:

The quantum, $hc = 1.986 \times 10^{-16}$ erg \cdot cm.

The Compton wave length, $\lambda = 2.426 \times 10^{-10}$ cm.

We derive a density, $hc/\lambda^4 = 5.73 \times 10^{22}$ erg/cm³ = 64 gm/cm³.

Electron structure depends on:

The angular quantum, $hc/2\pi = 3.160 \times 10^{-17}$ erg \cdot cm.

An effective radius of action, $r = \lambda/2\pi = 3.861 \times 10^{-11}$ cm.

These determine a mass-energy, $mc^2 = hc/2\pi r = 8.185 \times 10^{-7}$ erg.

The electrostatic field energy $e^2/2r$ is only 1/273 of the electron's mass-energy.

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