

A LOW-RESISTANCE THERMO-ELECTRIC PYROMETER AND COMPENSATOR.*

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THE thermo-electric pyrometer herein described is adapted for commercial and every-day shop use.

It is similar in principle to the Le Chatelier pyrometer, but is of low resistance and instead of the extremely delicate suspension galvanometer a Weston special dead-beat milli-voltmeter is used, and in place of the costly platinum-rhodium elements, inexpensive alloys are employed for the couples.

The low cost of the couple makes it possible to keep

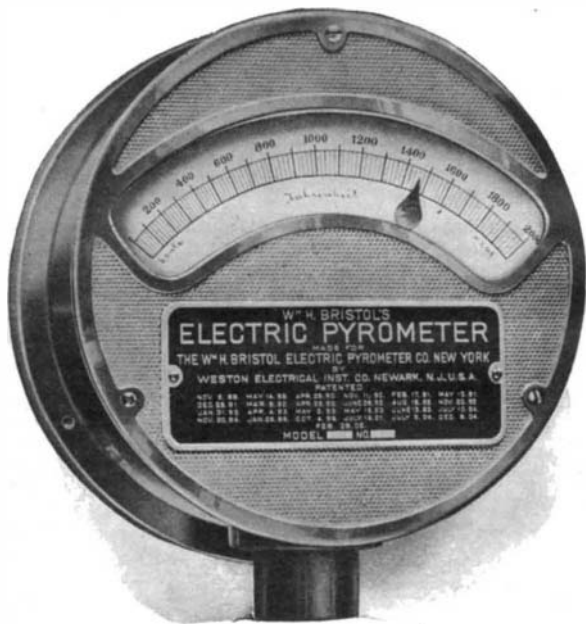


FIG. 1.

an extra one on hand for use as a standard to quickly and easily check the one that is in regular service.

The temperature at a number of localities may readily be observed on a single instrument, a couple and leads being provided for each locality in connection with a suitable switching device.

The same instrument may also be provided with scales for different total ranges.

For ranges of temperature up to 2,000 deg. F. instead of using porcelain tubes for insulation, each element of the couples is insulated with asbestos and a carborundum paint. Couples so insulated may be applied directly to the fire space where the temperature is to be measured, or where extra protection is desirable the couple may be slipped into a piece of common iron pipe with one end closed. Couples so protected are well adapted for use in liquids and molten baths, such as are employed for hardening and tempering of steel.

For instantaneous determination of the temperatures of molten metals as brass, bronze, etc., the ends of the couple are left disconnected and without insulation.

The same form of the couple may be used for quickly measuring the temperature of a metallic object. For this application the tips of the couple are pointed, so that the temperature at the two points of junction may become the same as that of the object immediately after the contact is made. This form of the couple affords a most convenient method for almost simultaneously measuring the temperature at different points of an object.

When desirable the couples are made with a separa-



FIG. 2.

ble junction, which permits the fire end to be removed and renewed at pleasure.

A compensator is adapted to automatically correct for atmospheric changes of temperature at the cold ends of the couple.

In order to make an equivalent and to reduce the

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For further discussion on this topic consult Transactions as follows: No. 23, vol. 2, p. 42: "Use of the Calorimeter as a Pyrometer for High Temperatures," J. C. Hoadley. No. 65, vol. 3, p. 187: "Specific Heat of Platinum, and Use of the Metal in the Pyrometer," J. C. Hoadley. No. 874, vol. 22, p. 143: "Recording Air Pyrometer," William H. Bristol.

cost of the platinum-rhodium couple for the measurement of temperatures above the fusing point of the low-priced alloys, a compound couple is formed with platinum-rhodium for the part to be exposed to the full temperature to be measured and of a length extending to a point where the temperature will not exceed 1,200 deg. F. The remaining portion of the elements of the couple are composed of inexpensive alloys.

Automatic continuous records of the indications of the pyrometer may readily be made on a chart sheet which is arranged to move at the proper speed back of the end of the indicating arm. This record sheet is unsupported over its active portion, which is periodically vibrated by the clock movement into contact with the end of the indicating arm and produces a record upon the chart sheet.

The record may be made by ink carried by the indicating arm, or the surface of the record sheet may be coated with some easily removable substance.

For automatically recording rapid changes of temperature a current from an induction coil may be passed through the record sheet from the end of the indicating arm at frequent intervals.

1. For a great variety of industrial processes and also in scientific research the ranges of temperature required do not exceed 2,000 deg. F.

2. The low-resistance pyrometer herein described has been developed to meet the existing demand for an instrument to fully cover this range of temperature; one which would be accurate, reliable and comparatively inexpensive, taking into consideration both the initial cost and the cost of maintenance; also one that might be readily adapted to varying conditions for industrial operations and be successfully operated by an ordinary workman.

3. As the title implies, this pyrometer depends primarily upon the well-known thermo-electric couple, consisting of two dissimilar metals or alloys joined at one end.

4. When the junction of such a couple is located at a point where the temperature is to be measured an electro-motive force is developed, which is a function of and depends for its value upon the difference of temperature at the junction and that at the opposite or so-called cold ends of the two elements forming the couple.

5. The phenomenon that an electric current is produced when the opposite functions of two dissimilar metals or alloys are of different temperatures was discovered by Seebeck in 1820.

6. Le Chatelier in his recent book entitled "High Temperature Measurements" states that in the year 1830 Becquerel had the first idea to profit by the Seebeck discovery for temperature measurements.

7. During the seventy-five years since that date many scientists have systematically studied and carried out investigations with thermo-electric couples, using a great variety of metals and alloys, with a view to discover a couple that would resist high temperatures and could be depended upon for constancy when used for their measurement. Le Chatelier who has made extensive researches to determine the most desirable metals for this purpose finally adopted a couple of which one element consisted of pure platinum and the other of an alloy of platinum and 10 per cent rhodium, from which couple an almost uniformly increasing electro-motive force is developed correspondingly with increasing differences of temperature between its opposite ends.

8. At the present time many of these couples are successfully employed for the determination of high temperatures. They are almost invariably used in conjunction with an extremely delicate high-resistance galvanometer, which, according to Le Chatelier, is indispensable, 200 ohms being mentioned as a minimum resistance allowable in the indicating instrument. This amount of resistance is necessary to practically eliminate the atmospheric temperature influence upon the resistance of the elements forming the couple, the leads and the coils of the galvanometer itself.

9. If the galvanometer be of a high-resistance type it is evident that if sensitive to the minute current of electricity corresponding to the very low electro-motive force produced by the couple, it must be delicately constructed and consequently requires great skill and care in its handling and operation.

10. The sensitive coil of the instrument is usually suspended by an extremely fine wire and the instrument must always be leveled and located upon a solid foundation before the observations can be made.

11. The platinum-rhodium couple instrument above described may be classed as a high-resistance pyrometer when compared with the low-resistance pyrometer of which the following is a description:

12. It consists of three parts: couple, indicator, and leads to connect couple and indicator. The leads between the couple and the indicator may be of almost any desired length to meet the special requirements; the combined resistance of the leads, couples and indicator is fixed to suit the total range of the instrument and varies from 3 ohms as a minimum to 10 as a maximum. The indicator is a low-resistance instrument of special design, and is made especially for the writer by the Weston Electrical Instrument Company. The accuracy, permanency, and portability of these instruments are well known.

13. Fig. 1 shows a wall or switchboard form of the indicator. Fig. 2 illustrates a portable form. These indicators are made with pivots in jeweled bearings in place of the delicate suspension by fine wires which are generally considered necessary in the high-resistance

type of indicator or galvanometer for this work.

14. The elements used in the low-resistance system give a much greater electro-motive force than the platinum-rhodium couple, which is a great advantage in gain of motive power for the operation of the indicating instrument.

15. The particular metals or alloys applicable for a pyrometer of this type should have a fusing point higher than the maximum temperature to be measured; and when formed into a couple should produce a high electro-motive force with practically uniform increase of same proportional to the increase of temperature.

16. As the result of many experiments with different metals and alloys to determine suitable materials to meet these requirements, couples have been finally

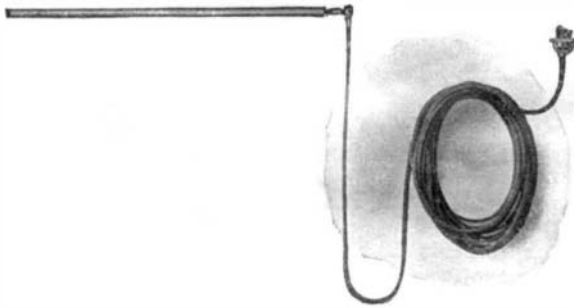


FIG. 3.

adopted which consist of alloys of tungsten, steel, nickel, iron, and copper; different alloys being employed to suit the total ranges of temperature that it is desired to have the scale cover.

17. Since no rare metals are used for the couples, this part of the pyrometer is inexpensive and it is possible to employ elements of large cross-section, which will not be affected in their resistance any appreciable amount by the variation of temperature along the lengths of the elements forming the couple.

18. The leads to the indicator are made of flexible insulated copper duplex cable and of ample cross-section to practically eliminate the influence of variations of atmospheric temperature.

19. The cross-section of the elements of the couple is reduced at their junction, thus rendering it sensitive to sudden changes of the temperature to be measured.

20. A novel feature of the couple is that it is made separable at the point where it passes through the wall of the space within which the temperature is to be measured.

21. The object of the joint is two-fold: first, to make it possible to renew the "fire-end" whenever it may be necessary; and second, to permit carrying the cold ends of the elements to a point toward the floor where the atmospheric temperature will be constant and not influenced by the temperature that is being measured.

22. Fig. 3 shows a complete element with separable joint, coiled leads and lamp plug on the end of the cable forming the leads for convenient connection to the indicating instrument shown in Fig. 1.

23. A special feature of the joint is that it is provided with large bearing surfaces to prevent possibilities of variations of resistance at the connection and is constructed to allow for easily breaking and making the connection. The details of the joint are shown clearly in Fig. 4, and from this it will be seen that it is impossible to make the connection incorrectly, as is usually done when there is nothing to guard against it.

24. The low cost of the couples makes it practicable for the user of the instrument to keep an extra fire

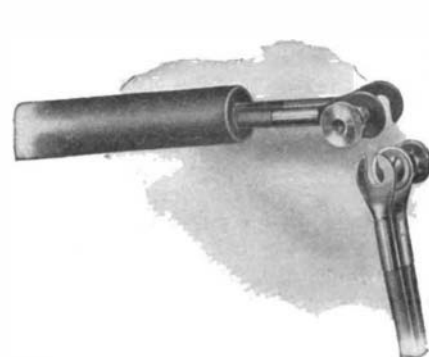


FIG. 4.

end in reserve, which may, at any time, be quickly substituted for the one that has been in continual service, thus affording an economical and positive check upon the accuracy of the instrument.

25. The elements of the couple are independently insulated in a novel and effective manner by winding each with asbestos cord and then coating the surface with carborundum paint, a solution of silicate of soda being used as a binder. This makes a clean, compact, and smooth insulation.

26. Couples thus insulated are flexible and can either be applied to the heated space directly or they may be inserted into a piece of ordinary pipe as a protection. This protection has proven itself to be effective and economical.

27. For continuous applications of the couples to temperatures in the neighborhood of 2,000 deg. F. or over, special protecting tubes of nickel, plumbago, or porcelain are employed.

28. These pyrometers are furnished with scales for

total ranges of 600, 1,200, 2,000, and 2,600 deg. F. Reproductions of these scales are shown in Figs. 5, 6, 7.

29. The graduations of these scales are determined by the fusing temperatures of lead, zinc, aluminium, and copper; which give sufficient points on the curves for use in making a complete graduation of the scales.

The divisions are also further checked by the use of a standardized Le Chatelier platinum-rhodium couple and a Siemens-Halske suspension galvanometer.

For very open scales over shorter ranges several couples may be placed in series, thus making it possible to read to small fractions of a degree.

30. A novel application of the thermo-electric couple is that of determining the temperature of molten metals, as cast iron, copper, brass, and bronze. It

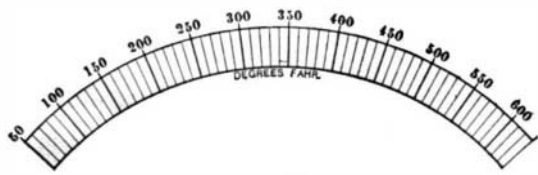


FIG. 5.

consists in leaving the ends of the elements disconnected and without insulation. When these ends are slightly immersed in the molten metal it makes a junction between the elements and the reading will be the same as if the elements of the couple had been originally joined. The advantage of this plan is that the reduced cross-section at the ends of the couple allows it to almost instantaneously attain the temperature of the molten metal, consequently there is no lag error—a most important advantage. As the couple is used over and over again, the ends become worn away, but the couple is, nevertheless, always ready for use by immersion of a fresh portion, which will not be changed in any way by continued use and will give the same reading for a given temperature as if the couple had not been worn away. A joint is provided near the end that is immersed so that a fresh tip can be applied to the couple before enough of the end has worn away to appreciably affect the resistance of the complete system.

COMPENSATORS.

31. As already mentioned, it is well known that the electro-motive force generated by a thermo-electric couple is a function of the temperatures at the hot and cold ends.

32. For refined measurements it is therefore neces-

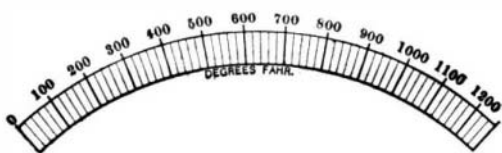


FIG. 6.

sary to make allowance for changes of temperature at the cold ends of the couple when readings are taken unless some means is provided to maintain them at a constant temperature. This is sometimes done by immersing the cold ends in ice water or by having a water jacket around the ends through which there is a flow of water at some known temperature.

33. In the low-resistance thermo-electric pyrometer system, comparatively small changes in the actual resistance of the circuit, including couple, leads, and instrument, will produce sufficient effect to correct for atmospheric changes at their cold ends.

34. A compensating device to automatically correct for changes of atmospheric temperatures at their cold ends has been devised which makes it possible to dispense with the cumbersome means for maintaining the cold ends at constant temperature or the necessity for taking readings of temperatures at the cold ends.

35. This compensating device is shown in Fig. 8. It consists of a glass bulb with a short stem, similar to an ordinary mercurial thermometer. Two platinum terminal wires are fused into the stem near its top. These are connected within the bore of the stem by a loop of fine platinum wire, thus completing the circuit as indicated in the diagram. The size of the bulb, the

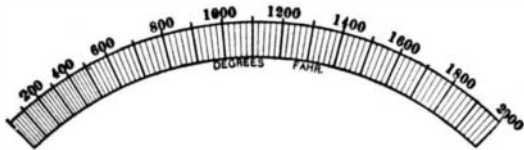


FIG. 7.

cross-section of the bore of the stem, and the cross-section of the platinum wire loop are proportioned to suit the case in hand.

36. The compensator will perfectly compensate for any particular point on the scale, as, for instance, the working point, where it may be desired that the reading shall be absolutely independent of changes of temperature at the cold ends. It will readily be seen that if the temperature rises at the cold ends the mercury rising in the stem will short-circuit a certain portion of the platinum loop, thus reducing the resistance of the entire circuit by exactly the necessary amount so that the diminished electro-motive force of the couple due to the rise of temperature of the cold end will send

the same amount of current through the circuit and instrument, and consequently give the same reading as if there had been no change of temperature at the cold ends.

37. The compensator acts on precisely the same principle, but in a reverse manner, when the temperature falls at the cold ends, the resistance of the circuit being increased as the column of mercury lowers in the stem. The increase produced in the resistance of the circuit prevents the increased electro-motive force of the couple due to the fall of the temperature at the cold ends from sending an increased current through the instrument, therefore the reading remains unchanged. The compensator may also be employed within the indicating instrument to correct for atmospheric changes of temperature upon the instrument itself where extremely accurate results are required.

38. It will be seen that a compensator of the form described cannot as conveniently and practically be applied to a high-resistance indicating instrument.

GENERAL ADVANTAGES OF THERMO-ELECTRIC PYROMETERS.

39. As compared with other forms of apparatus for measurement of high temperatures, the thermo-electric pyrometer has many advantages, of which the following are the most important:

They may be employed where the space is extremely small and inaccessible. They are practically independent of temperature variations intermediate of their hot and cold ends. They are independent of pressure and rough usage at the point where the temperature is desired to be measured.

40. The indicating instrument can be located at the most convenient point, practically at almost any distance from the couple. They are extremely sensitive to changes of temperature and respond instantaneously—that is, there is no lag error. They are constant in their indications when the couples are properly protected. They permit the determination of the temperature at many different points by means of several couples and leads connected to one instrument, provided with suitable switching device.

SPECIAL ADVANTAGES OF LOW-RESISTANCE SYSTEM.

41. The important advantages of the low resistance of thermo-electric pyrometer system may be summarized as follows:

First. A commercial switchboard or portable dead-

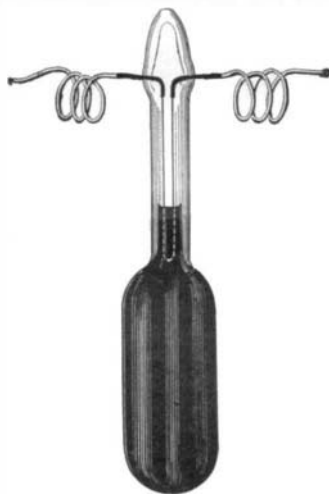


FIG. 8.

beat indicating instrument may be employed instead of the extremely delicate suspension galvanometer required for use with a single platinum-rhodium couple. This advantage is gained by the fact already stated, that the thermo-electric couples employed give several times as much electromotive force as the platinum-rhodium couples, which is ample to successfully operate a pivot instrument if of sufficiently low resistance.

Second. It affords a practical method for automatically compensating for the changes of temperature at the cold ends of the couple, as already described.

Third. It makes it practicable to use the same indicating instrument and the same couple for different total ranges of temperature by using different binding posts and having several scales drawn, the proper resistances being inserted for each individual total scale.

Fourth. The application of low-priced metals and alloys as a substitute for platinum and rhodium makes it possible to install a number of couples, and by means of proper switching devices use on instrument for quickly determining the temperatures at the locations of the different couples. In many instances the first cost of the expensive platinum elements prohibits their use in this way.

APPLICATIONS.

42. Many applications of this instrument will suggest themselves. A few of the important ones are mentioned, as, for example: in a boiler test where nineteen couples were simultaneously applied at different points between the furnace and the flue. From the data obtained a curve was drawn showing the temperatures at all points along the path of the products of combustion from the furnace to the flue, the abscissas corresponding to the square feet of heating surface, and the ordinates to degrees Fahrenheit. The value of such data for investigating and studying the economical working of steam power plants will be appreciated. The couple can readily be applied to the steam space of a boiler and used to show the degree of superheating.

43. These instruments have also been adapted to and are especially valuable in maintaining the desired

temperatures for annealing, hardening, tempering and bluing of steel.

44. When many small parts are handled, as in the manufacture of watches, a practical method of using the pyrometer is to adapt the pot containing the articles to the end of the couple and using it as a handle for inserting the pot into the furnace or into an ordinary forge fire. By revolving the pot it is heated perfectly uniformly, and as soon as the proper tempera-

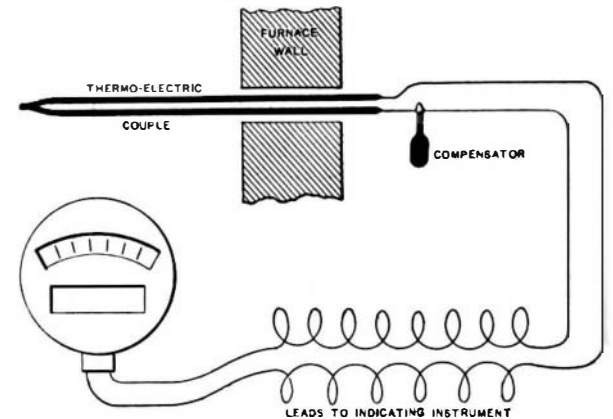


FIG. 9.

ture is reached it is known on the indicator, and all guesswork is eliminated.

45. They have been most successfully employed in lead-hardening baths. For this purpose the couples are protected by wrought-iron pipes, and will last for months without renewal. After constant daily use for many weeks the couples give the same readings as when first installed.

46. In addition to making it possible to obtain absolutely uniform results with a given lot of steel it has been found that the life of the pots has been increased, as they are not overheated. From this fact it naturally follows there must be an economy of fuel as a result of using the pyrometer.

47. Application has also been made by galvanizing baths, affording means for keeping the molten metal at the proper temperature for the work, preventing overheating and wasting zinc by vaporization.

48. They have been used to keep molten lead at correct temperature in the manufacture of shot.

49. These instruments have also been tried and are now being tested for indicating the temperature in the carbureter and superheater of a Lowe water gas plant.

50. Where the process of gas-making depends upon proper temperatures and the pyrometer shows when the steam and oil should be turned off and the blast turned on, and also when these operations should be reversed in order to obtain the most efficient results.

51. By using two or three couples in the carbureter it is possible to adjust the spray of oil so that every part from center to shell will be working to the best advantage.

52. The instruments have also been successfully employed in chemical works.

53. The field of usefulness seems to be very broad, as the instrument can be adapted to meet almost any individual requirement.

DISCUSSION.

Mr. Gus C. Henning stated that the simplicity and cheapness of the couple is also a very advantageous matter, and its interchangeability is unique.

The fact that temperatures can be correctly and continuously recorded is a great advantage.

With this apparatus the expert heater is no longer the most important personage in a works, and cannot play the tyrant as is so commonly the case. Once having determined proper temperatures in furnaces for different classes of work, these can always be reproduced and maintained, and it is no longer a matter of guesswork.

Moreover, one such apparatus with a switchboard makes it applicable to a great many furnaces at the same time.

Mr. Henry Souther said the use of a pyrometer in a

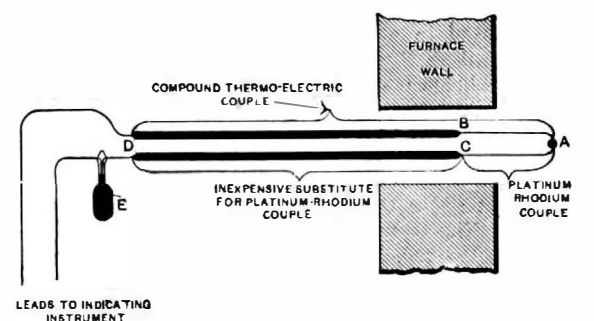


FIG. 10.

furnace where there are hot and cold drafts is always unsatisfactory, and he believed always will be. If the pyrometer is to be used in a furnace it should actually be buried among the parts or in the material being heated, and not subjected to the drafts of a furnace.

The ideal use for a pyrometer is in connection with a molten bath of lead, cyanide, salt, or whatever may be convenient. The temperature of such a bath can be perfectly measured, and the material immersed in it acquires the same temperature if left there long enough. The personal equation of the operator disappears almost entirely, which is not the case, nor can

it be in connection with a furnace where the couple is suspended over or near the work, and not actually in contact with it.

Prof. Bristol's thermo-couple will stand a lot of abuse, and, better yet, will stand immersion in molten baths for a considerable length of time. His electrical instrument is not of the delicate type peculiar to the high-resistance platinum, platinum-rhodium couple.

Mr. R. L. Penney, experimental engineer at Winchester Repeating Arms Company, New Haven, Conn., stated that in manufacturing firearms it becomes necessary in many cases to be able to determine quickly the temperatures of baths, furnaces, etc.

The first kind of pyrometer used was one made by one of the well-known companies, but we soon found this kind to be as variable as the weather, and could not be depended upon for anything like accurate work.

The Le Chatelier was then tried and found to give excellent results, but it was too delicate to be generally employed for shop use. It required a rigid foundation, and even then the fiber used to suspend the needle would break occasionally, besides trying to keep the temperature of the cold junction constant or at zero degree C. was very difficult.

Beginning with last June, we have introduced the William H. Bristol thermo-electric pyrometer, and at present we are using it in four different branches of our work, hardening, tempering, bluing, and annealing, also using it in place of the Le Chatelier for experimental work. The results obtained so far leave very little to be desired. The instruments are arranged so that the workman knows just what he is doing, and the element of doubt is eliminated.

The hardening furnaces each have a couple, a compensator, and a set of leads, while one instrument does for all. The instrument is placed on the wall in a place convenient for all the workmen; near it is a small switchboard containing a switch for each furnace, the switch having a common connection to the instrument. The leads are brought from the several furnaces to the individual switches. The furnaces and switches are numbered to correspond. By this means a workman, who, we will say, is working on No. 4, is required to keep his furnace at a certain temperature. He goes to the switchboard and throws in No. 4 and reads the temperature directly, without making any correction, without waiting for an oscillating needle to come to rest. The couples are introduced into these furnaces from the back, the fire-ends being inclosed in a porcelain tube. These couples have required no attention since they were set up.

The same scheme is applied to our tempering and bluing baths, using a lower range instrument. In these last two applications accuracy and permanency are very essential points.

With these pyrometers as now in use we are enabled to obtain results that are unchanging from day to day.

In annealing these instruments and couples are of great benefit. On account of the inexpensiveness of these couples we use two for each furnace, one to measure the temperature of the furnace and another to measure the temperature at the center of the box containing the work to be annealed. The leads from each couple are carried to a double-throw switch. The workman in charge throws the switch one way to find the temperature of the furnace, and the other way to find the temperature of the work.

The two couples are introduced together through the side of the furnace, one reaching into the furnace a short distance, and the other extending through the fire space into the center of the box through a hole in its side. This arrangement has been found to be satisfactory and enables the workman in charge to handle the furnaces as if they were machines, slacking and starting them up as necessary.

Having compared the Bristol pyrometer with the Le Chatelier and finding it accurate, we have used it for experimental work in many cases, of which the following is an example: Wishing to determine the rate of the rise of heat in a case of cartridges and the temperature at which they would explode, when heated gradually from the outside, two couples were introduced into the case, one a short distance and the other into the center. The instrument was about 90 feet distant, and heat was applied to the outside of the case, which was inclosed in a sheet-iron oven. The heating continued until all the cartridges had exploded. The cartridges exploded one by one, there being no general explosion. On examining the couples after the explosion they were found to be bent and twisted out of shape, but no indication of this was shown on the instrument during the experiment. One looking at the instrument would not guess that the couples were being used so roughly. The temperature rose steadily to a maximum and then dropped. If it had been necessary to use two platinum-rhodium couples this would have been an expensive and difficult matter.

We have found the Bristol pyrometer to be one that can be applied to every-day shop problems successfully.

STEREOSCOPIC EXAMINATION OF BANK NOTES.

ONE of the most accurate methods of examining a bank note, with a view to determining whether it is or is not genuine, involves the use of a stereoscope. If two authentic bank notes are adjusted and viewed in a stereoscope, the resulting image appears perfectly flat, since the images seen by the two eyes are precisely similar. If, however, one of the notes is not genuine, the slightest variations in the superscription produce relief effects, the printing appearing to stand out in some places, and to be recessed in others.

TIMES AND PLACES OF EARTHQUAKES.*

By Prof. H. H. TURNER, F.R.S.

THE occurrence of several disastrous earthquakes and eruptions during the last few months inevitably suggests the question whether all these events may not have a common and determinable origin. To avert any of these disasters, even to modify them in the slightest degree, may be entirely hopeless; but the vaguest foreknowledge of their probable occurrence might be of untold value in saving life and property. Has modern research obtained any clues which enable predictions to be made, or promise that prediction may be possible in the near future? It must be frankly admitted that as yet our knowledge is so slight as to have no commercial value; but still, there are one or two clues in the hands of those working at the subject which may ultimately lead them to more directly useful knowledge. We have learned something of the regions where earthquakes occur, and something of the times when we may specially expect them; and, though the something is in each case a very little, the magnitude of the issues involved lends it interest.

Systematic observation of earthquakes is only about a quarter of a century old, and for fairly complete records of all the shocks occurring in different parts of the globe we can date only from 1892. Before that date information could only be collected on the spot, and was thus frequently lost; but it was realized about 1890 that a series of earthquake observatories, with delicate instruments, could obtain records of shocks in any quarter of the globe, and identify the spot with certainty, even if there were no witnesses of the actual occurrence. From the records of these observatories it appears that there are every year some 30,000 minor shocks of earthquake in different localities, but of these only sixty are "world-shaking" and observable from a great distance. Such numbers indicate immediately that, from one point of view, the San Francisco earthquake cannot be regarded as exceptional; it was only one event out of sixty per annum. What rendered it disastrous was the existence of a great town in the shaken locality. But was the neighborhood known to be a dangerous one? Was it, at any rate, suspected, so that the building of a great city there was an error of judgment? And is it advisable to rebuild the city in the same place? These are questions of the gravest importance; and it is well worth while to review the little knowledge already accumulated with the utmost care to see whether it will give us even provisional answers to them.

Prof. Milne, in the tenth report of the British Association Committee, refers the "world-shaking" earthquakes observed in the six years 1899-1905 to thirteen great earthquake regions, designated by the first thirteen letters of the alphabet. Three of these—I, J, and L—are responsible for only five, three, and two shocks, respectively, and are thus of small importance compared with the others, which average about forty shocks each. Excluding them for the present, the remaining ten regions lie approximately in two rings on the earth's surface, a configuration which is most strikingly apparent when the regions are marked on a globe. The more important ring includes the following seven regions: A (Alaskan coast), B (Californian coast), C (West Indies), D (Chilean coast), M (south of New Zealand), F (Krakatoa region), and E (Japan). Its center is among the conspicuous group of islands which includes Tahiti, and the radius of the ring is about 65 degrees. The other ring has its center at the opposite point of the earth, which is in the Sahara Desert; and at a radius of 50 degrees from this center lie regions G (between India and Madagascar), H (the Azores), and K (Tashkend). Now, this is not merely a convenient geographical summary, but a physical fact of vital importance, according to recent researches of Prof. Jeans.

In a remarkable paper read before the Royal Society in 1903 he gave reasons for believing that the earth is by no means a sphere or a spheroid, as we have been accustomed to think, but is of a pear shape.

Under the gravitational stress it is continually approaching the spheroidal form—the pear is being crushed into a sphere by its own attraction, and the result is a series of earthquakes. These naturally occur in the weakest places, and if any one will experiment in crushing a pear toward a spherical shape, or even draw a diagram and consider where the weakest points would be, the reasons for the existence of two rings of greatest weakness will readily suggest themselves. The ends of the pear are the centers of these rings, one in Africa, one in the Pacific, and when once this is pointed out the pear shape of the earth is, according to Prof. Sollas, "obvious to mere inspection; it is a geographical fact and not a speculation." Prof. Sollas is indeed responsible for the particular suggestion above sketched, for Prof. Jeans had originally proposed a different axis, which he withdrew in favor of the obvious improvement. The confirmation of Prof. Sollas's view from the distribution of earthquake centers is remarkable. It does not seem, however, quite certain which is the blunt end of the pear; it has been hitherto placed in Africa, but there seem to be several reasons for regarding Africa as the stalk end. This point cannot, however, be dealt with here. The important thing is that there seems to be a real reason for the occurrence of earthquakes in these particular regions, and that they will probably continue to occur there. Prof. Jeans's conclusions have recently been examined by Lord Rayleigh, who announced at the

* London Times.

Royal Society only a few weeks ago that he found them generally confirmed, and that we must regard our earth as at present in a state far from stable.

The lessons to be learned from the distribution of earthquakes in space are accordingly tolerably plain in theory, though in practice we may not be able to take advantage of them. If we would be particularly safe from earthquakes we must take up our abode near one of the ends of the pear—either in Africa or in the Pacific. There is also a region of safety between the two dangerous rings—in America generally, for instance, excluding the West, or in Siberia. But the dangerous regions include so vast and so valuable a part of the earth's surface that it is impracticable to leave them unoccupied. Moreover, our knowledge is as yet not specific enough. In the dangerous regions themselves, some parts are much more dangerous than others; for instance, Japan, which is reckoned above as a single region, can be divided into at least fifteen distinct seismic districts. As observations are accumulated we may be able to make similar partitions of the other regions. For the present the general attitude toward earthquakes will probably be similar to that toward other dangers, such as those of travels and voyages for instance; the risk must be incurred. We know that there are at times fatal tornadoes, but other interests are at stake, and we put to sea in the hope that none will occur during our voyage.

We come to the second point, the distribution of earthquakes in time. Are there seasons of special activity such as the recent occurrence of several disasters seems to suggest? Here our knowledge is slighter still, and the observed facts have not yet been co-ordinated by a mathematical investigation. Still there seems to be some evidence in support of the view that exceptional irregularities in the rotation of our earth may be responsible for an increased number of earthquakes at particular times. That the evidence is slight must be attributed to the shortness of the time during which it has been possible to obtain it, and not necessarily to inherent weakness in the evidence itself. The brevity of the earthquake record has been mentioned above; that of irregularities in the earth's rotation is longer; but the discovery that such irregularities existed was made only twenty years ago, though the phenomenon was then traced back through the old observations. The irregularities are systematic in character, and the law governing them is approximately known already; so that, if the presumed connection between them and earthquakes is confirmed, we may be able to predict periods of great earthquake frequency. Such periods would be in some respects analogous to the times of spring tides.

It is a familiar fact that at new and full moon the tides are much greater than when the moon is at the quarters. The reason is that we have two tide-raising bodies, the moon and the sun, which sometimes act in concert, and then we get large tides; sometimes in opposition, and then we get small tides. If the influence of these two bodies were more nearly equal, instead of the moon being so predominant a partner, we can imagine times when the tides would be barely perceptible. Similarly there are apparently two contributors to the variation in our earth's rotation, which sometimes act in unison and sometimes in opposition. They are more nearly equal in influence than are our moon and sun, and consequently there are times when these two contributors nearly balance one another and the axis of rotation remains almost steady. But in due time the contributors reinforce one another and the axis acquires a considerable "wobble." Each end of the axis then describes a curve composed of wide sweeps and sharp bends, and the evidence seems to be that at the sharp bends we are particularly liable to earthquakes.

The exact statement of the case as given by Prof. Milne in his Bakerian lecture, "Recent Advances in Seismology," delivered before the Royal Society on March 22 last, is as follows:

"In a period of nearly thirteen years (1892 to 1904) I find records for at least 750 world-shaking earthquakes, which may be referred to three periods continuous with each other, and each two-tenths of a year, or seventy-three days duration. The first period occurred when the pole movement followed an approximately straight line or curve of large radius, the second equal period when it was undergoing deflection or following a path of short radius, and the third when the movement was similar to that of the first period. The numbers of earthquakes in each of these periods taken in the order named were 211, 307, and 232—that is to say, during the period when the change in direction of motion has been comparatively rapid the relief of seismic strain has not only been marked, but it has been localized along the junctions of land blocks and land plains, where we should expect to find that the stress due to a change of direction of motion was at a maximum. Until the magnitude of these induced stresses has been estimated it would be premature to assume that the frequency under consideration is directly due to change in direction of pole movement, it being quite as likely that both phenomena may result from a general cause."

It is eminently to be desired that a mathematical investigation of the point should be undertaken; but the difficulties are very great, and as yet no one has had the time and courage to attack them. It will be seen, then, that the seismologist is as yet not able to give forecasts of any commercial value, though he is by no means without hope of doing so.

There are, however, some lessons of immediate practical importance which have been learned by seis-