INVAR AND ITS APPLICATIONS.

Preliminary.

DESCRIPTION of Phenomena.—A new material requires a new name; that of "*invar*" has been adopted, on the suggestion of Prof. Thury, to avoid the periphrase "steel containing about 36 per cent. of nickel, which is characterised by possessing an extremely small coefficient of expansion or by the fact that its specific volume is practically invariable when considered as a function of the temperature." The name has been universally adopted, and the title of this article is thus justified.

The discovery of invar, as is the case with most discoveries, was preceded by observations indicating the direction of the researches from which it had its origin. As early as 1889 the late Dr. John Hopkinson noted the singular fact of the existence of a ferro-nickel containing about 25 per cent. of nickel, the density of which was found to have diminished by about 2 per cent. after cooling to the temperature of solid carbon dioxide; and in 1895 M. J.-R. Benoît, director of the Bureau international des Poids et Mesures, having to determine the length of a metre scale composed of an alloy of iron with 22 per cent. of nickel and 2 per cent. of chromium, was extremely surprised to find that his measurements, made with an extreme range of temperature of about 2 degrees C., gave concordant results only on assuming for the alloy a totally abnormal coefficient of expansion, equal to that of brass, and consequently half as

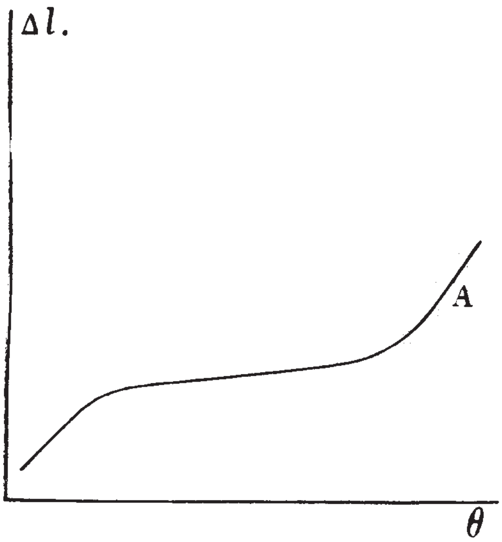

FIG. 1.—General form of the expansion curve for a reversible nickel-steel.

great again as that required by the law of mixtures generally applicable to such cases. This alloy was not magnetic, and thus resembled Hopkinson's alloy before cooling, although the latter after exposure to a low temperature became endowed with magnetism.

It was natural to coordinate these two anomalies and to consider the non-magnetic iron of the second alloy as being very expansible. At the time I considered that the alloy, after being rendered magnetic by cooling, would possess a normal coefficient of expansion; but as the alloy studied by M. Benoît did not become magnetic either in carbon dioxide or in liquid air, I was forced provisionally to renounce this hypothesis. For the liquid air I was indebted to the kindness of Sir James Dewar at a time when liquid air was not obtainable in Paris. I did not, however, abandon this research, and it was in seeking for alloys capable of a transformation similar to that observed by Hopkinson that I was led to examine alloys possessing a negatively abnormal coefficient of expansion. I may add that I was able later perfectly to reproduce Hopkinson's discoveries and to extend them in various directions, but I am unwilling to linger over the details in an article of a practical character, these discoveries having hitherto been fruitless of industrial applications. It will be sufficient to consider later in a brief manner the common cause of the anomaly observed by Hopkinson and of the phenomenon which I have studied.

Reversible Alloys.—The alloys of iron and nickel which contain more than 25 per cent. of the latter metal may or may not be magnetic, according to the temperature at which they are studied. The passage from one state to another is gradual, the magnetism declining continuously as the temperature is raised, whilst on lowering the temperature the reappearance of the magnetism follows the same curve. The temperature at which the magnetism totally disappears depends on the composition of the alloy. For alloys containing from 26 per cent. to 27 per cent. of nickel it is little above 0° C.; as the proportion of nickel increases it rises very rapidly until a maximum, corresponding with 70 per cent. of nickel, is reached at a temperature fixed by M. Osmond at 550° C., when the curve falls to the transformation point of nickel at 340°. This curve of variation is, so to speak, an *indicatrix* of the properties of the alloys; above the curve the expansion is abnormally great, but at the moment of crossing it with descending temperature the rate of the contraction diminishes, and a region is soon reached in which the anomalous negative expansion exists. Subsequently at a much lower temperature the normal state is reached. The curve given in Fig. 1 shows the general character of the variation for alloys of this class; its phases are more or less elongated, the different regions more or less inclined, but the curve always consists of a region of negative abnormality with two confluent curves, one side being characterised by large expansions at high temperatures, the other by a normal expansion. The abnormal region covers generally several hundred degrees.

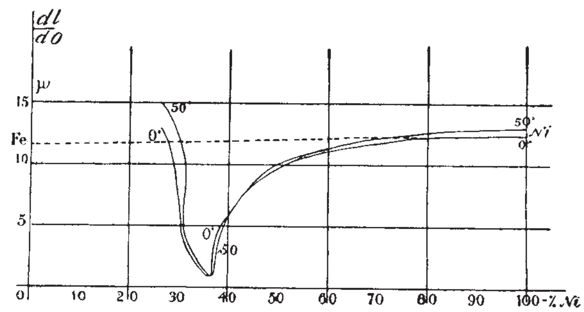

FIG. 2.—Coefficients of expansion at 0° and 50° C. of the various reversible nickel-steels.

The temperature indicated by the abscissa of the point A corresponds sensibly with the ordinate of the indicatrix in question at the point belonging to the same alloy; in other words, it is at this point that the magnetism finally disappears as the temperature rises.

Curve 1 shows that it is impossible to assign a general value to the expansion of a particular nickel-steel; the value chosen must always apply to a definite region and to a more or less extensive range of temperature. If we consider, for instance, the temperatures 0° and 50° C., the two curves of Fig. 2 can be traced, representing at these two temperatures the inclination of the tangent to curve 1 for all the reversible alloys of iron and nickel. It is the minimum of this curve which corresponds with invar, strictly so-called. This minimum will be displaced toward the left for alloys considered at lower temperatures and conversely.

It should be noted that beyond the minimum the curves cross; we are then in the region corresponding to the left-hand side of curve 1, where the true expansion diminishes with rising temperature. This result of the measurements is of interest because, independently of its being observed for the first time, it has given rise to an interesting application.

Theoretical Views.—Without entering into the details of a theory for the development of which I may refer to an article in the *Revue générale des Sciences* (July 15 and 30, 1903), I will indicate at least the source of the phenomena which have been described.

In the two transformations which take place successively in iron in passing from the α condition to the β and γ conditions of Osmond, the metal undergoes different apparent changes, of which the most characteristic are the transitions, in two distinct stages, into the non-magnetic state and a

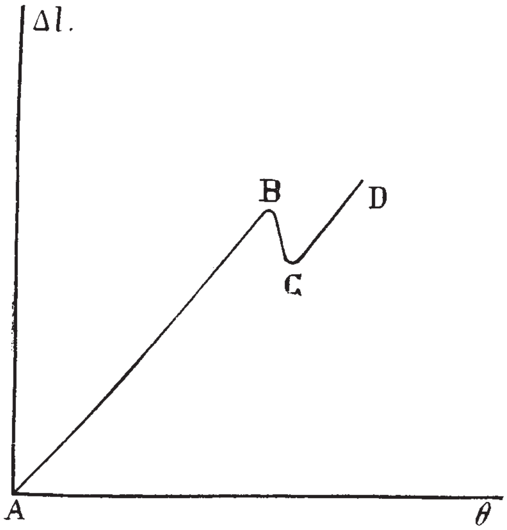

FIG. 3.—Expansion of iron.

sudden diminution of the specific volume of the iron at the moment it reaches the higher condition. The expansion of iron up to high temperatures is indicated by a curve such as ABCD, Fig. 3. The addition of a little carbon modifies this curve considerably, as was observed especially by M. Le Chatelier and MM. Charpy and Grenet. The addition of nickel begins to separate the change more and more into two inverse transformations, which commence at very different temperatures (Hopkinson's phenomenon); as the proportion of nickel increases, the change again becomes simple, but instead of being sudden, as with pure iron, it is spread out over a wide interval of temperatures, at each of which the reciprocal solution of iron in its two extreme states and of nickel strives to attain a stable equilibrium. For the greater part the attainment of equilibrium is practically instantaneous; it is much more rapid, for example, than that which is observed in an aqueous solution in which large crystals are placed, and resembles rather that which would occur in a saturated solution containing an infinite number of crystalline nuclei of the same density as the solution. In a medium thus constituted equilibrium is reached almost instantaneously. The perfect dissemin-

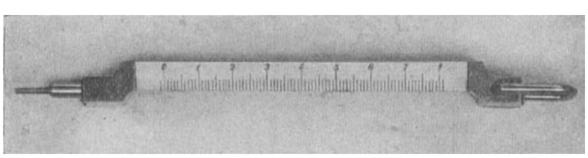

FIG. 4.—Scale at the end of a wire (the divisions are millimetres).

ation of iron throughout the nickel or the converse is evidently a very important factor of the phenomenon. For Hopkinson's phenomenon the same transformation is still produced, but with an enormous thermal hysteresis.

It is necessary to mention, however, a retardation in a minor part of the change which follows very slowly the principal instantaneous phenomenon. This retardation, due perhaps to a migration of some of the molecules engaged in the change, is rendered visible in the case of invar, strictly so-called, by a gradual elongation with time. It is enormously accelerated by heating the alloy, for example, at 100° C.[1] Nevertheless, when a bar of invar has been heated thus it still increases in length very slightly after several years at the ordinary temperature. At the end of five or six years the total elongation is nearly 1/100 mm. per metre, but the subsequent lengthening each year does not exceed a fraction of a micron.

This phenomenon is of theoretical interest. Practically it restricts the use of invar, and although, by systematic heating, a much smaller limit of variation can be reached than that above indicated, such a change prevents the alloy from being employed in the preparation of *standards of the first order*. It is necessary to point this out before proceeding to consider the apparatus in which invar has introduced decided elements of progress. For a consideration of other qualities which may render it valuable I will refer to information already given in this Journal.[2] I can describe here only a few of the uses of invar, and will choose three of the most typical.[3]

Applications.

Standards of Length.—If the slight defect of stability referred to above prevents the employment of invar in the preparation of fundamental standards, the requirements of which are infinite, a wide field of application still remains in the construction of standards which can be referred from time to time to fundamental units, and during these intervals are employed at temperatures which are not readily ascertained, as is the case with the majority of measuring instruments which cannot be maintained in a liquid bath. With a brass scale, for instance, an uncertainty of 0·1 degree C.

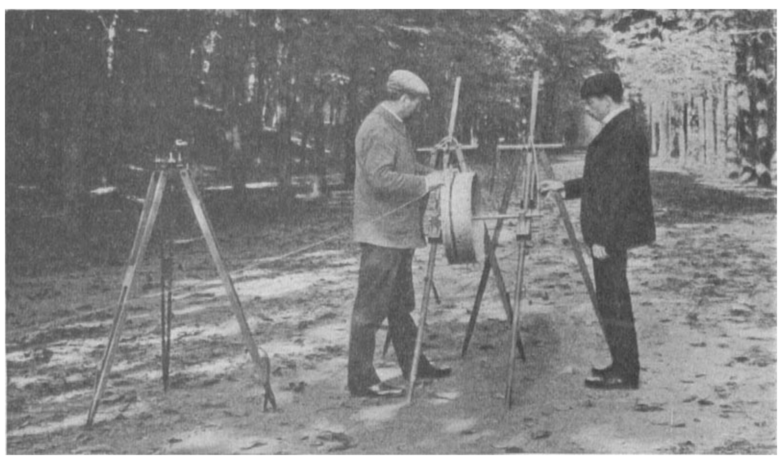

FIG. 5.—Rolling of a 2 km. wire on an aluminium drum.

in the temperature introduces an error little less than 2μ per metre of length. But a rod of invar, thoroughly annealed and aged, will not change to the same extent in an interval of three years. The interpolation of definite values up to five or six years can be made with even less uncertainty. Measurements in which the instability of invar will introduce an unacceptable error are very rare; in the case of standards prepared with the usual metals they would correspond with errors of temperature which are exceeded in nearly all ordinary measurements.

But the greatest claim that invar can make to utility is in its application to geodesy; working in the open air under extremely variable atmospheric conditions makes the deter-

1 The variation of the rapidity of the change with temperature seems to follow van 't Hoff's law of geometrical progression.

2 NATURE, No. 1822, September 29, vol. lxx. p. 527.

3 A more complete description will be found in my recent work, "Les Applications des Aciers au Nickel."

mination of temperature very uncertain, and, on the other hand, a control on returning, by means of a standard of reference in a geodesical or metrological establishment, is always possible. With this idea M. Benoît and myself, at the request of General Bassót, have designed for the use of the Geographical Service of the French Army a scale of 4 metres which is made of invar, and has been found so practical by the surveyors that four other scales of the same type have been constructed for other countries.

This scale has an H-section with a side of 40 mm.; its direction lies in the plane of the neutral fibres, and it has such rigidity that the flexure is quite admissible in an accurate standard supported at only two points. As a consequence, the scale can be placed on a light support which is subjected to no especial conditions of rigidity, since it has not, as in most of the older apparatus, to assure the rigidity of the standard. The support which we have adopted is an aluminium box that completely envelops the scale and protects it from shocks, dust, and accidents of all kinds, as well as from rapid changes of temperature. The complete apparatus weighs 56 kg., whilst the old form of Brunner, consisting of two scales and a rigid support, weighs 72 kg., and affords no protection for the standards.

For direct employment in the field, especially when the apparatus has to be carried to great distances (the scale will, in the near future, be used in the Andes), the facilities introduced, compared with those existing in older apparatus, are considerable, and if they constituted the sole progress in geodesy they would deserve serious consideration. But the use of invar has permitted a more complete transformation in the measurements of bases. Twenty years ago M. Edw. Jäderin made trial of a method which consisted of the use of long wires stretched under a constant load and serving the purpose of fixing between two limits of the base the distance of a series of movable bench-marks, ranged between these limits. The advantage of this method, the rapidity of measurement, lightness of material, and facility in the choice of ground, will be readily appreciated, but it will also be recognised that the uncertainty of the temperature of the wires made the method doubtful in cases where greater accuracy was required than that usual for the ordinary requirements of topography or land-surveying. M. Jäderin has diminished these uncertainties by employing two wires of brass and steel respectively, by means of which each of the ranges was successively measured. The difference observed for the two wires was taken as an indication of their common temperature, whence the temperature of the steel wire, considered as the principal standard, was deduced. Without going into the details of the calculations necessary to the method, it is easy to see that small inevitable errors influence the result; the real difference of temperature of the two wires at the time of the measurements and errors of reading reappear in the result, multiplied by factors of a variable nature, but all greater than unity.

These uncertainties disappear completely with a wire made of invar, especially as the greatest care can be given to the manufacture of comparatively small quantities of the alloy when it is required for particular purposes in which the price, between certain limits, is a secondary consideration; samples may be chosen so as finally to descend below the minimum of the curve in Fig. 2 and cut the axis of the abscissæ. Zero and even negative expansions have thus been realised. The specimens having a minimum expansion are strictly reserved for geodetic purposes, and considerable quantities of wire have thus been obtained of which it is unnecessary to know the temperature within about 10 degrees even for the most precise measurements of base lines. Commonly, a knowledge of the temperature within 5 degrees is sufficient; an error of this magnitude hardly makes a difference of 1 part in 1,000,000.

These advantages could not escape surveyors. As early as 1898, M. Jäderin himself requested me to obtain for him wires[1] made of invar for the purpose of perfecting his method, at a time when M. Benoît and myself were undertaking, at the Bureau international des Poids et Mesures, experiments to ascertain their suitability for such a purpose. The trials were so encouraging that the following year it was decided to equip the Swedish-Russian expedition to Spitsbergen with similar wires, by means of which all its base lines were measured. At this time, however, the experiments were not sufficiently advanced to obviate the need of taking many precautions, and the expedition acted very wisely in not considering the wires as standards of length. The true standards were two iron bars, previously verified at the Bureau international, which served to measure the short bases (the Swedish base was 96 metres long) on which were standardised the wires of 24 metres, which subsequently served to measure the true bases of several kilometres in length. This was the first practical trial of invar in the field, and, according to the reports which I have received from several members of the expedition, notably from M. Jäderin, the success exceeded every hope. Two independent measurements of the Swedish base showed a difference of 19 mm. per 10 kilometres, that is, of 1/500,000 *without introducing any correction for the temperature.*

FIG. 6.—Reading the position of the end scale of the wire against a movable mark.

The same sense of safety in the employment of these wires is felt after reading the report by M. Backlund, of the Russian expedition, and of Commandant Bourgeois, on the measurements of the French Survey in the territory of the Republic of Ecuador. The difference in the measurements of a base made in 1901 with a bimetallic scale and with a wire of invar was 1/3,300,000; the agreement is so good that it must be attributed partly to chance, but such chances are rare when the systematic elimination of errors has not been pushed to extremes.

In any case a more complete study of the wires of invar became necessary, and, on the ground of the studies already commenced by M. Benoît and myself, the International Committee of Weights and Measures entrusted to us, at the end of 1900, on the request of the International Geodetic Association, a detailed investigation of this question.

We therefore erected against a thick basement wall, protected by the building of the laboratory of the bureau, a series of bench-marks spacing out a length of 24 metres at intervals of 4 metres, measured by means of an invar standard. On the outside of the last uprights are two pulleys on ball bearings over which pass two cords that carry weights of 10 kilograms and are attached to the wire on which observations are to be made at the distance of

[1] These wires were manufactured at the steel works of Imphy belonging to the Société de Commentry-Fourchambault and Decazeville, by whose collaboration I was enabled to carry out the work described in this article.

the extreme marks. These wires carry at their extremities scales of invar, having the form represented in Fig. 4, with their edges in the same line as the axis of the wire. This arrangement, somewhat complicated in appearance, is necessary to ensure constancy of length, whatever be the inclination of the scale in a transverse direction.

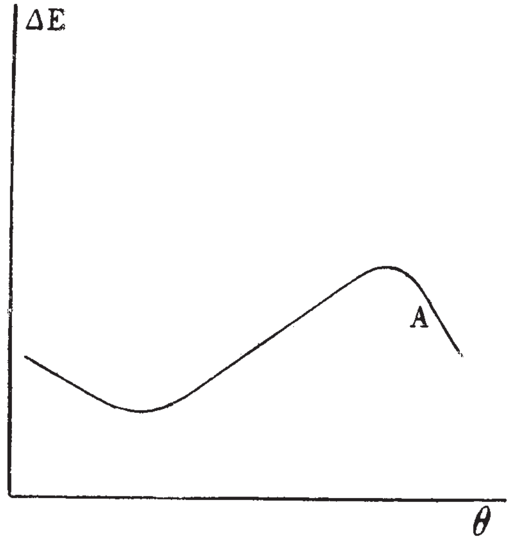

FIG. 7.—General form of the curve of change of Young's modulus for a reversible nickel-steel.

During four years measurements have been made weekly with a great number of wires which have been submitted to different treatment. Owing to the complexity of the subject, more than a hundred thousand comparisons between the wires and the base were necessary to elucidate all the questions relating to the stability of the wires and the precision that they guarantee. After four years, and after the method of treatment of the wires has been gradually modified so as to ensure the greatest possible degree of stability, we can emphatically assert the excellence of the method of measurement by wires constructed of invar. When a wire of the usual diameter of 1·65 mm. is stretched by loads varying from an insignificant weight to that of 20 kilograms, the permanent elongation which it undergoes is not measurable; moreover, it can be rolled as often as desired on a drum (Fig. 5) of sufficient diameter (at least 50 cm.), or kept rolled for months without showing on subsequent measurement a variation greater than that due to errors of observation. Several wires which were measured at the bureau were returned after use in the field; in the beginning, variations in the length of the order 1 in 200,000 were observed in several instances, but recently the constancy of the length has become much more decided. Whilst reserving the results obtained by long trials in severe climates, it may be concluded from the results obtained in the laboratory that a surveying expedition equipped with several wires constructed of invar and subject to mutual control will be able to measure several long bases without fearing a departure from accuracy in the wires greater than that permissible in such measurements, assuming, of course, that the wires are always handled with due care.

The considerable increase in the accuracy of geodetic measurements, caused by the substitution of wires of invar for those of steel or brass, necessitated a corresponding improvement in the apparatus. We have therefore proposed certain new principles which have been realised in instruments constructed with the aid of M. Carpentier, of which a provisional model has been already mentioned in NATURE.[1] A description of the final types which have been adopted would carry me too far; Fig. 6, which indicates one of the measures, may take its place. It will be sufficient to add that, thanks to the new material which has been discovered, the measurement of a base by means of wires answers all the needs of a surveyor; the relative error of the base has fallen below that of the angles; bases can be measured across broken ground, cultivated land, streams and rivers. Above all these advantages, the complete staff, including auxiliaries, need not exceed ten men for a rate of progress of 5 kilometres per day. This arrangement, compared with that by which ten years ago fifty men using rules and microscopes could advance 500 metres a day, exhibits an economy of 98 per cent.! To-day the measurement of a base with all the accuracy required in geodesy costs little more than chaining, and the proof has been so thorough that the French Survey finds its advantageous to measure all its bases by the new method.

The advantages of measurements by wires have been quickly recognised by surveyors. Several departments of survey have requested the Bureau international to standardise wires suitable for base measurements; we have thus had the satisfaction of examining the apparatus for use by the Argentine Republic, Australia, Cape Colony, France, Germany, Japan, Mexico, Roumania, Russia, Servia, and Switzerland.

This simplification in the fundamental measurements of the survey will lead to a reversal in the future of the respective positions of the base and angular measurements. In the old method of surveying measurements of bases were reduced as much as possible and angles multiplied indefinitely; in the new geodesy angles will be controlled by frequent measurement of numerous long bases. This general plan has already been introduced in the United States in the fine work carried out during the determination of the length of the 98° meridian.

Horology and Chronometry.—The possibility of constructing a compensated pendulum with its rod of invar is so obvious that it is hardly necessary to emphasise it. It will be sufficient to observe that the slight change which invar undergoes is not for this purpose a serious defect. As it is necessary to determine the rate of a clock at frequent intervals, variations in the daily rate of the order

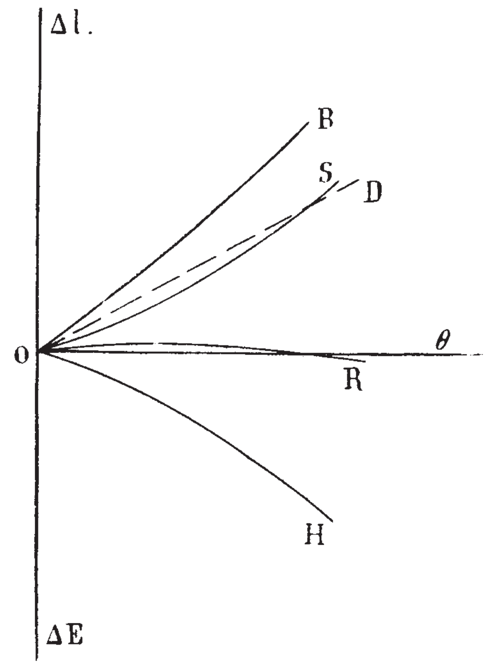

FIG. 8.—Diagram of the compensation of a chronometer with a steel-brass balance.

of a few hundredths of a second in a year will be merged in the variation of the longer period, and will give rise to an error hardly to be feared; but other applications will need some explanation.

In order not to prolong the preliminary part of this article, I omitted to mention a singular property of the nickel-steels,

[1] June 2, 1904, vol. lxx. p. 104.

which for ordinary watch-making is of prime importance. To resume those considerations. At the end of 1896 I found that when an alloy containing 24 per cent. of nickel passes from the non-magnetic to the magnetic state, its modulus of elasticity undergoes a diminution of 10 per cent. This change is the more remarkable inasmuch as the limit of elasticity is simultaneously raised, as was shown by Hopkinson. I was intending to study the same change in invar when M. Thury at Geneva and M. Paul Perret at La Chaux de Fonds, after my first publication, established for the alloy the singular fact of a positive variation of Young's modulus with increasing temperature. A systematic investigation of the change by M. Perret and myself led us to results which, completed by the theoretical views which were developed, permitted me to assign to the total variation of the modulus of a nickel steel endowed with reversible properties a course indicated by the curve in Fig. 7. Point A has the same significance as in the curve of Fig. 1, and two regions of variation in a normal sense are shown, between which lies a region of abnormal variations connected with the first by two confluent curves.

The existence of these confluent curves has a great importance for horology. The necessity of fitting good watches with a bimetallic compensation balance arises

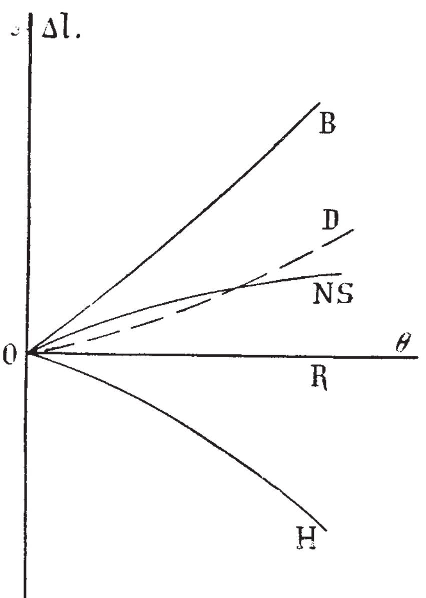

FIG. 9.—Compensation with nickel-steel-brass balance.

almost exclusively from the need of securing comparable rates at different temperatures owing to the variation in the modulus of elasticity of the steel spring. This variation is sufficiently great to cause a retardation of five minutes in the day in a watch fitted with a steel spring and a monometallic balance, the temperature of which undergoes a change from 0° to 30° C. The employment in the spring of a nickel-steel the properties of which are represented by one of the confluent curves (that is, of an alloy having Young's modulus a maximum or minimum at the average temperature to which the watches are submitted) will obviate the need of a costly compensation. The compensation is, of course, not perfect; the difference between the form of the curve and a straight line, and still more, the difficulty of obtaining an alloy passing through a maximum or minimum at ordinary temperatures, limit the application of these springs to ordinary watches, and preclude their use in accurate chronometers. But in their own province they represent a real advance, as they reduce the error of an uncompensated watch by 90 per cent., and the cost of watches which were approximately compensated by a rough balance by 6*d*. in the shilling. The trade of watchmaking gains as much by direct economy as from an increase in quality; the annual saving is certainly 10,000*l*., and is likely to become 20,000*l*. or 30,000*l*. Competition, moreover, is so keen in the trade that a diminution of prices passes at once from the manufacturer to the consumer, so that the public gains the whole advantage of it.

Another application in chronometry, although its advantages from a monetary aspect are insignificant, seems to me of greater interest, because it appeals to a higher range of thought, and represents an advance in a region in which perfection had apparently been reached.

In 1833 the celebrated English watchmaker Dent discovered that a chronometer regulated for two extreme temperatures gains at intermediate ones, and the correction of "*Dent's error,*" as it is called, has exercised the ingenuity and invention of the best watchmakers. In England particularly, the country *par excellence* of marine chronometry, great efforts have been made to introduce corrections for this error. The auxiliary systems of Loseby, of Kullberg and others have permitted the attainment of great accuracy, but at the expense of a considerable increase in price and of complications which are not exempt from inconveniences. The cause of Dent's error is almost entirely the non-linear variation of the elasticity of the steel of which the hair spring is composed. The curve OH, Fig. 8, represents this variation. The action of the balance is proportional to the difference of the expansions of the metals composing the bimetallic ring; if we represent the expansions of steel and brass by the curves OS and OB it

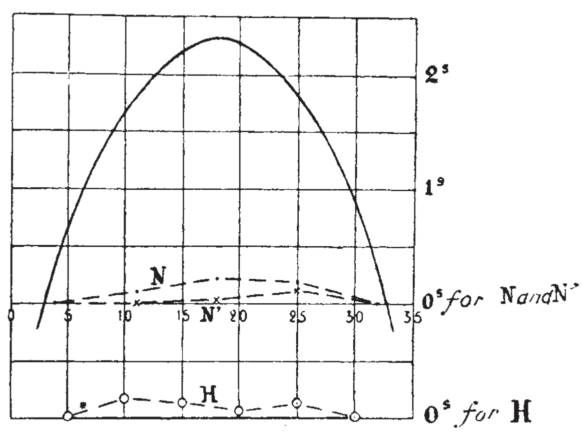

FIG. 10.—Results obtained at Neuchâtel and Hamburg with Nardin chronometers fitted with nickel-steel-brass balances.

will be seen on referring to the numerical formulæ whence these curves are obtained that, whilst their average inclination is very different, the variation of this inclination is nearly the same. The variation of the difference of inclination is therefore nearly zero, and the curve giving the difference of the expansions practically becomes the straight line OD. The rate of the chronometer at different temperatures is given by the algebraical sum of the ordinates of the curves OH (natural variation) and OD (corrective function), that is, by the curve OR. Such is the reason of Dent's error, which has been corrected hitherto by adding to the natural corrective function of the balance a term of great curvature given by an auxiliary system.

But the same result would be attained by substituting for one of the metals of the double ring another metal or alloy of which the increase of expansion is much greater than that of brass, if that metal is rejected, or much less than that of steel, and preferably negative, if the brass is retained. The curve of Fig. 1 offers in this respect numerous possibilities. Practical reasons lead one to retain the brass and to associate with it an alloy having an expansion which is a retarded function of the temperature. Fig. 9, in which the curve OS belonging to steel has been replaced by ONS referring to nickel-steel, shows a curve OD that can be rendered symmetrical with regard to OH; the sum OR of the curves is then always zero, and the problem has a practical solution.

I had established this theory in the year 1899, when two of the principal Swiss watchmakers, M. P. Nardin, of Le Locle, and M. P. Ditisheim, of La Chaux de Fonds, expressed a wish to make a trial of the new balance. The first attempt gave so perfect a result that the balance has not since been modified; its adoption by Swiss watchmakers was very rapid, and to-day it is employed in the majority of their best timepieces. It was with a pocket chronometer fitted with this balance that M. P. Ditisheim beat in 1903 all records at Kew with a total of 94·9 points, the previous best being 92·7. The compensation was awarded 19·7 points, the maximum of ideal perfection being 20. The dark-lined curve of Fig. 10 shows the theoretical variations of a perfect chronometer compensated by the usual method; the curves N, N′, and H represent the average results obtained at Neuchatel with two groups comprising in all sixteen chronometers, and at Hamburg with six chronometers, all made by M. Nardin.

Incandescent Lamps and Crookes's Tubes.—In conclusion, a few words may be given to an application, less scientific in its nature than the preceding, but likely to be welcomed by all who regret the systematic destruction of the world's store of platinum. The curve in Fig. 2 shows that two nickel-steels of definite composition have an expansion equal to that of glass; but only one of these can be practically considered, namely, that containing about 45 per cent. of nickel; the alloy which contains 29 per cent., at a slightly higher temperature passes the point A of Fig. 1 and enters the region of high expansion.

For a metal to fuse in glass it is indispensable, but insufficient, that it should possess the same expansibility as glass; fortunately the alloy containing 45 per cent. of nickel possesses all the other properties which are necessary, provided that it be not unduly oxidised during the softening of the glass. As a matter of fact, several manufacturers of incandescent lamps have adopted, under the name *platinite,* this welcome substitute for platinum, thereby economising several hundred kilograms of the precious metal. If this economy spreads, a ton of platinum may be saved annually for science and those industries in which its use is indispensable.

Conclusions.

It is time to conclude this over-long article. The applications which have been described are not the only ones which might be predicted or have been attempted with these curious alloys, the properties of which for a time seemed so paradoxical that a number of physicists and metallurgists refused to believe in their existence. All the applications which to-day give new resources to science and new economies, representing large sums, to industry arise from a peculiar phenomenon of equilibrium in the mutual solution of two isomorphous metals; that is one interesting side of the question. There is another on which I would insist in concluding; it is that these results have been obtained as a sequel to a long series of delicate measurements in which the thousandth of a millimetre was the ordinary unit, and without which no discovery in this domain would have been possible.

CH. ÉD. GUILLAUME.

SHOWER OF ANDROMEDIDS FROM BIELA'S COMET (?)

WHAT certainly appears to have been a well defined shower of Andromedids occurred on November 21 and following nights to November 28. Yet this display, if it really represented the débris of Biela's comet, like the meteors seen in November 1872, 1885, 1892, and 1899, was not true to its time, for no return was to be expected, in ordinary circumstances, until 1905 or 1906. The period is about 6·7 years, and if the shower displayed itself this year it must mean that the swarm has been much disturbed, or that the meteors are rapidly distributing themselves round the orbit, and will soon form a continuous stream, visible annually as the earth intersects it in the third week of November.

Dr. Schulhof and Prof. Abelman (*Astr. Nach.,* 3516) pointed out some years ago that a convulsion of the orbit-motion of the Andromedids would occur in 1901, as Jupiter would approach the group to within 0·5 of the earth's distance from the sun in March of the year named. The effect would be a displacement of the node to the extent of 6°, which would bring the maximum on November 17, or ten days earlier than in 1872 and 1885.

The Rev. W. F. A. Ellison, of Enniscorthy, Ireland, writes me that the most remarkable meteoric shower he witnessed in November was furnished by the Andromedids. He was extremely surprised to find the radiant of this stream very active on November 21. At 7 p.m. he counted 8 meteors in fifteen seconds, and although this rate was not maintained, he continued to observe numerous Andromedids until midnight. From 7h. to 8h. 24 were seen, from 8h. to 9h. 22, after which the number decreased. Until November 28 meteors continued to fall from this radiant, and many of them were objects of remarkable brilliancy, quite equal to the Leonids, but the motions were slower and the paths shorter. The prevailing colour was pure white, the trains being greenish. The radiant seemed further north than Mr. Ellison expected to find it, the position being at about 21° + 50°.

The following are some of the larger meteors recorded by Mr. Ellison:—

Nov. 21. 8h. 2m. G.M.T. = Vega. From a point a little above α Cygni exactly across δ and about 15° further, directed precisely from Vega.
,, 21. 8h. 49m. = ♀. Low down in west where no stars could be seen to fix the path, but evidently Andromedid.
,, 21. 9h. 8m. = ♃. From 337° + 7° to 329° − 7°.
,, 21. 9h. 16m. = ♃. From 354° + 30° to 348° + 18°.
,, 26. 7h. 35m. = ♀. From 52° + 27° to 64° + 8½°. Duration 2 sec., vivid flash at end.
,, 28. 8h. 50m. > ♀. From about 215° + 50° to 215° + 46° Very short path, swift and flashing. Impossible to fix path accurately.

It seems desirable to inquire whether any other observers noticed an abundance of meteors on about November 21, and if so whether their paths were directed from the usual radiant point of the Andromedids.

W. F. DENNING.

UNIVERSITY AND EDUCATIONAL INTELLIGENCE.

CAMBRIDGE.—Mr. J. H. Jeans, of Trinity, has been appointed university lecturer in mathematics in the place of Prof. Macdonald, now of Aberdeen University.

The late Mr. G. T. B. Wigan has bequeathed to the university some 9000*l.*, the interest of which is to be used for the purpose of promoting scientific education and research. It is proposed to divide the fund equally between the board for physics and chemistry and the board for biology and geology. Each board will administer the income of its moiety subject to the condition that no portion is to be applied to one specified purpose for longer than five years at a time.

The name of the late Frank McClean, F.R.S., the founder of the Isaac Newton studentships in astronomy, and a generous donor to the observatory, has been added to the university roll of benefactors.

Dr. Donald MacAlister, the representative of the university on the General Medical Council for the last fifteen years, has been elected president of the council in succession to Sir William Turner, K.C.B., principal of Edinburgh University.

Mr. F. F. Blackman, of St. John's, has been appointed reader in botany in the place of Mr. Francis Darwin.

A university lectureship in botany, stipend 100*l.*, is vacant by the resignation of Mr. F. F. Blackman, recently appointed reader. Application is to be made to the Vice-Chancellor by December 17.

Prof. E. Waymouth Reid, F.R.S., has been approved for the degree of doctor of science.

Prof. Woodhead has obtained from friends resident in or connected with Huddersfield a sum of more than 1600*l.* for the endowment of a Huddersfield lectureship in special pathology. The general board proposes that the gifts be gratefully accepted by the university, and that the lectureship be forthwith established.

The museums and lecture rooms syndicate reports that