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OBJECTIVE AND HUMAN PHYSICS

The twofold view of nature is as old as theoretical physics. The picture in which nature presents itself to the observer is complicated; but Democritus, the great Greek thinker, had already recognized that this complication is only apparent, and the result of the peculiarities and limitations of the human senses. It was the idea of Democritus that the picture of nature to which true thinking leads must be of much greater simplicity than that which man receives through his senses. The necessary condition for the simplification of physics had therefore to consist in the liberation of physics from all human, from all subjective, points of view.

Democritus also recognized that the objects of the simplest physical events must be much smaller than any object amenable to sense-perception. The exploration of hidden atomic events thus became the essential aim of objective physics.

As soon as the true size of atoms was evaluated by exact methods, the primarily speculative hypothesis became exact scientific knowledge. To-day we can determine the mass of atoms with comparatively greater accuracy than the mass of the earth. Not only through one but through the most varied and independent methods the characteristic constants of atoms can be determined in the most accurate manner; and all these methods, independently of each other, have led to the same values. If it can be regarded as an argument for the existence of our external world that the sensations of sight, hearing and touch all lead us to infer the existence of the same objects, then theoretical physics has certain proof of the real existence of atoms in the fact that their characteristic constants, as obtained by fundamentally different methods, have nevertheless always the same values.

Modern physics, based on the exploration of atomic processes, has revealed to us a picture of nature of great simplicity. It has clearly shown that it is not nature that is complicated, but only the path leading to a knowledge of it, and that this path consists in the gradual transformation of the subjective world-picture into an objective one.

But if the objective picture be the true one, then it should also be possible inversely to construct the subjective human picture from the objective one. We can then raise the question of how, under given powers and limitations of the human senses, nature may reappear in a picture produced by these senses. We can ask how, from such a subjective picture of nature, a physical science can originate and how, out of the objective qualities of nature, the real development of physics, created by man, is to be understood. I shall discuss briefly these questions.

First, let us ask how nature, of which man receives a certain picture through his senses, may be constituted in reality; how it would appear to a spirit, say to an imaginary demon whose perceptive faculty admitted of no restrictions whatever and who could compare sizes and compare times, but for whom words like "large" and "small," "quick" and "slow" would have no meaning at all.

To such a spirit, matter would reveal itself in countless primordial particles of only twofold sorts. Could he isolate some of them and examine their mutual influence, he would find out that primordial particles of the same sort repel each other, whereas those of opposite kinds attract each other. If he were to construct the fundamental mechanical conceptions, such as force and mass, in the same way as is done by man, he would recognize that the particles of one sort have a mass about 1,850 times greater than the particles of the other sort. He might distinguish the particles of greater mass as positive protons from the other sort which he might call negative electrons.

The spirit would perceive aggregates in which positive and negative primordial particles are comparatively close together, but where the positive particles always have a majority. He might call these aggregates nuclei. Furthermore the spirit would find how negative electrons revolve round these nuclei like planets round a central sun. Such a system formed out of a nucleus and revolving negative electrons might be called an atom by the spirit.

He would find that the orbits in an atom can not be arbitrary ones, but only such that a certain magnitude characterizing the motion in the orbit is exactly a whole number multiple of a definite elementary magnitude. Something like the so-called "harmony of the spheres" would reveal itself in the regularities of the orbits described round the nucleus.

The spirit would also recognize that, as a rule, the number of negative primordial particles contained in an atom is either perfectly or with a small difference equal to the number of positive primordial particles. In the first case (the case of perfect equality) it might speak of a neutral, in the second case (the case of imperfect equality) of a charged atom. Among the various species of atoms perceived by the spirit, one type would strike him by its particular simplicity, namely, those atoms in which only a *single* negative primordial particle runs around a single positive primordial particle which represents the nucleus.

The spirit would also find that out of atoms of a single or of several kinds complexes are formed by mutual attraction which often contain two or more atoms. In this case he might call the said complexes molecules. In some cases he would find single atoms which might be called monatomic molecules.

The spirit would recognize as the most frequent state of matter a state in which the molecules are wildly shooting in all directions, causing perpetual collisions between them. Such a state of matter might be designated by him as gaseous. On the other hand, he might speak of a *solid* state if the atoms are arranged in a definite manner so that the internal motion of matter consists in oscillations. Between the two extremes of the gaseous and the solid state intermediate stages will be perceptible.

Moreover the spirit would find that only a vanishingly small fraction of space is really filled with matter; but that, on the other hand, matter is concentrated in formations which contain, at least in order of magnitude, the *same* number of primordial particles, a number between 10^{55} and 10^{59}. Such formations, rising and disappearing, might be called stars by the spirit. He would find that in the stars the internal motion and also the force of collisions are so tremendously violent that any durable formation of molecules and probably also of complete atoms is prevented.

Around the stars the spirit would recognize formations like our earth which consist of a thousandth or a millionth as many primordial particles and in which the motion gradually being retarded is relatively much slower than in the central stars. When, for instance, the spirit considers the processes on earth, he would find that the internal motion is relatively so slow that both the most solidly constructed nuclei and the atoms and, as a rule, even the molecules wholly withstand collisions.

If the spirit considered any position in space for a given instant, he could determine the magnitude and the direction of the force which would be exerted upon a primordial particle should it be there. This force, measured by any scale, might be called the electric field-strength existing at the given position at the given instant. The spirit would find out moreover that the strength of the electric field can vary periodically in its magnitude and direction, as well as in space, namely, from position to position, and in time from instant to instant. If there exists such a double space-time-periodicity, the spirit might speak of electric waves.

He would find space filled with such waves of very different lengths and of very different frequencies. If a wave has a frequency two, four, eight or sixteen times as great as another, the spirit might say that its oscillations lie one, two, three or four octaves higher.

The spirit would also recognize that there exists a close correlation between the electric waves and alterations in the structure of matter. Besides the normal states of atoms and molecules there are possible, as the spirit would find out, also abnormal states in which the grouping of the electrons round the nucleus differs from the usual. Such alterations of configuration either require a supply of energy, or energy becomes available through the alteration. The spirit would perceive that the energy liberated can be transformed into energy of an emitted electric wave. Conversely he would find that the energy supplied can spring from an absorbed wave. But he would recognize that in both cases the frequency of the wave can be considered as an immediate measure for the resulting transformation. This rule might be called by the spirit the frequency-condition.

As the simplest atom, we have previously considered one in which a single negative primordial particle revolves round a single positive primordial particle. If this simplest atom passes from its normal state to an abnormal one, which differs the least from the normal, this transition would appear to the spirit as the simplest among all possible alterations of configuration occurring in the atoms. The frequency corresponding to this simplest transition might be considered by the spirit as a standard frequency. Frequencies which extend to about twelve octaves lower or to about fourteen octaves higher than this standard-frequency are produced by alterations in other atoms or in molecules.

Apart from the attraction and repulsion between the primordial particles, the spirit would find a universal attraction of matter. This attraction which he would recognize to be proportional to the product of masses might be designated by him as gravitation. He would notice that gravitation is vanishingly small when compared with those electrical forces already mentioned. If he considered, for instance, two positive primordial particles and if he calculated the ratio between their mutual force of repulsion and their gravitational force, he would find it to be about 10^{36}.

Gravitation, therefore, can act its part only between enormous accumulations of primordial particles, for gravitational effects of the particles are always added, whereas the electrical effects originating from the primordial particles compensate each other by reason of the *neutrality* of matter.

Only in exceptional cases can electrical forces rising from large bodies become so strong as to be able to move other bodies, which are also composed of countless primordial particles, provided the neutrality be removed in a sufficiently large part of the molecules or atoms. Similar results are produced by certain forces which are exerted upon each other by two revolving electrons on account of their revolutions, and which the spirit might designate as magnetic forces. These forces generally compensate each other, but in some substances the compensation can be so imperfect that the magnetic effect may be revealed by comparatively strong forces between bodies containing countless atoms.

Thus far, I have tried to sketch the objective picture of nature as it would appear to a spirit. From the same nature man receives a subjective picture by means of his senses. To all things he first applies a human standard. His body consists of an enormous number of atoms, about 10^{28}, each of which represents in itself a planetary system. Thus it is not astonishing that man considers as exceedingly small such objects as present themselves to the spirit as complexes of many millions of atoms. The shortest movements executed by the human body appear tremendously long from the standpoint of atomic processes. In the time which man needs even to lift an eyelid, each of the electrons in each of his atoms performs millions and millions of revolutions. In a similar way the electric waves filling space perform millions and millions of oscillations during the lifting of an eyelid.

On the other hand, the duration of man's life appears vanishingly short as compared with some physical processes recognized by our spirit, for whom such words as "long" and "short" do not exist. Much that may appear to the spirit in impetuous evolution, like the stars, may afford to man the deceptive impression of duration and immutability.

As the most important human sense-organ, the spirit would recognize one which reacts upon electric waves belonging to a very narrow region. This region comprises but a single octave and reaches from about three to about two octaves below the standard-frequency I mentioned before. The spirit, however, would find that this human sense-organ which he might call the eye is not sensitive to the electric waves which lie beyond those narrow limits.

The spirit would find in man also a sense-organ through which man can recognize whether the internal motion of matter with which he is in contact is more intensive or less intensive than the internal motion of the matter forming the human body, which motion is nearly constant in its intensity. This human sense might be called the sense of temperature.

By means of his eyes man obviously can perceive or, as we might say, he can see such objects which either emit electric waves or which absorb waves of definite frequencies from the totality of electric waves filling the space, provided (and this is very essential) that the frequencies emitted or absorbed belong to the range of that octave for which human eyes are sensitive. If for such objects the visual angle is not too small, man can perceive them and recognize their size and shape by their boundaries.

On the earth where man lives, matter possesses an internal motion which is relatively so slow that he is surrounded by durable nuclei, atoms and, as a rule, also molecules. Those molecules and atoms which absorb any frequencies belonging to the octave perceptible to the human eye give rise to colored impressions. This happens mostly in the case of solid bodies, but not in the case of the gaseous matter which covers the solid earth as atmosphere and which remains invisible to man owing to the absence of respective absorptions.

Man will differentiate countless substances according to the molecular properties which reveal themselves to him. These substances correspond to the numerous forms in which about twenty frequent varieties of atoms are found combined. Occasionally man perceives the result of a process which would present itself to the spirit as a formation of new molecules caused by the decomposition of other molecules of two or more sorts. Such rearrangements must appear to man, who distinguishes substances according to their molecular properties, as transformations of substances.

On the other hand, the forces acting between the atoms of one and the same substance must also undergo a loosening with increasing intensity of the internal motion. This will become manifest to man by finding that the state of matter depends upon temperature. He will find that bodies which usually have a solid form lose it with increasing temperature and even evaporate under a still higher temperature.

Apart from the bodies found on earth, the stars distributed in the space of the universe will be the object of human perception. Their distances, of course, can not be estimated by an untrained observer. He will put them all into the same indefinite distance. In this way the aspect of a sphere is produced which appears to be covered with stars and might be called by man the firmament.

The velocities of the stars are exceedingly great as compared with terrestrial velocities. Nevertheless, owing to the enormous distances involved, perceptible changes in the apparent configuration of the firmament are not, as a rule, possible during the lifetime of a man. The only exceptions are made by such objects in the firmament as belong, like the earth, to the sun and which might be called by man planets. The changes of their positions in the firmament caused by their proximity must soon awaken the interest of the observer; and in a still higher degree this must be the case with the moon, the companion of the earth.

Thus from the very outset several fields of phenomena become apparent to the careful observer which might be made the objects of scientific research. He first finds plenty of work in two fields in which he can develop an activity, which might be called "cataloguing"—on the one hand by the description of the firmament, on the other hand by the description of the substances amenable to sense-perception and of their properties and changes. Two branches of science which might be called astronomy and chemistry must thus first result from the consideration of the subjective world-picture.

Furthermore, man observes changes of position or motions both on the earth and in the firmament, without at first recognizing a connection between terrestrial and celestial motions. In the case of terrestrial motions he again distinguishes two kinds: on the one hand, so to speak, the forced motions which he produces himself either immediately by means of his arms or indirectly by means of mechanical contrivances invented by him; on the other hand, there are the natural, or ordinary motions which are caused by the gravitational field of the earth and which are chiefly revealed to man in the phenomenon of falling.

Now and then man may also discover motions which are caused by electrical or magnetic forces. These will occur when matter appreciably differs from neutrality or from complete compensation of the electron orbits. These anomalies are, of course, due to special molecular or atomic properties. Therefore, man will ascribe the faculty of putting other bodies into motion, only to substances that appear unique to him.

Another object of the study of nature may be the process of vision itself. The untrained observer of nature can not have any idea what the physical process may be which occurs in the space between the eye and the object perceived. As his conception of nature is thoroughly subjective, he will even assume this process to originate in and from his eye.

But, in any case, it becomes evident that electric waves in the objective sense of this word change the direction of their propagation if they strike upon bodies or pass through them. For under certain circumstances man sees objects in other than their real positions. He discovers a reflection—by closer observation occasionally also a refraction—of the rays which he assumes cause vision. In any case, many problems result from the spatial relations of the three positions: where the eye is, where the object is in reality, and where the object seems to be.

Finally, the sense of temperature must also open up to man a peculiar field of phenomena in which he can make various observations. On the one hand he perceives continuous fluctuations of temperature in nature. On the other hand, he learns artificially to vary the temperature. The changes which are produced in the structure of bodies by changes of temperature may also become subjects of research; and above all man must be interested from the beginning in the processes thus taking place in the atmosphere.

Thus, in the first period, human physics, based on the subjective world-picture, chiefly consists in the recording of the phenomena which nature spontaneously offers to the observer. During this earliest period of physics—I should almost like to say during its prehistoric period—man first recorded the stars perceived by him. According to the accidental apparent proximity in the firmament, which proximity in itself has nothing to do with the real arrangement in space, he classifies the stars in groups or so-called constellations. He pursues the apparent course of sun and moon and the apparent orbits of the planets in the firmament. He recognizes those properties of the various substances found on earth which are amenable to his sense-perception. He pursues the course of the rays which he assumes cause vision. He observes, although at first in a rather superficial manner, the natural and the forced motions; and for practical reasons he occupies himself with the question of how, if he makes use of mechanical contrivances, he can bring about the desired effect with the least expenditure of force. And this question must lead him up to the investigation of the equilibrium of simple machines.

Among these various fields of phenomena, there are two in which numerous physical theorems may be gained from relatively few empirical conceptions, by means of deductive mathematical methods. On the one hand, the comprehension of a single simple case of equilibrium is sufficient for the solution of rather difficult problems of equilibrium by means of geometrical knowledge. On the other hand, the geometrical method also renders possible a study of the complicated problems of reflection of rays, provided a single, simple physical law be discovered in this branch of science.

Thus the earliest phase, the cataloguing phase, of physics is followed by a period in which physics begins its development into an exact science. During this period it still shows a purely mathematical character. The great achievements of the Greeks in statics and catoptrics are characteristic of this early period. Chemistry and the study of heat, on the other hand, remain in their rudimentary phase. In astronomy the study of stars advances, and a geometrical theory, becoming more and more complicated, tries, with increasing accuracy, to describe the apparent orbits of planets.

Thus exact physics in its beginning is but a branch of applied mathematics. But by and by, through the work of physicists, the small amount of existing empirical material will be enlarged. The result of this work must greatly accelerate progress in physics, for new physical knowledge brings about new methods of research.

While in the first period physics remained restricted to passive observation of spontaneously occurring events, now the processes to be investigated are artificially produced by systematic experiments. Thus man becomes not only able to vary at will the essential attendant circumstances and the degree of the processes, but events which must remain hidden to the passively observing individual become amenable to his natural or to his refined instrumental perception. The inductive method is finally combined with the deductive one. The investigator derives from the established facts by mathematical deduction new conceptions which he then verifies by new experiments.

In the period of physics which follows the purely mathematical one, mechanics and optics are chiefly developed. Exact dynamics originates from the investigation of the simplest motions caused by forces, such as from falling. The exploration of this phenomenon delivers the key for the discovery of the fundamental laws of motion. The exploration of the mechanical properties of air which are hidden from immediate sense-perception shows how human perceptive faculty has already grown beyond the limits drawn for human sense-organs.

In optics the study of refraction causes the invention of means which artificially raise the faculty of the human eye to a high degree. Instruments thus invented not only produce previously unsuspected discoveries in various fields of natural science, but also allow a much closer observation of the optical phenomena themselves. Thus gradually the knowledge arises that light constitutes a wave-like process.

The science of heat developed much more slowly than that of mechanics and optics. Because here the establishment of magnitudes which might be exactly measured is much more difficult than in mechanics and optics where all quantitative relations are based upon lengths, angles and times.

In chemistry experimental researches lead to the finding of numerous, previously unknown substantial transformations. Their closer investigation leads to the gradual discovery of the chemical elements which correspond to the varieties of atoms and which reveal themselves as the undecomposable constituents of chemical compounds.

The advancing perfection of experimental methods must finally place in the foreground those phenomena which are the most original and important from the objective point of view, but which play the most subordinate part in the primitive subjective world-picture, namely, electric and magnetic phenomena. That these phenomena may become perceptible, matter must, as I have already mentioned, deviate from its usual neutrality. The physicist gradually contrives means artificially to raise these divergences. Thus he can explore phenomena which the untrained observer perceives only in a weak, occasional and exceptional way. In studying bodies which are built up of countless atoms, he gradually discovers those electric and magnetic laws which are valid in the atoms themselves.

The detailed investigation of phenomena in the various branches of physics must necessarily render physics more and more objective. Such a liberation from subjective human points of view is first to be expected in astronomy. An ingenious thinker discovered that the most complicated planetary motions appear very simple if astronomy gives up her subjective geocentric point of view. In the same way, a great physicist arrived at the discovery that the motions of planets and their satellites represent the same phenomenon as the motions of falling, daily perceived by man on earth.

The identity existing between the internal motion of matter and visible motions must likewise reveal itself to the physicist. It becomes manifest by the fact that in the production of heat by mechanical work as well as in the converse process a constant ratio is found to exist between the quantities of heat and mechanical energy mutually converted. Thus the theoretical physicist is led to recognize that the phenomena of heat consist only in invisible and hidden motions. He also finds how by this assumption many perceptible properties of gases can be simply explained.

That physics becomes more and more objective also becomes manifest in the investigation of electric waves (in the objective sense of this word). In the investigation of these waves man advances more and more beyond the boundaries which at first are drawn by the limitations of vision. Already the untrained observer perceives not only those electric waves of a single octave which appear to his eye as light, but also electric waves of a much greater wave-length which he feels as heat-rays through his temperature sense. The identity of light and heat-rays must become manifest to advancing science. On the other hand, chemical effects discovered with usual light render possible an investigation of waves shorter than those of visible light. Thus physics advances in both directions beyond the limits of the visible spectrum.

Finally the physicist becomes able to produce oscillations and waves by contrivances used by him in the experimental study of electricity, and he finds that these electric waves artificially produced show the same properties as he has long since known of the much shorter waves which he perceives as light. Thus the electric nature of light reveals itself to man. As he found the science of heat to be a branch of mechanics, he now recognizes optics to be a branch of the science of electricity.

The great advances made in all branches of physics must finally open up to the investigator an insight into the world of atoms. The real existence of atoms first reveals itself to man in chemical laws which must be interpreted by the assumption that the smallest particles of chemical compounds are built up of atoms of elements. Still more clearly the atomic structure and electric nature of matter manifest themselves in such chemical changes as are due to electric currents. Finally a system of elements can be established, and in it such similarities between chemical elements appear which, in reality, are caused by similar arrangements of electrons in atoms.

In the science of heat the hypothesis of hidden motions in itself leads to a molecular conception of matter. And the deeper understanding of the laws discovered in thermodynamics makes them appear as results of molecular statistics.

In the science of electricity, the perfection of experimental methods must lead to the finding of processes in which electrons or parts of atoms constitute a perceptible radiation; and thus their closer investigation leads to the discovery of the primordial particles themselves. On the other hand, greatly refined methods of observation make it possible to perceive the consequences of rather rare events, that is occasional disintegrations of nuclei. Also from these phenomena, known as phenomena of radio-activity, important conclusions can be drawn in regard to the building stones of matter.

The most valuable empirical material for the investigation of atoms is, however, offered by the phenomena of the line-spectra. By means of the frequency-condition previously mentioned, theoretical physicists learn to understand the language of the spectra which reveal to man the internal structure of atoms.

Thus physics has arrived at its present state and at its present knowledge which I took the liberty of symbolizing in the spirit. To believe that physics has already reached perfection would, of course, be a dangerous illusion. But perhaps the physicists of to-day may have a similar conception of the state of physics as geographers may have of the state of their science.

Geographers know that to-day there are no more continents and seas to be discovered. They, however, have no doubt that in their science fundamental problems are unsolved as yet and still may occupy scholars through centuries. The state of physics, the world-picture and evolution of which I have tried to sketch, may perhaps be similar.

Arthur Haas

Vienna

LOUIS AGASSIZ FUERTES

As already noted in Science, Louis Agassiz Fuertes was suddenly killed at Unadilla, New York, August 22, when the automobile he was driving was struck by a moving train. In the many printed notices which appeared immediately after his passing, superlatives have been used freely and justifiably. "Foremost American painter of birds," says one; "Cornell's best beloved alumnus," says another; and all testify to the extraordinary personal popularity which he enjoyed.

He was indeed a unique character, the like of which is scarcely produced except in America. He was born at Ithaca on February 7, 1874. His father, Estevan Antonio Fuertes, one time dean of civil engineering at Cornell, was a man of outstanding character and ability. This father, whom Cornell students used to call "The Mogue," was of Spanish lineage, born in Porto Rico, but completing his education in New York. The mother, Mary Stone Perry Fuertes, now surviving at an advanced age, is a fine American type of English, Dutch and Huguenot ancestry. The remarkable combination of qualities developed by Louis Fuertes doubtless owed much to this parentage.

His especial professional godfathers were Abbott Thayer and Elliott Coues with whom he had close association for which he never ceased to make loyal acknowledgment. As a boy, his passion for the beautiful in nature had fairly free rein and his early drawings of birds were made practically without suggestion or guidance from others. However, neither he nor his parents thought seriously of ornithology or painting in any practical way, and his father expected him to enter the engineering or architectural profession. This idea was overcome to some extent through the influence of Liberty H. Bailey, and shortly before Louis graduated from Cornell in 1897 a fortunate coincidence led him to send a few samples of his bird paintings to Elliott Coues for criticism. The enthusiastic reply received from the great ornithologist was fulsome beyond his hopes. He was electrified with joy, and from that moment was never in doubt as to his purpose in life. Coues literally took him under his wing, hailed him as a new and better Audubon, and introduced him to the ornithological world in such a way that contracts to illustrate several books were soon in his hands.

He began at once to portray bird life in a way that appealed alike to the artist and to the ornithologist. At this time the long era of woodcuts and expensive lithographs was just passing. General interest in outdoor life and especially in birds in this country was awakening and the demand for good books of nature was growing. To say that Fuertes arrived opportunely to take advantage of the period does him injustice, for his influence was very powerful in stimulating and supporting the movement and but for him it would have been delayed or curtailed. Other artists and good ones came into the field, but it was Fuertes who set the standard, who inspired the ideal of all, and by abundant production spread broadcast the charm and beauty of birds, not merely in accuracy of line and color, but in the expression of subtle intangible qualities approaching spirituality. In effect the word went about that birds had souls and that Fuertes could see and transcribe them.

For thirty years his activity and industry were phenomenal. He illustrated book after book, sometimes with only a frontispiece or a few plates, but usually with a whole series covering all the species known from a wide area. A large percentage of the more important bird books published in America during this period contain pictures by Fuertes. One of the most important was the series of large plates in full color for Eaton's "Birds of New York" (1910), covering practically every species of eastern North America. At the time of his death he was under contract with the State of Massachusetts for a similar and even better set of plates, one volume of which had been finished and issued. He also furnished plates for various ornithological journals, for museum publications, for the National Geographic and other magazines, and for the widely distributed pamphlets and reports of the federal government. In all this, he was often under pressure, but his standard was high and the average quality of his production was never far from it. The demand for mere illustrations, however, prevented him from giving his talent the widest range. Had he lived, it was his well-determined intention to finish his contracts, to take no more which savored in the least of pot boiling, and to devote an entire year to untrammeled self-expression or, in his own words, "to paint whatever I want to paint, whether I can sell it or not"—not merely birds, but pictures, pictures with birds in them.

He had, in fact, painted such pictures before, but