Fundamental Optics

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The Various Speeds of Light

By

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PREFACE

A ‘ray’ of light, like the geometrical line, has only length and no width; it therefore has no sides. When new optical phenomena were discovered in the seventeenth century, such as double-refraction, they could not be understood in terms of unidimensional rays, and the need arose for the invention of a three-dimensional material medium—the aether—to accommodate them. Ever since, the science of optics appeared quasi-schizophrenic—it seemingly possessed two lines of logic, one geometrical (metaphysical) the other physical—‘Geometrical Optics’ and ‘Physical Optics’.

This book does not deal with the long-standing dilemma concerning the actual nature of light, whether it’s a material corpuscle, a wave in a material ether, or a mental construct in mathematical terms which combines the two. Optics is a branch of Physics, and Physics nowadays is wedded to Mathematics which is part of Metaphysics, whereas here we emphasize the quantitatively perceptible reality advocated by Ernst Mach and Max Planck: “Physics is an exact science and hence depends upon measurement, while all measurement itself requires sense-perception.” [1] We return in this way to where Newton has left off in his *Opticks*, or in Justus Liebig's words: the progress of science is like a winding staircase which by the end of each turn arrives close to the starting point, but hopefully a bit higher.

Since light is in *Space* and requires *Time* for its *Motion* these terms are defined as the basis of the following actual new observations. Similarly, the second chapter furnishes the historical background. The Optokinetics chapter (from Gr. *opticos*, concerning light and vision, and *kine* concerning movement) deals with the actual new laboratory data, while Optokinematics examines anew light's general motions in space.

Some of the main points of divergence from the orthodox system are in the treatment of reflection (Kepler and Newton’s axiom II), reciprocity (Kepler and Newton’s axiom III) and refraction. Optical phenomena are here interpreted by the one measurable physical property common to all lights–-their motions. The crux of the problem in the classical system may have been its difficulty, when dealing with color (monochromatism), to distinguish between complicated physiological perceptive information from simple quantitative physical stimuli, even though at least two prominent contributors to the system, Thomas Young and Hermann Helmholtz, were medical doctors exceedingly well versed in the mechanism of the eye. Modern physicists often avoid treating of colors altogether: "The actual connection between color and frequency is very involved and will not be studied in this book." [2]

As shown by Johannes Müller almost two centuries ago, different stimuli can produce the same sensations.[3] In addition, psycho-social factors may have delayed advances beyond the orthodox system of Optics, such as the inordinate idolatry of Isaac Newton's *Optics* after the success of his *Principia,* and of Albert Einstein *Relativity* after being granted the Nobel Prize for the *Photoelectric Effect.*

> “Many of the views which have been advanced are highly speculative, and some no doubt will prove erroneous; but I have in every case given the reasons which have led me to one view rather than to another. False facts are highly injurious to the progress of science, for they endure long; but false views, if supported by some evidence, do little harm, for everyone takes a salutary pleasure in proving their falseness; and when this is done, one path towards error is closed and the road to truth is often at the same time opened.” [4]

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I. DEFINITIONS

Names and words often mean different things to different people, and since we cannot smell them, a rose may not be a rose by any other name. Definitions are essential in telling us who is who and what is what so that we do not confuse the elements in the story. Our story is an attempt on our part to understand an event in nature—light—and we finish by introducing the terms by which we define nature. “The first cause of absurd conclusions I ascribe to the want of method; in that they begin not their ratiocination from definitions”. [1]

This quest to define the natural world—to tell the nature of Nature—is as old as civilization itself, and was usually in the purview of Metaphysics (originally a book written by Aristotle after his Physics) which treats mainly of topics unrelated to experience, best known among them being Mathematics.[2] But for our purposes we need definitions that relate to the reality of the world as perceived by our senses and conceived by physiological thought processes—defined terms that aid comprehension of real natural phenomena. Thus the definitions here are not presented with a purpose of forming a logical system of axiomatic premises whence our knowledge is then deduced by a strict mental discipline, but are meant merely to describe the milieu in which the events in this volume occur. We attempt to employ Francis Bacon’s method of evidence-based epistemology as the proper induction to reliable knowledge, while appreciating that this 'empiricism' was derived from the ancient Greek word for practitioners of medicine called ‘empirics’.

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1.1 MAN

The existence of man is axiomatic, namely, it cannot be proved or disproved by man, and hence must be accepted for granted, *a priori.* The axiomatic nature of man seems at first puzzling; historians and anthropologists assure us that there was a time when man did not exist, and present developments are sufficient reason to fear that he will soon cease to exist. But these considerations emanate from man himself, it is he who says so. Logically no thing can possibly be proven or demonstrated by the thing itself, which leaves no choice for our purpose but to accept the axiom of man.

A lone person on an island cannot prove his existence. Unless some signal from him or his remains is received by the rest of mankind, he does not exist. His reality is not fact nor truth, for there is no way of demonstrating it. He can still prove his existence to the fish, but then the fish must take their own being as an *a priori* fact. What the man on the island lacks is another human frame of reference. Man may imagine a world without man, but it is man who does the imagining. All human endeavors—including science—begin with man, even though man himself cannot be proven or demonstrated.[1]

Early in his history man evolved a concept named 'truth', God given, and at least on one occasion chiseled in stone on Mount Sinai. When in the Renaissance blind emotional faiths were gradually replaced by more enlightened rational thoughts the concept of transcendental truth remained but its contents changed. Scientists, as theologians before them, often believed that their truths were self-propelled by some innate power of passive buoyancy which, like oil in water, must sooner or later rise to the surface—*vincit omnia veritas.* Belief in this abstract entity was termed by Jacques Monod [2] 'the postulate of objectivity', where objective meant without man, as distinct from the subjectively human. It was perhaps best expressed by Ernst Mach: [3]

> If the historical sciences have inaugurated wide extensions of view by presenting to us the thoughts of new and strange people, the physical sciences in a certain sense do this in a still greater degree. In making man disappear in the All, in annihilating him, so to speak, they force him to take an unprejudiced position without himself, and to form his judgments by a different standard from that of the petty human.

Holding strong convictions one naturally liked seeing them transcend petty humanity -- beyond human doubt and frailty. When last century Mach's countrymen took the annihilating a bit more literally it impressed with horrifying impact the perils of dehumanizing science. The idea of absolute and objective truth generated also absolute and objective 'laws', which abound in some branches of knowledge, and serve perhaps to remind us of Tolstoy's saying that where there is law there is injustice. The brunt of the endeavor and the aim of science was the discovery of facts, axioms, and phenomena that had existence independent of man, while at the same breath conceding that it was man doing all this.

It is now generally recognized that human psychological and social factors influence man's perception of reality.[4--9] In order, therefore, to fathom the validity of assertions concerning 'true facts' one must allow for the psychological state of those asserting them, and the social context—of the society of scientists and society at large[10]—in which the assertions were made. The innocent belief in true reality independent of man has been recently amended to include man; namely, a society of experts. A true physical fact is now often understood to mean a state of affairs that appears in only one particular way to the largest number of interested observers, a process named by Michael Polanyi 'mutual authority',[11] and by John Ziman 'maximal consensuality',[12] the democratic rule by jury and consensus. Not everyone is interested, say, in Cosmology; if one has a question in cosmology one accepts as true answers given by men interested in the subject, and their knowledge in turn was largely formed by absorbing the knowledge of their similarly minded (interested) ancestors and contemporaries. The ill side-effects of specialization that thereby often ensue are well known,[13] and may simply be based on normal adaptation—breathing the same air long enough, one cannot smell it anymore.

The concept of consensuality is nevertheless useful, provided we remember cases like that of René Blondlot's fantastic N-rays[14,15] (accepted by mutual consensus of French authorities), and not forget Francis Bacon's words: "Anticipations [theories] are a ground sufficiently firm for consent; for even if men went mad all after the same fashion, they might agree one with another well enough." [16]

We need not here dwell on this very large topic once named Epistemology, and now Cognitive Science; the point is that truth, including scientific truth, is a relative phenomenon: what was true yesterday is false today, true to one false to others. The validity of a new truth will therefore generally depend on how many people are at that moment ready to accept it, and this depends largely on how many are pleased by it—either by the emotional comfort it provides, by its rational elegance, or by its practical utility to society.

When almost all perceive an event in only one particular way it attains almost absolute certainty. A heated wire emits lights, everyone can see it—it is true reality—except in a society of the blind, but then this society itself is not a true representation of mankind. A true fact of perception is, therefore, related to the established view of man's physiological normalcy.[17] And finally, since realistic concepts can be formed only on the basis of some perceived information, it follows that the veracity of a concept depends on its affinity to truly perceived data. We may, of course, form concepts— like heaven and hell—that are not based on perceived data, but then their validity can ill be proven and is justly in doubt. In order for a physical fact to be accepted as true it ought to be perceived as nearly as possible independently of the position where the fact was observed—what is true in New York must be true also in Moscow.[18] True facts of nature ought also be independent of time: the heating effect of fire must have been as true to prehistoric man as it is to us. The assumption is that man's physiology and his perceptual mechanisms did not materially change over time. Therefore, all true facts are reproducible in different places at different times.

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1.2 SPACE

Newer advances in understanding the human body and its various functions—particularly in cognitive neurophysiology and developmental psychology [1-5] -- underpin the apparent fact that human cognition is based on neuronal activities. This understanding altered the view, first developed by Immanuel Kant (1724-1804), which saw cognition founded upon certain transcendental concepts beyond human experience.[6] It now appears that knowledge that we are conscious of—as a form of information storage—resides in the cerebral cortex, whereto it arrived by means of nerves from special sensory endorgans and other parts of the body; other knowledge arrives to subcortical centers and remains largely subconscious, whence it may be retrieved, as Freud showed, by an arduous act of search and analysis.[7] This neuronal activity of information retrieval and storage begins *in utero* before birth, as evidenced, for instance, by the embryo's reactions to sound. The term 'knowledge' does not here include rudimentary automatic activities, such as metabolism, which evolved by genetic transmission of chemical compounds.

Aside from data perceived through specific sense organs, the brain is fed proprioceptive information about the position of the body and its extremities. Proprioception is very primitive, remains mostly subconscious, and starts before specialized sense organs attain their proper function. It is prerequisite to normal muscular activity, for in order to activate a muscle, information must be available about its state of contraction or relaxation, and the state of contraction of its antagonistic muscle.[8] At the time of birth man thus already possesses information, first about his own body, concerning positions in space—three dimensional space.

The concept we form of three-dimensional space, based on perceived sensory data, is present at birth and yet is not transcendental; namely, it is not an essential feature that must necessarily be accepted a priori when talking of man and his world. Practically though, no human-being has yet been described who lacked—consciously or subconsciously—a concept of three dimensional space.

'Biological and psychological research combine to confirm the conclusion that, as regards the intuition of space, the nativistic view can all the more be maintained. The chick has scarcely broken from its shell than it is seen to be at home in space and pecking at everything that excites its attention.' [9]

Saying that three-dimensional space is 'common-sense' and 'common experience' means that the largest possible consensus, a consensus formed by all mankind, perceives it in only one way. This perception of space is augmented after birth by specific information gained through the sense organs—such as the visual perception of nearness and distance, left and right, up and down—information closely tied to that received from the semi-circular canals situated in the inner ear on three different planes, corresponding to the three dimensions. This development of spatial perception after birth had been thoroughly studied by Jean Piaget and his school.[10-13]

Accepting man a priori, and recognizing that he arrives in this world with a concept of three-dimensional space, it is yet necessary to describe this space.[14] The prerequisite task of exploring space with the intent of discovering or arranging in it a rational system is based on the need to understand events in it. We need a systematic order amenable to human perception and easy conception which will aid orientation in space prior to taking action in it. In empty space we know not where we are—nor whether we are coming or going— but with some order we can find our way and then march on.

Given space and the task of instilling some order in it, we begin with the smallest conceivable building block within space. For a definition to be widely applicable it must consist of a minimum number of new terms, the aim being to define and explain the maximum number of entities and events by the least number of entities that are beyond definition and comprehension.[15] In addition, a strictly valid definition cannot include the term to be defined, or at least ought to admit as little of it as possible.

The smallest amount of space is termed 'a point'. When we say 'a' we mean 'one' and imply that we know that it differs from 'two' or any other number. A point is said to have no dimensions—no length, width or depth—and may thus seem a purely imaginary abstract concept. Inasmuch though as any image, any concept, is based on some perception, the dimensions of a point are related to the size of the space under discussion. In the All of the universe a point may have the dimensions of the sun while within the space of a molecule a subatomic particle may be seen as a point; every point marked on paper has real three dimensions, albeit very small. James Clerk Maxwell [16] named it 'A material particle: A body so small that, for the purposes of our investigation, the distances between its different parts may be neglected.' The concept of the point, as the first step on the way towards rationality, stands at the beginning of geometry and other systematic knowledge, and was thus no small feat of the human intellect.

A single point in space does not establish any order, and, therefore, we introduce another point. We term the space between the two points 'a line', or 'unidimensional'. The smallest amount of space between two points is given when they are adjacent to one another, and this space we term 'a straight line'.

The term 'straight' often presumed knowledge of what was crooked. When Euclid [17, 18] conceived of the straight line he tacitly assumed its existence on a flat plane, but 'flat' is a term that may be defined only in relation to a third dimension. Euclid's axiom that the smallest space between any two points was a straight line tacitly presupposed that the position of the points was already fixed on a plane, and that the form of the plane was similarly known. These presuppositions (premises) were not written into Euclidean geometry because they were taken for granted as common-sense human experience. It was thus possible in the last century to invent geometries in which the positions of points and the shape of the plane was made to vary—a manifold of n-dimensions, and where Euclid's axioms did not all hold; these non-Euclidean geometries were not based on experience, and were termed 'analytic' as distinct from the 'synthetic'.

When the position of two points is given, the line between them consists of an infinite number of points because these are defined as infinitely small. From within the line no order of magnitude or sequence may be established because no matter what the spatial interval between the delimiting points, the number of points remains infinite whether the line is 'long' or 'short'. Suppose you stand with many other people in a line. All you see is the front or back of one person to your one side, and the front or back of a person to your other side. You can form no idea of where the line begins or ends, if at all, or what shape it has, and hence you can have no idea what position in the line you occupy. If you wish to form an order of magnitude you may look at yourself and the space you occupy, and imagine that ten people to your right ought to equal ten people to your left. But you cannot be certain, because all the people to your right may be fat, and all those to the left slim, so that an equal number of each will yet occupy unequal space. Position in line, the shape of a line, and distances within it may only be ascertained when you consider it from outside the line, i.e. from a second dimension.

The elementary branch of Mathematics, Arithmetic, presupposes the concept of singularity—the one—without me, without man, there is nothing—zero. Zero is assumed to have a fixed position whence the numbers proceed in a given linear direction to the right: 1,2,3, … n. The position of zero is, however, ambiguous because without 'one' there is no entity at all in relation to which a position may be fixed. The definition of zero would have to be expressed as: 0=1-1, where the negative sign symbolizes the elimination of 'one'.

Traditionally 1 denotes a unit position to the left of zero, presupposing again that zero has a fixed position on a plane from which another position may be established to form a straight line with some direction. Along this unidimensional line on a two-dimensional flat plane the numbers proceed to the left or right. When zero denotes 'nothing', negative numbers are meaningless. When zero denotes the starting position, negative numbers denote elimination units, subtraction units in terms of 'distance': 4-2 means four distance units to the right of zero and two units to the left of zero, which leaves two units to the right.

There is little doubt today that the concept of numbers evolved from real perceived experiences, though Pythagoras and his school were so impressed with the seemingly transcendental power of numbers and their geometrical equivalents that they divined them to form a religion. True believers have existed in every period since.

This leads us to an important concept -- the concept of distance. A real point may be sensibly perceived only when it has three real dimensions, although these may be chosen as small as the space under study requires. Distance similarly correlates to real perceived information. When we look at two points on paper the distance between them relates to the space between retinal receptors in the eye, which is in turn judged by reference to preconceived information about the size of the page, or the room. However, one and the same distance in space may occupy different distances on the retinae of different eyes according to how their sizes vary: a large eye that may possess per area more numerous retinal elements than a smaller eye, or receives a larger optical image, is able to divide that distance into smaller units (i.e., its visual acuity is better) and it may see distances that are invisible to a smaller eye. A person with one large and one small eye sees a given line longer in one eye than in the other—aniseikonia; [19] his brain must then choose between the two images in order, for instance, to decide how big a step to take for a given distance. One eye is therefore subconsciously chosen as the dominant. At the same time, each eye within its own system can, of course, decide what size is larger than another, but no *absolute* sense of long or short is possible.

There is no distance apart from human perception, and this perception is not an independent entity but exists only in relation to a similar entity, an agreed upon standard. In order to define and determine distance, a frame of reference is prerequisite, and the choice of this frame is completely arbitrary. Traditionally, the frame was chosen from among those systems or objects which appeared the largest and most stable. Each nation had its own distinct system—such as the English yard, the Portuguese covado, or Japanese shaku. To a commission gathered after the French revolution the earth seemed large, stable, and convenient enough a frame to which events on it could be referred. The earth's circumference was chosen as constant, and its division into units—the meter—was set by this convention and then established by tradition. There is nothing sacred, transcendental, or universally true about this frame of reference, but a choice had to be made. It was thereafter possible to state unambiguously what was short or long, and where on earth was one position compared to another.

The entire science of Euclidean geometry deals with comparisons and congruities: one line is shorter than another, one triangle is incongruent to another, or one volume contains another. The unspelled premise of the science was the definition of distance. This was taken for granted, but may be termed 'The Universal Constant of Euclid'. It has since become clear that in order to state unambiguously the position of a point or the length of a line, a frame of reference must be given, because position and distance are relative terms that exist only in comparison to similar terms. Take, for instance, a sentence from Maxwell: "The position of B relative to A is indicated by the direction and length of the straight line AB drawn from A to B."[20] When he said "position" he already tacitly presupposed a frame of reference, and was then able to talk about "direction", "straight" and "length". Properly phrased the sentence must read: 'Within a given and known three-dimensional frame of reference, the position of B… etc.' One point in empty space does not constitute a position, and positions and lengths cannot be known in reference to only a single other point.

According to whether we have a frame of reference or not we can distinguish between position and 'real position', between a line and a real line, etc. On a real line ABC distance AB equals distance BA, the points A and B are equidistant. On a real one-dimensional line no more than two points can be *mutually* equidistant. The distance BC may equal AB, but all three points ABC together are not equidistant because the distance from C to A does not equal its distance to B. When A has a real position the line has a direction starting with A, and *from this position,* in this direction, the distances are sequential and no two are the same.

Thus based on perceptual reality we are able to define points and the unidimensional distance between them. In order to widen our concept of space we now introduce a third point not in line with the other two. The space between these three points is termed a 'plane', or two-dimensional.

For any chosen minimum unit of unidimensional (linear) distance, the smallest two-dimensional space is an equiangular (equilateral) triangle.

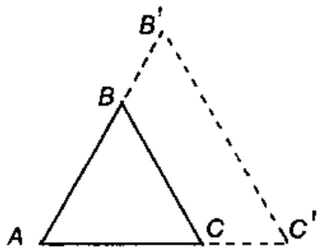

Fig 1.1. Congruent distances

From among any three points, one distance, say AB, may be set as standard; compared to this frame of reference AC or B'C' are 'longer'(Fig. 1.1) But in a system consisting of only three points not in line, the position of any one of them cannot always be unambiguously defined because at a minimum the three form an equilateral triangle in which no preferred distance is discernible to which other distances may be referred. In order to decide with certainty what is longer or shorter we need a fixed standard for comparison, and three points between themselves do not furnish such a standard because they may each be equally distant from one another.

When position B (Figure) is changed to B' while C is equidistantly changed to C' it is impossible to state whether A,B, or C changed their position. On a plane, no more than three points can be mutually equidistant. Points A,B,C may be equidistant, and also points A, B', C, but not points A,B,C,B' together, because AB is not equal to AB'

We then add a fourth point not on a plane described by the other three. The space between the four points is termed a 'solid' or three-dimensional, and for any minimum unit of distance, the smallest three-dimensional space is a tetrahedron of equiangular triangles. This tetrahedron does not provide a frame of reference for its constituent parts, i.e., any of the four points may occupy equidistant positions relative to the others without means of ascertaining from which one of them is the position to be judged. In three-dimensional space no more than four points can be mutually equidistant. When a fifth point exists, its distance to one of the other four must differ from all other distances. One may in this manner choose a preferred position from whence all others may be compared. Once a preferred position is chosen, one may state in reference to it what is long and what is short. In this three-dimensional system no two real points may occupy the same position.

The four points, defining three lines, constitute a system of coordinates named after its inventor Rene Descartes, who for the first time systematized the need for some frame of reference. The space described by this system is termed 'Euclidean space', or real space. There seems to be no magnitude, physical or other, without a frame of reference; in itself the symbol D for length, V for velocity, or T for temperature has no real meaning. The assumption that a frame of reference was an artificial product of pure human imagination and reasoning, without factual basis, allowed some metaphysicians (mathematicians) great liberties, and when these were then turned around and applied to the real world of facts they often led to inconsistencies. Concerning real space Henri Poincare said: "The language of three dimensions seems the best suited to the description of our world, even though that description may be made, in case of necessity, in another idiom".[21]

The other idiom Poincaré referred to was the non-Euclidean geometries, first invented by Carl Friedrich Gauss (1777-1855) who pointed out that Descartes' frame of reference need not be the only one. These geometries were further developed by N.I. Lobachevski (hyperbolic geometry), G.F.B. Rieman (elliptic geometry), E. Beltrami, J. Bolyai, and others. They sprang originally from Euclid's parallel axiom and demonstrated the logical coherence of systems other than Euclid's three-dimensional one. The intellectual capacity to conceive these spaces did not deny the existence of the real three dimensions, but rather seemed to add to it. Over the centuries man has held many conceptual systems, completely valid and logically consistent within themselves, whereby their real veracity and utility depended on their affinity to perceptual data. The term that distinguished Euclidean space from all others was 'distance'.

In geometry, and mathematics in general, it is admissible to premise one dimension or coordinate as an *a priori* constant. There is no question as to the reality of the coordinate—it is presupposed as given without requiring proof of its physical and perceptual existence. Instead of Euclid's three dimensions, some constructed a two dimensional system, for instance, such as would be formed by bending a sheet of paper unto some well defined form [a bent plane must of course be in three dimensions]. On such pseudospherical surfaces various axioms (such as parallel lines) were proven false, or different, which previously appeared immutable according to Euclid. The new space—like the inner surface of a sphere—was unlimited (had no beginning and no end) but finite (of certain area). With the admission of certain propositions and axioms the

Euclidean and non-Euclidean geometries validly (logically) existed side by side.

When the non-Euclidean geometries became better understood and more widely disseminated towards the end of the last century it caused noticeable disturbance among natural philosophers: if it was possible to construct a geometry where Euclid's axioms did not all hold, then these axioms could not be transcendental—taken *a priori* as true. And since understanding of physical reality was based on geometrical and similar axioms, and on the logical constructions that deductively followed from them, their mutability cast doubt on the validity of the established conception of the physical world. And yet, to quote Helmholtz:

> Land surveying as well as Architecture, Mechanical Engineering as well as Mathematical Physics, are all constantly computing the most varied spatial relationships according to Euclidean geometrical laws; they expect the success of their experiments and constructions to follow these computations, and there is yet no known case in which they were disappointed, provided they computed with correct and sufficient data.[22]

Elements of Logic teach us that *logically* something may be absolutely *valid* but *in reality* quite *untrue;* there is a fundamental difference between logical validity and real truth. The difference manifests itself in the relationship between conceptual ideas (hypotheses) and perceptual (experimental) data, or between theory and practice. Unless there is a flaw in the logical construction—in the computer— a theory is always valid. Its real truth may only be tested by checking first its premises (input) and then its conclusions (output).

Various logical systems, such as Euclidean and non-Euclidean geometries, may validly coexist simultaneously side by side. [23] In the physical realm such a state of affairs is unacceptable. The premises and presuppositions of one system, say Chemistry or Physics, must coincide with those of all others, such as Physiology or Biology. No two systems that differ in their presuppositions and their conclusions will exist simultaneously for very long. A certain grand order in nature consistent in itself is always tacitly assumed, and it is the business of science to discover it. Understanding nature means feeling in unison with the real external world—it is then less mysterious and threatening, more friendly and predictable.

> The theoretical investigation of the mathematical possibilities above referred to [non-Euclidean geometries], had, primarily, nothing to do with the question whether things really exist which correspond to these possibilities; and we must not hold mathematicians responsible for the

> popular absurdities which their investigations have given rise to. The space of sight and touch is three-dimensional; that no one ever yet doubted. [24]

In the real physical world the premises, the coordinates, and the universal constancy of any entity, cannot be *a priori* assumed without experimental—perceptual—proof, and this proof, for its part, is continually changing by ever increasing number of empirical data acquired by evermore sophisticated tools. A physical system founded on old coordinates or universal constants will not remain true when new data contradict them. In contrast to any number of logical (mathematical) systems that are each consistent, the one physical system -our entire concept of the real world -- must be altered when inconsistency arises, since we cannot admit of the existence of two different worlds for the one man. [25] When the shortest physical distance between two points is x meters for Tom, it must also be so for Dick. If Harry says that according to his system the shortest distance is y meters, then Harry is not a human being equivalent to Tom and Dick— although he may certainly and without any inconsistency at all be a pseudo-spherical non-Euclidean entity who grows shorter and younger as he swiftly moves along and vanishes into his finite but unlimited horizon. [26, 27]

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1.3 TIME

The definition of time has always posed a great many difficulties. Time, according to Aristotle, was in*finite* and therefore could not be de*fined*. 'What, then, is time?' inquired St. Augustine.[1] 'If no one asks me, I know what it is. If I wish to explain it to him who asks me, I do not know.' What is time? In order to define anything it must relate to something else, or the term must be described in other terms, but time seems an entity standing alone and of its own. Kant, for example, believed that time was a purely subjective condition of our intuition—it was axiomatic, transcendental. Intuition means subconscious knowledge, and since all knowledge—all information and cognition—must originate somewhere, intuitive subliminal information must also reside concretely in some form, perhaps in the guanine or the adenine molecule of DNA. That our knowledge of time is derived from some form or shape of molecules has not yet been established.

In the absence of guidelines from this direction, we must seek a meaning for time elsewhere, for if we are to operate with the term time, we need a workable definition, or in the opinion of the mathematician Albert Einstein: "Physicists have been obliged by the facts to bring down from the Olympus of the a priori our concepts of time and space in order to adjust them and put them in a serviceable condition." [2] If anything, a concrete object or an abstract term, is to be used rationally, it must be known and defined. The definition may change as the human intellect evolves, but a provisional definition is useful, and therefore preferable to none.

The predicament that attended a definition is perhaps best illustrated by standard dictionaries. For instance, Webster defined time as 'the measured or measurable period during which an action, process, or condition exists or continues'. This definition, as many similar ones, breaks a cardinal rule of logic which states that a definition must not contain a term equivalent to the term to be defined. What is 'a period'? Webster said: 'a portion of time', 'an interval of time'. Substituting this sentence into his original definition of time we obtain: 'Time is a portion of Time', which makes little sense. Another definition in Webster's states: 'The point or period when something occurs'. The definition of 'when' is given as: 'at what time' or 'at or during which time'. Hence, by substituting: 'Time is a point or period at what time, or during which time, something occurs', which is again obscure. The error illustrated by the dictionary is termed a Circle in the Definition *(circulus in definiendo),* and leads, as all circles do, back to the starting point, with no advancement of knowledge.[3]

Isaac Newton was hesitant to furnish definitions: "I do not define time, space, place, and motion, as being well known to all." [4] But he nevertheless proceeded in order to distinguish between definitions meant for philosophers and those for common folk. Newton's true definition of time was: "Absolute, true, and mathematical time, of itself, and from its own nature, flows equably without relation to anything external, and by another name is called duration." The question is, what did he mean by the term 'flow' and the term 'external' in relation to time? A river flows when its waters change position; what does it mean when time flows? A tree is external to a house; what is external to time? The ambiguity of Newton's definitions did not compromise the further development of his thesis, for the state of knowledge did not then require a more accurate definition. This need became acute only after Henri Becquerel, one morning in Paris in 1896, discovered that the photographic plates in his drawer bleached, [5] a discovery which eventually led to Hiroshima.

Over a century ago it was said:

> "It might appear possible to overcome all the difficulties attending the definition of 'time' by substituting 'the position of the small hand of my watch' for 'time'. And in fact such a definition is satisfactory when we are concerned with defining time exclusively for the place where the watch is located." [6]

This definition regrettably also seems unsatisfactory even for the place in which the watch was located because we have no definition of a 'watch'. A definition cannot be in more obscure language than the term to be defined. If time is the position of the hand of the watch, we must know what determines this position. Looking at the position of mercury in a thermometer provides as little enlightenment concerning thermodynamics and the nature of heat, at the place where the thermometer is located, as looking at a yardstick would provide on the nature of space. Measuring devices presuppose some idea of what is to be measured, or as Voltaire once said, "*l'horloge implique 1'horloger*". No matter how long and arduously we investigate a watch, all we shall find is screws, springs, and spinning wheels, but are not likely to arrive at a definition or understanding of the entity 'time'.

The apparently insurmountable obstacle on the way to forming a definition of time may have been the absence of a clear frame of reference:

clear terms with which to form the definition. What terms may we use to form a valid definition of time? We can only use what we have, and what we have so far is Man in his three-dimensional Euclidean space. We are therefore constrained to define time with these facts, which means, at present, that time is not an independent fact. The first fact, Man, is axiomatic, and the second, space, is a fact of perception. Thus far, no independent perceptual mechanisms meant to sense time are known.

Given at least one-dimensional space the following definition will apply:

Time is the only entity present with one point in different positions.

A point can have no more than one and the same position at the same time. Whenever in space a point occupies two or more positions, time exists; when nothing in space changes position, there is no Time, or, in modern words, time is frozen.

The definition appears valid on the following grounds: 1. It is not circular, it does not contain terms equivalent to the term to be defined. When we dealt with position in space, we noted that any position, and change in position, exists only within a given frame of reference; there is no absolute position. Consequently, time, too, is always referred. The meaning of this relativity is clarified when we retrace our steps to the concept of Man and his three-dimensional space. 2. Our definition is not too wide or too narrow; it deals with a fundamental concept, and its width is proportional to the task. 3. The definition is *per genus* ('a point') *et differentiam* ('in different positions'). 4. It is precise and clear: 'the only entity'. The universe contains, of course, innumerable other entities, but in an attempt to understand any of them we may begin with the smallest common denominators, that is, points in space. 5. It is not formed by negative attributes.

But even if we are perhaps satisfied that this definition of time meets with the criteria of logic, we must not rest here, for time is also a physical entity, and as such must conform to the real physical world. What is the reality of time?

We know that position—and hence also a change in position—is always related to an arbitrary frame of reference, the larger and more stable the latter, the better. Since the dawn of civilization in Babylon the arbitrary frame for time has been the sun—or another large celestial body—to which a change in the earth's position was referred (or vice versa when the Ptolemaic system prevailed). If one day the earth should stop changing its position relative to the sun, there will be no solar time;

all solar clocks (dials) will have stopped, and the solar day will last forever. If the circumference of the earth's orbit should double, the length of the solar year will double. Nowadays time is occasionally reckoned by atomic clocks, the frame of reference being the rate of radioactive decay, which means the change in the position of atomic and nuclear particles. Should the number of positions and their distances suddenly decline to half their original value, the duration of the atomic hour will change commensurately.

While Babylonians reckoned their time relative to the sun, the Israelites set their time relative to the position of the moon. Babylonian and Israeli times—the duration of the month—did not coincide because the positions were incongruous, and any specific position within the calendar, any date, did not occur at 'the same time', or in Greek—they were not synchronous, or in Latin—not simultaneous; Jewish Holidays continually fall on different dates according to any other non-moon calendar.

On earth itself the position of longitude has been set, arbitrarily and by convention, to be that meridian that passes through Greenwich, England, and clocks were synchronized according to Greenwich Mean Time. There is nothing sacred or innately true about this measure of time, but it had to be done if some order was desired, similar to the necessity of choosing an arbitrary unit of length.

A zero time interval on solar clocks exists when the earth ceases its spin and orbital rotation around the sun; zero time on atomic clocks exists when radioactivity stops; total zero time exists when absolutely nothing changes its position. Should all possible positions in the entire universe remain stable, no time whatsoever would elapse; when all electrons cease spinning, and all celestial bodies stand still, time will not be there—the temporal interval will be zero. A man will not grow older in whose body have stopped all atomic and molecular changes which determine metabolic and neuronal activity as long as this state of immobility remains. Life under these circumstances will be frozen.

Time positively exists when any position is changed—it is zero when no position whatsoever changes. Nothing is more immobile than stationary, more fixed than at rest. It follows that 'negative' time is impossible; time flows in only one temporal *direction*.[7, 8] As soon as something moves, time elapses; is it stationary—time is zero. One may theoretically remain frozen at any given age, but sadly one can never grow younger.

The unidirectional flow of time sets a limit to determinism and predictability. Since time is not cyclical, no event is ever the same, just as no human-being is ever the same as any other. The predictive value of scientific laws, on which Laplace placed such great confidence, is somewhat limited on this account. One occasionally reads that in a Newtonian system time was perfectly reversible, or that astronomical time was reversible.[9] This depends on the frame of reference: for instance, in the long run, the sun loses its mass by constant radiation, and the orbits of the planets and earth cannot therefore remain unaltered, thus solar time must change -- the days will be longer but not run backwards.

The question sometimes arises as to the meaning of the term 'the present'. The present moment was said to be between the eternity of the past and the eternity of the future. The next question that must then follow is: what is Eternity? Eternity, according to our definition, is that state in which time does not exist. Since time exists only with change in position, eternity will begin tomorrow if tomorrow all positions in the universe will be stationary. Opponents of Darwin's evolutionary theory argued that it was possible that the world was created yesterday: it was created with everything already in it, including our archives and memories of what we believed has happened 'last year'. There is no way of contradicting them—their logic was valid, but of dubious truth and utility.

Eternity may indeed exist at any moment past or future, unless we assume that time always *flows equably*, which is to say, the *sum total* of all changes in positions in the universe is always constant. As expressed by Newton, the assumption that 'Absolute, true, and mathematical time, of itself, and from its own nature flows equably', implies a general principle of motion, namely, the sum-total of all motions is forever constant, were it not—time would not flow equably, at a uniform rate.

Suppose for the purpose of illustration that in the entire universe only six points exist, six atoms or six stars. Four of them, not on one plane, are stationary relative to one another and form the frame of reference. A fifth point A changes position a distance x referred to the frame. Time is determined by this point A and is supposed to flow equably, i.e. the rate of change in the positions of A is continuous and uniform. Now take a sixth point B, which covers distance y. Since we suppose that A moves uniformly, B's rate cannot change, because if it increased, for instance, the rate of motion of A referred to B necessarily decreases, which cannot be when we assume that the motion of A is uniformly constant and determines the time; the time of B would then have to be decreased, i.e., it dilates, which is incompatible with the assumption that it flows equably. It is, of course, then possible to change the frame of reference and refer time to point B, but then A cannot change its rate if B is assumed to flow uniformly. If there is only one time, and this time flows uniformly, the sum of position changes of A and B must remain constant.

It is not our aim here to go into Dynamics, but when we define Energy as the cause and effect of change in position, it becomes immediately evident that the concept of time flowing equably (the sum total of all motions being constant) leads to the laws of Thermodynamics dealing with the Conservation of Energy, or, the laws of Thermodynamics presuppose uniform flow of time.

One last concept in connection with time which occasionally leads to some ambiguities is termed ‘instant’, or ‘instantaneity’. The talk is often about ‘instant event’ or ‘instant action’. When the implied definition of instant is: “a very short interval of time” then the expressions make sense; when the definition is: ‘at some point in time’, it is false. No matter how swift the event, how fast the motion, it cannot exist without the lapse of time. At a point in time there are no events and no motions—only stationary positions. When a mathematician said “we may subject the axes x,y,z, at t = 0 to any rotation we choose” he may wish to explain how the rotation ensued without the passage of time (t = 0), otherwise his mathematical model of reality will not truly apply.[10]

“The speed of the train at 12 o’clock” is meaningless because at any given point in time the train may only have a position, “it was in Greenwich”. The proper statement would be “the speed of the train between 11 and 12 o’clock”.

To cite another example from Maxwell: “Thus when we say that at a given instant, say one second after a body has begun to fall, its velocity is 980 cm/sec, we mean that if the velocity of a particle were constant and equal to that of the falling body at the given instant, it would describe 980 centimeters in a second.” [11] In fact, however, one second after a body has begun to fall it had no velocity at all—only a position. As the distance and time period of measurement is reduced, the motion approaches a stationary position and becomes more and more uncertain and indeterminate. Maxwell added: “The ideas which are suggested to our minds by considering the motions of a particle are those which Newton made use of in his method of Fluxions.”

Operations of Infinitesimal Calculus aim at ascertaining an expression for velocity, for instance, when the distance covered approaches zero (dx-0). When two positions approach unity, the time needed to go from one to another approaches zero, and commensurately, our knowledge of the velocity tends to zero, or our ignorance tends to infinity. The result may be termed ‘ignorance principle’, or, in deference to common reluctance to admit ignorance, ‘uncertainty principle’.[12] Newton originally invented calculus to help describe planetary kinetics in the large solar system. Applying his method to swift motions of electrons in a molecule may be as difficult, in spatial terms, as locating the position of a room on a map of the solar system.[13]

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