the area of the hysteretic loop when the iron was not subject to vibration. Hysteretic loss could not perhaps be considered the proper term to apply to the loss in iron under these conditions. The general term "energy loss in iron," as used in the second part of the Paper, might be more applicable. He had made no statement with reference to the nature of any magnetic phenomena that would carry the discussion to a speculative field, involving theories as to intermolecular actions. It was his intention to make a definite statement of the results obtained by measurements, the accuracy of which had been amply and repeatedly confirmed. Mr. Parshall.

Correspondence.

Mr. PHILIP DAWSON thought it was owing to the use of cast steel in the construction of railway-motors that efficiency, durability, and large output had been combined with comparatively light weight. In supplying the great demand in America for railway- and tramway motors and generators during the past few years, the knowledge of the materials available in their manufacture had made it possible to produce them so that their magnetic as well as their electrical powers were interchangeable, a point of the greatest importance. The large 2,000-HP. direct-coupled railway generators, a number of which had been now successfully running for over three years, introduced by Mr. Parshall as designing engineer of the General Electric Company of America, demonstrated the value of his careful study of the subject-matter of the Paper. These generators were all erected and tested in their final position, and the results obtained were practically identical with those calculated. In several parts of the apparatus inductions as high as 20,000 C.G.S. lines per square centimetre were used. It could not but be of great importance to know accurately the influence of the various chemical ingredients when it was a question of producing machines which with identical windings would give identical results and work harmoniously. Mr. Dawson.

Dr. H. DU BOIS, of Berlin, remarked that the important and valuable data given by the Authors, together with those obtained by Dr. E. Taylor Jones and himself, gave a tolerably full indication of the high position the iron and steel industry had in a few years attained in this respect on the Continent as well as in the United Kingdom. It would seem as if producers had clearly differentiated the two materials—high-permeability metal for dynamos, low-hysteresis metal for transformers—so as Dr. du Bois.

Dr. du Bois. to meet the particular requirements of users in both branches. The former was also to be used for all kinds of "stationary" electro-magnets. Some applications, though of less commercial importance, however, remained in which both qualities were necessary; for example, yokes for experimental work, shells for iron-clad galvanometers, in which he was especially interested. He had tested his material from both points of view, his magnetic balance (described by Professor Ewing on p. 197, *ante*) being used up to fields of a few hundred C.G.S. For strong fields he had applied the well-known isthmus method. A few of the data were given in the following Table:—

H.	B. Krupp.	B. Swedish.
5	10,600	12,550
10	13,200	14,300
15	14,150	15,000
20	14,650	15,400
30	15,450	16,000
40	16,000	16,450
50	16,350	16,650
100	17,450	17,550
5,000	25,250	27,500
10,000	31,900	32,900
15,000	37,200	38,200
H_c	= 1·8	0·8
U	= 12·4	6·6

As usual, H stood for magnetic force, B for induction, H_c for coercive force (all in C.G.S. units), U for hysteretically dissipated energy in kilo-ergs per cycle per cubic centimetre. U and H_c referred to the maximum loop, the cycle being taken between such limits that their increase would no more materially affect the size of the loops. The column headed "Krupp" referred to this firm's "Dynamo-Stahlfaçonguss," and was identical with "VI" in the Table on p. 210 of Professor Ewing's Paper. He had adduced these figures to show their surprising concordance (almost within 1 per cent.) with Professor Ewing's obtained with a ring. It might be concluded that the homogeneity of the cast material on the one hand, and the accuracy of the measuring devices on the other, were satisfactory. In the Reichsanstalt very nearly the same curves for this cast steel had been obtained by the bar-and-yoke method (p. 198, *ante*). This homogeneity and consequent uniformity of results afforded a striking contrast to the great differences observable (even in one piece) of non-cast material. The figures in the column headed "Swedish" related to the best Swedish rolled iron obtainable. They remained below the "pure iron" of the Elswick works (I, p. 210); the coercive force and hysteresis was, however, remarkably small. In this connection Dr. Ebeling, of the Reichsanstalt, had found a coercive force of only 1·2 C.G.S. for a specimen of cast steel annealed in a porcelain furnace with the utmost precautions.[1] On the other hand, the "hardest tungsten steel" showed a coercive force of 72 C.G.S., and dissipated 265 kilo-ergs per cycle per cubic centimetre. Dr. du Bois.

Mr. F. OSMOND regarded the Authors' work of as great importance to the metallurgists as to the electricians. The magnetic constants of a given metal not only concerned the engineer who employed the metal for the construction of dynamo machines and transformers; they were, up to a certain point, characteristic of the chemical composition, of the thermal or mechanical treatment, and in the end of the mechanical properties. Unhappily physics and metallurgy had too long ignored the services they could mutually render each other. Most workers in the field of magnetism considered, for example, "Swedish iron," or "Sheffield steel," sufficient designation for the materials they employed, so that it was impossible to generalise the results obtained in a particular case. The number of data necessary for defining a steel bar was considerable, particularly in the case of hardened steel, in which it was important to know:—(1) the chemical composition; (2) the previous history of the metal, or at least the microstructure, which permitted of its approximate reproduction; (3) the method of heating; (4) the rate of heating; (5) the maximum temperature of heating; (6) the temperature at the moment of quenching; (7) the dimensions of the bar; (8) the state of the surface; (9) the nature of the hardening bath; (10) the temperature of the hardening bath; (11) the weight of the hardening bath; (12) whether the hardening bath was agitated or not; (13) the temperature of emersion of the bar, if it was not the same as that of the bath. Even this list might still be incomplete. What metallurgists asked of physicists was, that they should ascertain the exact function of each of these factors in the final magnetic properties. This the Authors had perfectly realised in determining beforehand the chemical composition and the conditions of manufacture of their specimens; and the precaution greatly increased the value of their results. When the relations sought for were more Mr. Osmond.

[1] Zeitschr. f. Instrumentenkunde, vol. xvi. p. 86, 1896.

Mr. Osmond completely known, magnetic trials would assume considerable importance in metallurgical works. Twenty years ago Mr. Ryder, engineer to the Otis Steel Works, had proposed to classify steels by the residual magnetism of short bars,[1] and Mr. Osmond, in studying this method of classification, had found it practically in accordance with that based on tensile strength. A great advantage of these magnetic tests was that they could be applied to the finished pieces, and not merely to a test-piece more or less restricted as to shape. He could not see why the ingenious methods of Professor Ewing could not be applied, with suitable modifications, to the very pieces manufactured. It did not appear impossible, or even difficult, with a well-designed installation, to test all the rails, all the axles, or all the tires produced in any works, and, the conditions of manufacture remaining practically the same, to discard all the products which did not reach a certain prescribed standard.

Mr. Wilson. Mr. ERNEST WILSON observed that on p. 192 Professor Ewing described a convenient arrangement for the determination of curves of induction and hysteresis employing the ballistic galvanometer. In calibrating his instrument the Author made use of the absolute determination of current, but Mr. Wilson considered the Clark standard cell could be very conveniently used for the purpose of finding sensibility. He asked, with regard to the magnetic bridge, if the disturbance of the linear distribution of current-turns on the test-piece gave the same result as when the turns were kept constant and the current varied. The sample of steel-forging III (p. 210) was exceptionally good for the purpose of magnet limbs where high induction density was used, being almost equal to the very pure iron I. He had no doubt Professor Ewing had not specially chosen the hysteresis data for magnet steel given on p. 215 as being low. Experiments recently made in the Siemens laboratory on a ring of this steel had given the following results, which were considerably lower than those given in Professor Ewing's Paper :—

Limits of Induction per Square Centimetre, B .	2,000	4,000	6,000	8,000	9,000	10,000
Dissipation of Energy by Magnetic Hysteresis in Ergs per Cubic Centimetre per Cycle . . .	350	1,000	2,050	3,400	4,300	5,300

[1] *Engineering and Mining Journal*, January 13 and March 31, 1877.

Mr. Wilson. With regard to Mr. Parshall's Paper, the investigations mentioned on p. 233 were of great interest. He had been engaged a short time ago on research to find if the rate at which energy was dissipated by magnetic hysteresis for a given frequency and for a given maximum induction per square centimetre was different when the same specimen was subjected to first, an alternating magnetic field, and secondly, to a uniform rotating field of constant intensity.[1] He was not aware that the dissipation of energy in the two cases had been demonstrated to be the same. He asked if the effect of induced currents had been eliminated in the curves shown in *Fig. 21*, as this was not warranted by the mere fact of the armature-core being smooth.

Dr. Veillon. Dr. HENRI VEILLON, of Basle, had devoted a considerable time to the investigation of the magnetization of steel by the oscillatory discharge of the Leyden jar, and had embodied the results of his experiments in two Papers[2] which he thought would be found useful to those interested in the subject.

Prof. Ewing. Professor EWING, in reply to the Correspondence, regarded the additional data contributed by Dr. du Bois to be valuable, especially as affording an example of iron exceptionally free from hysteresis. The Swedish iron quoted by Dr. du Bois had a lower coercive force than any sample he had ever tested, and low coercive force was associated with low hysteresis. On the other hand, it was interesting to notice that the permeability of the material under comparatively strong magnetizing force was considerably short of the permeability he had found in many examples of steel casting. The exceptionally low hysteresis of the Swedish sample was in agreement with what he had himself remarked, that the best transformer plates were rolled from Swedish iron. Why this iron should be so destitute of hysteresis was a question to which the results of analysis could not be said to furnish the answer. Mr. Osmond's suggestion that magnetic tests might come to be used as a guide to the mechanical qualities of steel opened up a large question, that of the relation of the magnetic to the general mechanical qualities of the material. He doubted whether there was any sufficiently simple and invariable connection between mechanical

[1] Report of the British Association for the Advancement of Science, 1894, p. 576.

[2] "Sur l'aimantation de l'acier par les décharges oscillantes de la bouteille de Leyde." Archives des Sciences Physiques et Naturelles, Geneva, vol. xxxiv. October, 1895; and "Über die Magnetisierung des Stahles durch die oscillatorische Entladung der Leydener Flasche." Verhandlungen der Naturforschenden Gesellschaft in Basel, vol. xi. part 2. Copies of these essays are placed in the Library.—SEC. INST. C.E.

Prof. Ewing. and magnetic qualities to allow one to serve as an index to the other. The steel castings now so largely used for dynamos were not easily distinguishable from good forged iron in their magnetic qualities, but when tested mechanically they had nothing in common with forged iron. A more promising field of inquiry in this connection appeared to him to be opened up by the researches of Mr. Osmond and others into the microstructure of iron. It was impossible to look at the beautiful micro-photographs of steel sections, in the taking of which Mr. Osmond was a pioneer, without feeling that microscopic examination undertaken alongside of magnetic examination might yield important results.

In reply to Mr. Wilson's question, it was the case that any such variation in the linear distribution of current-turns as occurred in the use of the permeability bridge did not give rise to inconvenience or inaccuracy. The turns were so arranged in the winding of the coils as to make this variation comparatively small. When a state of balance had been reached with say 100 turns in a single coil, the switches could be shifted so that the same number of turns was made up by other coils, namely by the tens and units, and the balance still remained good. Similarly ten one-turn coils could be substituted for any one of the ten-turn coils without disturbing the balance. Tests of this kind show that the coils, as arranged, had practically the same effect per turn no matter what was their distribution over the bar. The sample of dynamo-magnet steel for which hysteresis data were given on p. 215 of the Paper had not been selected as having specially little hysteresis, but only as being an example for which the Author had particularly complete data. In point of fact it had more hysteresis than most samples of dynamo casting, and much more than some samples. The question whether hysteresis had the same value in a reversed field as in a rotating field had been made the subject of a recent communication by Mr. F. G. Baily to the Royal Society. He found more hysteresis in the rotating field, until the induction was raised to a high value. Then the hysteresis in the rotating field began to diminish, and under stronger inductions it continued to diminish until almost all trace of hysteresis disappeared. This result was in striking confirmation of Professor Ewing's theory of the molecular process in magnetic induction, which ascribed the stability of the molecular magnets to the mutual forces they exerted on one another in consequence of their magnetic polarity, and explained hysteresis as the dissipation of energy involved in breaking up stable conformations of molecules.

Mr. Parshall.

Mr. PARSHALL, in reply to the Correspondence, considered that a sufficient number of measurements were embodied in the Paper to prove the accuracy of the statement, that, "within the limits assumed, the hysteresis loss remained the same, whether the magnetism rotated through the field, as in the case of a dynamo, or was simply reversed, as in the case of an alternating current transformer." He was aware of the results of Mr. Baily and others, showing that for very high magnetizations, outside of the field discussed in the Paper, the statements did not hold good. The limitation as to the correctness of the statements, was, however, definitely stated at the beginning of the discussion on "Hysteresis"—that was, within the limits of the magnetization obtaining in practice and those within which such material could be produced to give uniform results. Beyond these limits it was not the purpose of the Paper to discuss. As to the effect of induced currents, it was generally known that in the air-gap armatures with projections offered a variable magnetic reluctance, and currents were therefore induced in the pole-pieces; for this reason the tests were made, as stated, upon smooth core armatures. The armatures were in each case concentric with axes of rotation, so that there was no variation of magnetic reluctance, and consequently no induced currents in the pole-pieces. The disks of the armature were carefully laminated from each other, so that parasitic currents in the body of the core were avoided. The error due to Foucault currents from the appreciable thickness of the plates was negligible. An analysis of the curves would show that there was no indication of the loss increasing with the square of the magnetic intensity which was sufficient indication that there was no appreciable error brought about by electrical losses.