feature of regularity it is that confers momentum upon them; their motion does not constitute heat, and is not to be considered as temperature; they are moving like a wind, rather than with the irregular unorganized motion appropriate, and solely appropriate, to the terms "heat" and "temperature," and to the ordinary kinetic theory of gases. Crookes indeed hazarded the surmise, by one of those flashes of intuition which are sometimes vouchsafed to a discoverer but are often jeered at by orthodox science at the time, that he had obtained matter in "a fourth state," and also that he had got in his tube something equivalent to what was contemplated in the "corpuscular" theory of light. There is something to be said for even this last mode of statement, when the particles are moving quickly enough; but how true the first was—that the matter in the dark space was in a fourth state, neither solid nor liquid nor gaseous—how true that was we shall presently see.

Meanwhile let us summarize the evidence with the view that the cathode rays are at any rate charged particles of some kind in extremely rapid motion. That they are in motion must be granted from the facts of their bombardment—driving mills, heating platinum, and the like; and in order to show that they are charged, the most direct plan is to catch them in a hollow vessel connected with an electroscope, as Perrin did; but another plan is to show that they have the properties of an electric current. If they are charged while in motion they constitute a current on Maxwell's theory, and therefore should be able either to deflect a magnet or to be deflected by it; and here comes one of the most simple and important experiments in physics at the present time. A definite form of old experiments by Goldstein and many other vacuum tube observers was arranged by Crookes in 1879, when he made the track of the rays visibly luminous by passing a selection of them through a slit and letting them graze along the surface of a film of mica covered with phosphorescent powder, and when he then brought near them a common horseshoe magnet. When this is done the track of the rays is at once seen to be curved; showing that it is not a beam of light we are looking at, but a torrent of charged particles behaving like an electric current and deflected by a magnet. It is really the same phenomenon as can be observed with difficulty when a current flows through metals, which was discovered by E. H. Hall, and known as the Hall effect.

The fact that the particles are thrown off the cathode, being evidently vigorously repelled by it, is sufficient to suggest that they must be negatively charged; the direction of the curvature caused by a magnetic field enables us to verify at once that the flying particles are negatively charged, and no comparable rush of positive particles in the opposite direction or in any direction has been observed. In that respect evidently the magnetic curvature of cathode rays in gases differs from the magnetic curvature of a current in metals, viz., that whereas in metals it is sometimes the negative and sometimes the positive current which is acted upon, according to the nature of the metal, and is always small, in gases it is the negative alone that appears to be acted upon and the action is always large. It seems, therefore, that for some reason or other the negatively charged bodies in a vacuum tube are much more mobile than the positive, and that the mobility of the negatively charged bodies is extreme. One striking method by which their mobility was displayed consisted in the observation by Prof. Schuster that all parts of gas in a closed vessel became conducting when an electric discharge had taken place in one corner of it, so that even though the vessel consisted of different compartments, one compartment was made feebly conducting by a discharge in the other, provided that the two had any kind of gaseous communication, a fact which looked as if some extremely mobile particles, probably the negatively charged particles of cathode rays, could wander about to a considerable distance in a very short time and take their share in the conveyance of an electric current. The conductivity of gases appeared to be, indeed, entirely due to these loose or dissociated or detached charged particles, and where they were absent the gas did not conduct at all; it could be broken down, being a weak dielectric, by a sufficiently strong force, but it would not leak; whereas, when these loose charged particles were about, it leaked readily, becoming to all intents and purposes an electrolyte amenable to the feeblest electric influence. And the act of breaking down the air by an electric discharge was found to render the surrounding air for a time thus electrolytic. Its electrolytic quality, however, did not last long. The mobility of the particles which enabled them to travel to a considerable distance also enabled them to get rid of themselves by clinging to the sides of the vessel, or perhaps by re-uniting to some opposite but comparatively immobile positive charges, which after some time in their rapid journeys, they must casually encounter. Mr. Townsend,* however, found that the conducting power lasted unexpectedly long if no dust was present; the dust particles evidently acting as intermedial receivers and stores of charge, promoting interchanges, which otherwise might be delayed from accidental non-collision. And the time that thus elapsed before the whole of the conductivity disappeared from dust-free air suggested that the moving particles must be very small, so that collisions were comparatively infrequent.

The mobility or diffusiveness of a gas depends on its mean free path, and that depends on its atomic size; the smaller it is, the more readily can it escape collision. Hence it is the collisions are so rare in astronomy; the bodies are small compared with the spaces between them. The behavior of charged particles seemed to indicate that they must in some cases be something smaller than atoms. It seemed hardly likely that material atoms could behave in the way they did, so it was recollected that it had occurred to some philosophers, among them Dr. Johnstone Stoney, that electric charges really existed on an atom in concentrated form acting as satellites to it; so on that view it was just possible that these flying particles might be not charged atoms at all, but charges without the atoms, the concentrated charges detached, knocked off, as it were, in the violence of the discharge and afterward going about free; traveling at an immense pace because they would still be liable to the full electric force that they had experienced before, and yet would have shaken off the incumbrance of the material atom with which they had been associated. It is true that no such disembodied charges or electric ghosts had ever been observed. All the experiments that had been made in electrostatics had been made on charged matter, the surface or boundary of the matter acting as the locality for an electric charge. The facts of electrolysis had suggested or proved that the atoms themselves could carry charges, and hence that if a liquid were electrified, what was really happening was that a number of the atoms on its surface turned their similarly charged poles outward; and the same might, for all we know, be true for metals also, and thus every charge seemed associated with matter.

Yet at the same time the occurrences at an electrode, where an ion gave up its charge and escaped without it, indicated the *possibility* that perhaps the electric charge could exist alone, at any rate that it could be handed from one atom to another, and thus might conceivably exist alone for an instant. During this momentary isolation some might, in the freedom of a rarefied gas discharge, possibly escape, and wander about free.

To such hypothetical isolated charges, the unit charge or charge of a monad atom, the name "electron" has been given, and when I speak of an electron I mean to signify the at present purely hypothetical isolated electric charge. Whereas by the term "ion" I always signify the atom and its charge together.

Now, if the flying particles which constitute the cathode rays were electrons rather than ions, if they were detached charges, leaving the atoms behind them (probably leaving the atoms from which they were detached positively charged), their extreme mobility and diffusiveness and high speed would be perfectly natural; and although they would not be matter in the ordinary sense, yet no difficulty need be felt at their possessing some of the properties of matter, at any rate such properties as appertain to matter by reason of its having inertia, because, as we have seen, an electric charge itself does possess a certain kind of imitation inertia. Hence these electrons in movement would possess momentum, and might therefore propel windmills; they would possess kinetic energy, and therefore might heat a piece of platinum; and if suddenly stopped by a massive target when traveling at a high speed they might readily give rise to phosphorescent appearances, and even to the sudden pulse of radiation known as X-rays. But the existence of this last property ought to be capable of clear deduction on electrical principles if the matter is further gone into.

INCREASE OF INERTIA DUE TO VERY RAPID MOTION.

But now rises the question whether the distribution of charge on a charged body, together with its lines of force, will remain constant and unaltered while the body is rapidly moving; because if the distribution of lines of force is altered, then perhaps the inertia due to their lateral motion may be altered too.

Thus, for instance, imagine that the lines of force of a body in motion became more concentrated toward the axis or line of motion; the effect would be at once to diminish the lateral component of their motion, therefore to diminish the magnetic force which that lateral component causes, and thus to diminish the apparent or electromagnetic inertia of the moving charge.

On the other hand, if the lines opened out and became concentrated toward the equator, or plane normal to the line of movement, then a greater component of their motion would be of a kind suitable to excite a magnetic field; moreover, since both the fields would by this concentration increase in intensity, the whole transmission of energy would be greater, and the inertia would apparently increase.

Thus, then, it may be possible that electric inertia may depend in some fashion on speed, a thing unknown in ordinary mechanics. I do not say that such dependence must be *untrue* in ordinary mechanics, on the contrary, I feel reasonably sanguine that it will be found true for matter moving sufficiently fast, and that it may even have a practical influence on some exceptionally rapid movements in astronomy. But however this may be, there is no doubt that theory points to an increase of electromagnetic inertia at excessively high speeds, and Mr. Heaviside has calculated its amount.

It will be observed that when a charge moves, it generates circular magnetic lines of force. Now these magnetic lines are not stationary, but are themselves moving at the same rate as the body, hence they generate fresh electrostatic lines, i. e., cause an electric displacement away from the axis, which displacement is superposed upon the original radial displacement (away from or toward the center) due to the charge.

At ordinary, at even violent speeds, this second order electric effect is insignificant, but it is there all the time, and must not be ignored when the speed becomes extravagantly high. It rapidly rises into prominence when the speed approaches the velocity of light, but at any speed much smaller than this such a second order effect is vanishingly small.

Its effect will be therefore to alter the distribution of the charge, making it move away from the poles and concentrate toward the equator of the charged sphere, when the speed is very great; ultimately becoming wholly concentrated upon the equator, all the rest of the sphere being denuded, when the speed attains that of light. And the electric lines of force will then be opened out into a fan or equatorial plane, like the spokes of a wheel which is rushing furiously along an elongated axle, the circumference of the wheel representing the direction of the magnetic field.

The magnetic force due to motion can be shown to depend on the ratio of the speed of the motion to the velocity of light, u/v. The secondary electrostatic force due to the motion of this magnetic field likewise depends on the same ratio. Hence the second order disturbance of the original uniform electrostatic field will be of the order u^2/v^2; and whenever we can afford to neglect quantities of this order, the distribution and therefore the inertia of the moving charge continue practically constant.

But when its speed of motion begins to approach the velocity of light, say even no more than one-tenth of that speed, then a perceptible disturbance is to be expected, and something like a 1 per cent increase of inertia must occur.

The complete investigation makes the inertia infinite when the speed reaches that of light, but there is probably no need to press this to extremes, unless the charge were an absolute point; clearly, however, the inertia will then be very great, and possibly therefore it may always be impossible to make matter, or at least charged matter, move with a speed greater than that of light. There may be ways out of this, however, just as it is possible for a bullet to move through air with a velocity greater than that of sound. This is managed by the violent adiabatic condensation of the air in front of such a bullet, the effect being to raise the appropriate velocity of sound to the required value. If there is any way out of it in the case of the ether, however, it is not likely to be *this* way.

It has been shown both by Mr. Heaviside and by Prof. J. J. Thomson that if the speed of motion is ever greater than that of light, the fan or radial plane of lines of force bends backward and becomes a conical surface, gradually closing up as the speed increases; an effect singularly reminiscent of the conical pulse traveling with a sufficiently rapid bullet, and demonstrated in Mr. Boys' bullet photographs.

No known speed which can be conferred upon matter is sufficient to bring this latter effect into prominence. The quickest available carriage is the earth in its journey round the sun, 19 miles a second, or 60 times faster than a cannon-ball; but the earth's velocity is only the 1-10000 of the speed of light, and consequently any spurious inertia due to its orbital motion is only 1 part in a hundred million; and even the accuracy of astronomy could not display any effect of that order of magnitude.

There are stars which move 200 miles a second, but even these have only one-tenth per cent of the speed of light, and the excess inertia will be only 1 part in a million. The only known place where charges or charged matter move at speeds greater than this is in a vacuum tube. There the cathode-propelled particles are flying 20,000 miles a second or one-tenth the speed of light, and they may have 1 per cent excess inertia; or more if they can be persuaded to go still faster.

The substance of the above digression on the effect of rapid motion was written in connection with the Liverpool meeting of the British Association in 1896, and was communicated orally and very briefly to Section A in a discussion on the mechanism of the production of X-rays; for I then thought that unless great speeds, sufficient to disturb the static field, were reached by the cathode particles, they would not serve as efficient producers of the rays when suddenly stopped; but the matter has been gone into more fully now, and not only Mr. Heaviside's Vol. I. of "Electromagnetic Theory," p. 57, may be referred to, where the circumstances of sudden stoppage of a charged body moving with the speed of light are illustrated, but also a paper by J. J. Thomson in the Philosophical Magazine for February, 1898, dealing powerfully with the more general problem.

(To be continued.)

CONTEMPORARY ELECTRICAL SCIENCE.*

OSCILLATORY CONDENSER DISCHARGE.—Braun's application of oscillatory condenser discharges to wireless telegraphy has made it very desirable to have a convenient method of determining the period of rapid oscillations of wave-lengths varying from 10 to 100 meters. P. Drude has devised a resonance method which is more accurate than that indicated by Braun and elaborated by Mandelstamm. For short waves, of lengths less than 12 meters, the primary condenser circuit whose period is to be determined excites a secondary circuit consisting of two accurately parallel copper wires, 1 mm. thick, joined permanently at one end, while at the other a metallic yoke can be displaced along the wires until accurate resonance is obtained, as indicated by a maximum luminosity of a vacuum tube laid in the center between both ends. Then the wave-length equals the total length of the secondary circuit plus the length of the yoke plus 3 cm., due to the capacity of the luminous tube. For longer waves, the author uses a parallel circuit 2 meters long, which at one end contains a condenser consisting of two circular plates, whose distance can be finely regulated and accurately determined. The wires are bridged by a movable yoke, and maximum resonance is tested by a vacuum tube applied to one condenser plate.—P. Drude, Ann. der Physik, No. 11, 1902.

DYNAMICS OF THE ELECTRON.—M. Abraham has formulated a dynamical theory of the electron as a basis of an electromagnetic system of dynamics, suggested by Kaufmann's proof that the mass of the electron is purely apparent, and due to electromagnetic inertia. He starts from the supposition that the electron, such as we see it in free motion in the cathode or Becquerel rays, is a sphere of radius 10^{13} cm., in the volume of which the electric "charge"—whatever that may be—is equally distributed. The "electricity" is to be attached to the volume elements of the electron just as ordinary matter is attached to volume elements of a rigid body. The whole dynamics of the electron are based upon a fundamental kinematical equation, the Maxwell-Lorentz field equations, and a fundamental dynamical equation which implies that the resultants of the inner and outer forces and couples vanish. The main differences between these dynamics and ordinary dynamics are that the electromagnetic dynamics are valid for velocities nearly as high as the velocity of light,

* Mr. Townsend, of Trinity College, Dublin, then working in the Cavendish Laboratory, Cambridge, now Waynflete Professor of Physics in the University of Oxford.

* Compiled by E. E. Fournier d'Albe in the Electrician.

whereas ordinary dynamics apply only to small velocities. The author works with a three-dimensional space, an atomic structure of electricity, and a continuous ether. He combines the mechanical equations of Lagrange, and more especially Hamilton's principle, with the Maxwell-Hertz differential equations.—M. Abraham, Physikal. Zeitschr., October 10, 1902.

THE ARCHITECTURAL REFINEMENTS OF ST. MARK'S AT VENICE.*

THE subject of architectural refinements is an unusual one and is of great interest, and is attracting wide attention especially abroad, and through the courtesy of Mr. William H. Goodyear, Curator of Fine Arts, Brooklyn Institute Museum, and its Trustees, we are enabled to present to our readers an abstract of some of the latest discoveries.

The preliminary contributions to the subject of medieval refinements by Ruskin and Viollet-le-Duc were so slight, in comparison to his own, that he may claim the distinction of being the pioneer in an otherwise untrodden field. In fact, the conception that architectural refinements were practised in the middle ages may be said to have originated in his investigations.

Hitherto, that is, before 1870, when Mr. Goodyear's investigations began, the use of architectural refinements was supposed to have been limited to the temples of the ancient Greeks. Even in their case the earliest discoveries of modern students were as recent as 1837, and the earliest publications of definite measurements were as recent as 1851. The architect who made and published these measurements, Mr. Francis Cranmer Penrose, was disposed to consider the Greek refinements as having had for their purpose mainly the correction of optical illusions, and this was notably the case as regards the now famous horizontal curves. The prejudice of modern temperament and of modern architects in favor of mathematically correct and rectilinear building eagerly seized on the proposition of Penrose that the Greek curves were intended to make the curved lines look optically straight and rectilinear. This theory was that the horizontal lines were curved upward to prevent them from appearing to curve downward. It is true that Penrose also suggests that an æsthetic and artistic preference for these delicate curves may have inspired the Greek builders, but this suggestion has received little attention from classroom and professional disseminators of his observations in England and America. The French and German authorities have generally laid more stress on the æsthetic significance of the curves, but since the measurements and observations which they quoted were taken from Penrose, their suggestions have not attracted such wide attention as his own.

On the other hand, Mr. Goodyear's studies have had the great importance of calling attention, within the limits of ancient architecture, to an otherwise neglected class of curves, viz., the curves in plan, as distinct from curves in elevation (rising curves), to which latter class the observations of Penrose had been confined. Mr. Goodyear was the first to point out that the curves in plan at Medinet Habou (which were discovered by Pennethorne in 1833, but not made known until 1878) had not been considered or even mentioned by any accepted theory on the optical effects or possible purpose of the Greek curves, and it is palpable that they bring a new element into the problem of purpose. By Mr. Goodyear's discovery that the lines of the entablature under the gables of the Temple of Concord at Agrigentum are not curved at all, whereas the entablatures of the flanks show the usual curves,* he probably gave the *coup de grace* to the proposition of Penrose that the purpose of the Greek curves originated in the idea of correcting the optical effect of sagging produced by a gable. But it is above all by the discovery of constructive horizontal curves in Italian medieval architecture, under conditions wholly different from those holding in Greek temples, that Mr. Goodyear has probably forced the world of archæology to an ultimate revision of the theories of Penrose.

* The Architectural Refinements of St. Mark's at Venice. With remarks on other Churches Showing a Similar System of Leaning Verticals; especially those in Orvieto, Vicenza, Milan, Pavia, Bologna, and Arezzo, and including the Renaissance Church of S. Giorgio Maggiore at Venice. By William Henry Goodyear. Published for the Brooklyn Institute of Arts and Science by the Macmillan Company.

We thus begin our account of the observations of medieval Italian buildings with the remark that they also react on the theories which have been so largely held by the students of classic architecture. These observations necessarily tend to accent that contention which has been so happily developed by the Sturgis Dictionary of Architecture, viz., that architectural refinements represent a repugnance to formalism, rigidity, and coldness of architectural effect. This formalism is confessedly the most striking and the most objectionable characteristic of modern work; which has been hitherto dominated by the ideal of mathematically accurate symmetry and by the methods of geometrical design.

The discoveries in Italian medieval architecture may thus be considered from several points of view. From a practical point of view they tend to suggest reform of a notorious deficiency in modern building. From a historical point of view they throw new light on the much underrated capacities of medieval artists and builders, and they also suggest the existence, in certain localities, of an unbroken continuity of tradition between the middle ages and classic antiquity, probably through the medium of Byzantine art.

† Journal of the Archæological Inst of America, VI., 2, p. 174.

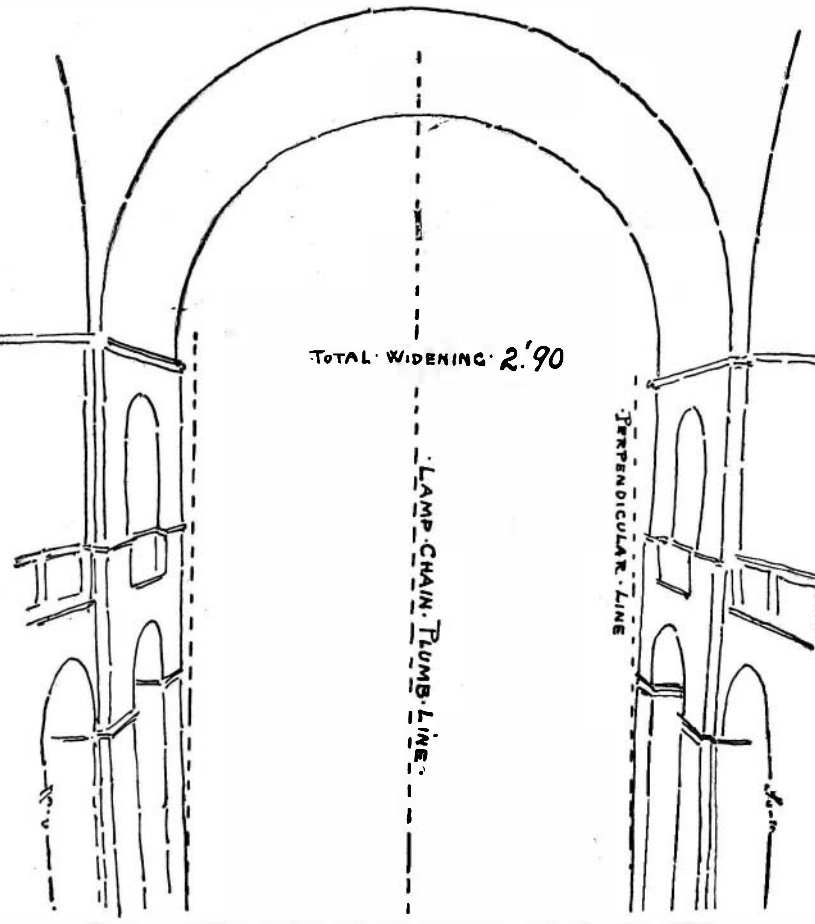

FIG. 2.—WIDENING OF THE NAVE IN ST. MARK'S.

Tracing from the photographic original of Fig. 1. Compare Fig. 3.

FIG. 1.—WIDENING OF THE NAVE IN ST. MARK'S, VENICE.

The nave in parallel perspective; from a Brooklyn Institute Survey photograph of 1895. The widening amounts to 2 feet 10½ inches at the transepts. Compare Figs. 2 and 3.

Not the least interesting result of these observations is the point that they indicate considerable obtuseness in that modern taste, which has so long and so strangely ignored the facts which may be fairly said to be open to expert observation in many famous churches.

The most extensive summary of the general results of these investigations which has ever been published appeared in L'Arte, the most important of the Italian art journals, vol. III., for 1900, p. 137, and was written by Antonio Taramelli, who declares that the publications in the Architectural Record Magazine are an "opera magistrale" (a master-work) and that their author ranks among the first of his nation as an authority on the architecture of Western Europe.

As coming from an Italian writer in the leading art journal of Italy, we shall quote the following list of the various phases of architectural refinements in Italian medieval buildings which have been announced by Mr. Goodyear:

(a) In many medieval churches, the piers which support the vaulting exhibit delicate curves in the vertical lines which are not caused by thrust; important examples are the piers at the transept crossing in the Pisa cathedral and the piers of the cathedral of Vicenza. (b) The survival of the classic entasis in medieval columns; examples at Fiesole and on the exterior of S. Michele at Lucca. (c) An outward inclination of piers or walls of churches not due to thrust, and giving a widening effect to the upper portion of the church; examples in the cathedral of Trani; in S. Eustorgio and S. Ambrogio, Milan; in S. Maria della Pieve, Arezzo; and in S. Mark's at Venice. Several other cases have been published. (d) Forward bends or leans in façades of churches, such as are seen in the cathedrals of Pisa. Pavia, Ferrara, and in the churches of S. Ambrogio at Milan and S. Ambrogio at Genoa. (e) Curves of horizontal lines, some of which are as delicate as those of classic antiquity; examples at Fiesole, Trani, Venice, Pisa, Genoa, Ravenna (S. Apollinare Nuovo) etc., cloisters at Bologna, Verona, etc. (f) A gradual diminution in the height or width of interior arches in the direction of the choir, giving an illusive effect of greater dimension; examples in the cathedrals of Pisa and Fiesole and in Santa Maria Novella at Florence. Some twenty cases have been quoted or published in detail. (g) Lowering the height of the second arch at the crossing of nave and transept; giving an illusive effect of greater dimension; examples at Piacenza, Siena, Pisa, and Florence (S. Maria Novella). (h) An upward slope of the pavement in the direction from entrance to choir; examples in the churches of S. Maria Ara Cœli at Rome; Capella Palatina at Palermo; cathedrals of Siena and Orvieto, etc. Over eighty cases have been noted. (i) Convergence of outer walls and of supports of the nave in the direction from façade to choir; examples in S. Stefano at Venice and S. Giorgio in Velabro at Rome. (j) Some thirty churches offer examples of oblique plans which cannot be explained as representing the bending of the head of Christ on the cross. (k) Numerous other phases of asymmetry, or "symmetrophobia," which cannot be attributed to carelessness or to the use of heterogeneous building materials, and falling under the general explanation of a disposition to avoid formalism and coldness of effect. The proofs recently published of constructive purpose in the Leaning Tower of Pisa belong to this class of observations.*

The entire number of churches in which well-

* Journal Archæological Institute of America, VI. 2, p. 190.