OUR ASTRONOMICAL COLUMN.

ASTRONOMICAL OCCURRENCES IN AUGUST:—

- August 8. 10h. 7m. to 10h. 44m. Occultation of μ Arietis (mag. 5.8) by the moon.
8. Saturn. Outer minor axis of outer ring, $17''\cdot37$.
8. 15h. Mercury at greatest elongation ($27^\circ 22'$ E.).
10. Meteoric shower from Perseus (radiant $45^\circ + 57^\circ$).
11. 14h. 49m. to 15h. 38m. Occultation of 118 Tauri (mag. 5.4) by the moon.
12. 12h. 31m. to 13h. 19m. Occultation of 8 Geminorum (mag. 6.5) by the moon.
15. Venus. Illuminated portion = 0.655, diameter = $17''\cdot4$.
15. Mars. Illuminated portion = 0.889, diameter = $6''\cdot0$.
15. Jupiter. Polar diameter = $29''\cdot8$.
15. Saturn. " " = $15''\cdot8$.
19. 6h. Venus in conjunction with Jupiter (Venus $1^\circ 51'$ S.).
23. 9h. 32m. Minimum of Algol (B Persei).
25. 10h. Mars in conjunction with Neptune (Mars $1^\circ 13'$ N.).
28. 12h. 53m. to 13h. 43m. Occultation of σ Capricorni (mag. 5.6) by the moon.

THE MINOR PLANETS.—Mr. John K. Rees, in a lecture before the New-York Academy of Sciences (*School of Mines Quarterly*, vol. xix. No. 3), delivered a very interesting discourse on the history of the discovery of the minor planets, a reprint of which has been sent to us. Mr. Rees describes from the beginning how, after the discovery of Uranus by Herschel, Prof. Titius, of Wittenberg, pointed out the existence of a remarkable symmetry in the disposition of the bodies constituting the solar system. It was he who suggested the relationship now known as "Bode's law," Prof. Bode putting into the place of the missing body a hypothetical planet. It is not generally known, perhaps, that Von Zach in 1785 actually calculated elements for this "unseen and unfelt body," and for fifteen years kept in his mind the need for a careful search. At the beginning of this century he organised, what was termed jocularly by him the "Celestial Police" to track and intercept this fugitive object, a force for the express purpose of systematically scanning the heavens; but it was left for the astronomer, Piazzi, who found the first of what eventually proved a series of small bodies, although he was carefully observing the heavens for quite another purpose, namely the formation of a star catalogue. This discovery of the minor planet Ceres was the first of many which followed, and the introduction of photography in this branch of observation has brought to light many small bodies which are now numbered in hundreds, besides rendering the task, which was beset with great difficulties, one that is now simplicity itself.

THE MOON AND AURORÆ.—From the earliest times the presence of auroræ was in some way connected with the influence of the moon, and there may be some, even to-day, who are inclined to hold to this opinion. Prof. H. A. Hazen, in the *Monthly Weather Review* (vol. xxvi. No. 161), discusses the evidence of such supposed influence, using as his data the observations made by the regular observers in the United States Signal Service. We need not, however, refer to the curves and tables which are brought together by Prof. Hazen, but simply quote the words which he uses in summing up the whole of the investigation in question. He says: "It will be seen readily that the whole theory of a lunar influence upon auroras breaks down from first to last under this analysis." That the appearances of auroræ may be connected with the periodicity of sun-spots is another matter, and it is here that probably a close connection exists.

Apropos of auroræ, we notice that Prof. Cleveland Abbe is publishing a very detailed and important historical account of the altitude of auroræ above the earth's surface as determined by observers all over the world. The first of these articles appears in *Terrestrial Magnetism* (vol. iii. No. 2), and is well worth reading by those who are interested in this important question.

MARS IN 1896-7.—Prof. V. Cerulli has just published, in the *Pubblicazioni dell'Osservatorio privato di Collurania* (Teramo) (No. 1), a most important memoir of the planet Mars, as observed by him during the period 1896-7. The volume covers

no less than 126 pages, and is accompanied by numerous plates, forming a valuable addition to our knowledge of this interesting planet. Perhaps a special feature of this publication is the determination of the latitudes and longitudes of sixty of the most prominent markings on the surface; and this will, without doubt, be found most valuable to those who wish to locate accurately any surface features which they may from time to time observe. In the remaining portion of the work Prof. Cerulli discusses these and other surface markings which were seen during this period of observation, and a comparison of these with the observations of others should be found of great interest.

RECENT WORK IN THERMOMETRY.

THERMOMETRY is one of those departments of physics which are left almost exclusively to specialists, and writings on the subject are apt to assume an amount of preliminary knowledge not possessed by physicists in general. There thus appears room for a brief account in popular language of recent progress. The space at my disposal being limited, I am obliged to confine my remarks to a comparatively small number of researches, and I can hardly hope that my choice of matter will meet with unimixed approval.

Thermometry possesses two main branches, which, though intimately connected, are yet more or less distinct. One branch deals with the detection of extremely minute differences of temperature, or the subdivision of small temperature intervals; the other aims at assigning a definite numerical value to temperatures on an exact scale. A worker in the first department may employ apparatus showing differences of one-millionth of a degree Centigrade, and he may even believe that he is measuring temperature to this degree of nicety. A worker in the second department, unless endowed with an exceptionally optimistic temperament, will probably not profess to measure temperature to nearer than the one-thousandth of a degree, and that only between the freezing and boiling points of water. Here I shall consider almost exclusively the question of the determination of temperature in absolute measure.

The first requisite is a normal scale to which all measurements can be referred. An ideal scale should be perfect in theory, and easily and exactly realisable in practice. From the former point of view, Lord Kelvin's absolute thermodynamic scale is generally regarded as *facile princeps*. In the meantime, however, it fails to satisfy the second condition. The International Committee of Weights and Measures, representing all the leading Powers, including Great Britain, accordingly selected in 1887 for the normal scale that of the hydrogen constant-volume thermometer, the gas when at 0° C. to be under the pressure of 1 metre of mercury under standard conditions; on this scale equal increments of temperature answer to equal increments of pressure. Apparently the choice was due mainly to two considerations, viz. the very low freezing point of hydrogen, and the existence of theoretical and experimental grounds for believing its scale to approach Lord Kelvin's absolute scale more nearly than that of any other common gas. Whether hydrogen will prove a manageable substance at high temperatures seems open to some doubt. Failure in this respect would be a serious drawback, in view of the rapidly increasing importance of high temperature measurements.

After the choice of a normal scale, we are next concerned with its relationships to other scales that are, or have been previously, in use. Here, however, one difficulty is conspicuously present. Nothing is commoner than such a statement as that a certain temperature was observed on the scale of the air thermometer; but there are air thermometers and air thermometers. Quite apart from the distinction between constant volume and constant pressure instruments, there are questions as to the pressure at 0° C., the purity of the air, the sufficiency or insufficiency of the corrections applied to the observed readings, and a host of others. In most investigations thermometry is but a means to an end, and observers are apt to treat somewhat lightly of preliminaries which are not of general interest. On the other hand, an observer is very apt to attach undue significance to the agreement between the several observations he makes, overlooking the fact that in thermometry such agreement need imply no

more than uniformity in the conditions and in the method of experiment. For these several reasons, in translating old temperature observations into the normal hydrogen scale, it would in general be a waste of labour to aim at the degree of accuracy possible in the best thermometric work.

Whilst the exact determination of other scales in terms of the hydrogen scale is from a historical standpoint less important than might appear at first sight, it is still rendered essential by the fact that for many practical purposes the hydrogen thermometer is inconvenient, and is unlikely to supersede other forms.

The most exact scale comparisons are doubtless those made at Sèvres, under the auspices of the international committee of weights and measures. These are described, with the exception of the most recent, in Dr. Guillaume's "Thermométrie de Précision," a work which all really interested in exact thermometry should study for themselves. Air being a composite medium, and so presumably less suitable for the basis of an exact scale than the elementary gases, has apparently not been dealt with at Sèvres; but the work there has included the comparison of the hydrogen, nitrogen and carbonic acid scales, especially of the first two. The investigation covered, in the first instance, the range -25°C. to $+100^{\circ}\text{C.}$, and was executed with great care by Dr. Chappuis. In point of time it preceded and, in fact, led up to the adoption of the hydrogen scale. The comparison of the gas scales was not direct, but through the intermediary of mercury thermometers. From the data on p. 258 of Guillaume's "Thermométrie," one learns that within the range 0° to 100°C. the difference between the hydrogen and nitrogen scales does not exceed $0^{\circ}\cdot011\text{C.}$, but at -25°C. it amounts to about $0^{\circ}\cdot016$. The differences between the hydrogen and carbonic acid scales are five or six times as large as these. The hydrogen temperature is algebraically less than the nitrogen or carbonic acid temperatures between 0° and 70°C. , but algebraically greater at temperatures below 0°C. In Guillaume's opinion it is probable that ordinary (constant volume) air thermometers give a scale near that of nitrogen, but lying somewhat on the side of the carbonic acid scale, *i.e.* more remote from hydrogen. The probable error in Dr. Chappuis' comparisons is given as $\pm 0^{\circ}\cdot001$ between 0° and 50°C. , and twice or thrice as great at either $+75^{\circ}\text{C.}$ or -25°C.

The differences between the several gas scales presumably increase as the temperature falls, but probably never become large. At all events, in 1896 Holborn and Wien (*Wied. Ann.*, vol. lix., 1896, p. 213), using constant volume thermometers (with, however, an initial pressure of only one atmosphere at 0°C.), found the hydrogen thermometer to read only about $0^{\circ}\cdot6\text{C.}$ higher than the air thermometer at -190°C. , a temperature close to the freezing point of air. Ten years earlier Olszewski found a difference of about 1° between the hydrogen and nitrogen scales at -150°C. ; but his thermometry was probably less exact. With only Olszewski's results before him, Guillaume infers that the hydrogen scale is almost certain to agree closely with the absolute scale, even at -220°C. ; and Holborn and Wien's observations lead them to a somewhat similar conclusion. Recent comparisons by Olszewski of hydrogen and helium thermometers (*NATURE*, vol. liv. pp. 378 and 544) are strongly confirmatory.

For every-day use, unfortunately, gas thermometers are somewhat cumbersome. The international committee accordingly assigned an important place in their programme to the determination of the relations between the hydrogen scale and that of the glass-mercury thermometers which they have selected as working standards. The thermal expansion of glass, though small, is not negligible compared to that of mercury, and varies in different kinds of glass. The international committee accordingly selected one special kind of glass, French *verre dur*, as standard. The selection of the glass does not alone suffice to fix the scale. No glass has yet been discovered whose behaviour is decided wholly by the existing conditions. When a thermometer after exposure to a temperature of 50°C. is placed in ice, it reads lower than it would have done prior to the exposure, and this depression of zero, as it is called, increases to a certain extent with the duration of the previous heating. It is thus necessary for high accuracy to decide on a uniform plan of dealing with this source of uncertainty. The plan adopted by the international committee is to refer every reading of a thermometer to a zero determined immediately after the reading. Under certain circumstances enough is known of the behaviour of *verre*

dur to permit of the substitution for the actual zero observation of results extracted from a table of zero depressions. After a reading is taken with a *verre dur* thermometer, a variety of corrections have to be applied. These are necessitated by inequalities in the bore or errors in graduation, by the influence of the external pressure exerted by the atmosphere and the internal pressure exerted by the mercury. Verification at Sèvres consists in evaluating and tabulating all the necessary corrections. After these corrections are applied, the result represents the temperature on the natural *verre dur*-mercury scale.¹ This scale has been compared with that of the hydrogen thermometer at Sèvres from about -38°C. to $+200^{\circ}\text{C.}$ Below -10°C. and above 100°C. the comparison is probably less exact than between these limits.

In considering the probable accuracy of temperature measurements made with *verre dur* thermometers, we have to take into account the consistency of readings taken with the same thermometer, the closeness of readings taken under the same conditions with different thermometers, and, from certain points of view, the degree of accuracy with which readings can be reduced to the hydrogen scale.

The consistency of readings taken with a single *verre dur* thermometer depends in the first instance to some extent on the success with which the correction tables have been constructed at Sèvres; it varies to a large extent with the skill of the observer, the conditions of the experiment, and the temperature to be measured. The ordinary *verre dur* standard thermometer is divided to $0^{\circ}\cdot1\text{C.}$ and read by estimation, with the aid of a lens magnifying from ten to twenty times, to $0^{\circ}\cdot001\text{C.}$ This involves subdivision of a space into hundredths by eye, a feat which the skilled observers at Sèvres accomplish with marvellous accuracy, but which is far beyond the powers of the ordinary experimenter. In some instances use can be made of a micrometer, but this can hardly be employed unless temperature is practically stationary; and, when this is the case, troubles are apt to arise from capillary action in the mercury. The more remote the temperature to be measured from that of the surrounding air, the greater, as a rule, is the probable error of an observation. Thus, speaking generally, observations between 0° and 40°C. are those capable of the highest accuracy; and here it would appear that the mean results obtained on different occasions by skilled observers for a fixed temperature with a *verre dur* thermometer may be expected to agree to within about $\pm 0^{\circ}\cdot001\text{C.}$

At temperatures below 100°C. the corrected readings of different *verre dur* thermometers on the same occasion show apparently about as good agreement as is to be expected from the readings of a single *verre dur* thermometer exposed on different occasions to the same fixed temperature. At temperatures, however, approaching 200°C. Dr. Chappuis found that the corrected readings of different *verre dur* thermometers might differ by as much as $0^{\circ}\cdot05\text{C.}$

The accuracy with which the relation of the *verre dur* to the hydrogen scale is known is hard to say. Until the Sèvres comparisons have been repeated at other places, under equally favourable conditions, there will always remain a certain amount of doubt as to the existence of possible local or temporary influences. In the meantime, it is not altogether reassuring that a recent partial comparison of the hydrogen and *verre dur* scales at 10° , 20° , 30° and 40°C. , by Dr. Chappuis, gives results differing from those of the original comparison at Sèvres by from $0^{\circ}\cdot001$ to $0^{\circ}\cdot007\text{C.}$

From the above data two considerations naturally arise. At temperatures between -20°C. and 100°C. the natural *verre dur* scale is probably that most easily and exactly realised in practice; and it is, perhaps, fully as correct to regard the present normal hydrogen scale as one deducible in a prescribed arbitrary way from the *verre dur* scale as to accept it as having any real physical existence. On the other hand, there is no such thing as a *verre dur* scale, unless we agree to neglect differences of temperature which are of the same order as differences actually found between different *verre dur* thermometers. At the present moment, for instance, we must apparently treat $0^{\circ}\cdot05\text{C.}$ as a negligible quantity in temperature measurements at 200°C. if we are to extend the *verre dur* scale to that point. It has to be borne in mind that identity in the chemical constitution of thermometer glass may not necessarily imply identity in temperature scale.

¹ For any natural glass-liquid scale, thermometer degree divisions include equal volumes of the bore.

Age or prolonged annealing may introduce an appreciable change in physical properties.

In addition to the work already referred to, a comparison has been made at Sèvres of the hydrogen scale with the natural scales of low range glass-alcohol and glass-toluene thermometers. At -70°C . on the hydrogen scale the toluene temperature is $-56^{\circ}\cdot63\text{C}$., as against about -63°C . on the alcohol scale. Notwithstanding its greater contraction of scale at low temperatures, toluene is preferred by Dr. Chappuis to alcohol, on the ground that the latter is much more difficult to get of uniform purity. At -70°C . differences of as much as 1° were observed in thermometers filled with alcohol supplied as pure by different first-rate chemists. Even with toluene thermometers, $0^{\circ}\cdot01\text{C}$. appears the limit of accuracy to be hoped for. English alcohol thermometers, I should explain, are not, as a rule, constructed to give temperatures on the glass-alcohol scale. The degree divisions are shortened as we go down the scale, in such a way as to make the thermometer, when exposed to freezing mercury, read $-37^{\circ}\cdot9\text{F}$.; this being the air thermometer temperature for freezing mercury according to Balfour Stewart's determination.

The thermometric work at the German Reichsanstalt¹ has included the comparison of the *verre dur* scale with that of several German glasses, notably the Jena glasses 16^{III} and 59^{III}. The former glass is fairly similar in character to *verre dur*; the latter is a boro-silicate glass capable of resisting very high temperatures, and showing exceptionally small depression of zero. Thermometers made of it, with compressed gas above the mercury to prevent boiling, supply a convenient means of measuring temperatures up to 500°C . or even 550°C . In such high temperature measurements it is often difficult to avoid having a long mercury column emergent above the bath or other source of heat whose temperature is in question. The consequent error can be found apparently with great accuracy by means of a special form of long bulb thermometer ("Faden-thermometer"). Dr. Guillaume, who apparently anticipated the Reichsanstalt observers in the idea, has curiously enough found it foreshadowed in the *Phil. Trans.* for 1777. Using the "Faden-thermometer," the Reichsanstalt observers apparently claim an accuracy of $0^{\circ}\cdot1\text{C}$. in comparisons made in a well-stirred bath at 500°C . They claim, however, an accuracy of $0^{\circ}\cdot02\text{C}$. in comparisons of Jena glass thermometers with the air thermometer between 100° and 300°C . Until these results are confirmed or similar accuracy is claimed by the Sèvres observers, a chronicler may perhaps be pardoned an attitude of reserve.

Even with the aid of compressed gas, the range that can be covered by a mercury thermometer is somewhat limited, in view of modern requirements; and within that range there are many cases in which other means of measuring temperature are preferable. Nearly every property of every natural substance is modified by heat, so that the possible ways of measuring temperature are practically innumerable. Several of the ways that have been proposed for measuring high temperatures are very ingenious and may have a great future before them; but the methods that have actually been utilised to an appreciable extent are but few. Of these the two that have been most to the front of late years have depended on the measurement of electric resistance and electromotive force respectively. The former method we may regard as embodied in the platinum-resistance thermometer. Its introduction and the improvements it has undergone are due mainly to Prof. Callendar and Mr. E. H. Griffiths, while its application to the determination of melting points of metals and alloys is largely due to Mr. C. T. Heycock and Mr. F. H. Neville. A clear description of the necessary apparatus and the mode of graduating platinum thermometers was given by Mr. Griffiths in *NATURE*, November 1895, p. 39. The essential fact is that a piece of platinum wire, suitably protected, is exposed to the temperature it is desired to measure, and its electrical resistance is found by a Wheatstone's bridge method. If R_1 be the resistance in steam, R_0 in ice, R at any other temperature, then

$$\phi t \equiv 100(R - R_0) \div (R_1 - R_0)$$

is termed the "platinum temperature." In common use ϕt is employed only to deduce a quantity t , connected with it through the relation

$$t - \phi t = \delta \{ (t/100)^2 - (t/100) \},$$

where δ is a constant, so chosen that t equals $444\cdot53$ when the

platinum wire is at the temperature of the vapour of sulphur boiling under standard pressure.

The investigations of Callendar, Griffiths, Heycock and Neville show that the values obtained in this way for t , over a range of at least 1000°C ., are very close in different samples of platinum wire, so that t represents temperature on what is at least very approximately a definite fixed scale. Further, Prof. Callendar found that the scale so arrived at approximates very closely to that of the air thermometer (at constant pressure) over at least the range 0° to 600°C .; whilst the values of t obtained by Messrs. Heycock and Neville for the melting points of silver, gold and copper, lie pretty close to the corresponding air temperature results obtained by Holborn and Wien at the Reichsanstalt.

If the wire of all platinum thermometers possessed the same value of δ , then every platinum thermometer would give the same ϕt when exposed to the same temperature t . We should then have a definite independent platinum scale, precisely as we now have a definite *verre dur* mercury scale between 0° and 100°C .

In reality, however, δ varies considerably—over at least 25 per cent.—in existing platinum thermometers, so that the present use of the term "platinum temperature" is open to criticism.

The question as to what is the best formula for use in platinum thermometry has been discussed by Mr. Hamilton Dickson recently in the *Phil. Mag.* (December 1897, p. 445, and June 1898). After considering Prof. Callendar's principal formulae, and others suggested at one time or another by him and Mr. Griffiths, Mr. Dickson decides in favour of the species

$$(R + a)^2 = \phi(t + b),$$

where a , b , ϕ are constants, and t is the temperature answering to a resistance R in the platinum wire. Mr. Dickson applies this formula to Prof. Callendar's original comparison with the air thermometer, to certain melting point determinations by Prof. Callendar and Mr. Griffiths, and to low temperature comparisons by Profs. Dewar and Fleming and by Messrs. Holborn and Wien.

Determining the constants in the several cases by the method of least squares, he finds the probable divergence of observed and calculated values to be of the order $0^{\circ}\cdot25\text{C}$.

The formula approved by Mr. Dickson is really of the type

$$t = a + bR + cR^2,$$

employed previously by Holborn and Wien in discussing observations made by them at the German Reichsanstalt. These gentlemen, perhaps owing to their less exact method of determining the constants, claim for their formula accuracy only of the order 1°C . Their comparison with the air thermometer extended down to -190°C ., so that it seems in any case a valuable tribute to the suitability of platinum thermometers for the measurement of low temperatures.

At high temperatures Holborn and Wien's experience of the platinum thermometer was not very favourable, the wire showing appreciable permanent changes. As Mr. Griffiths, however, points out, these changes occurred at temperatures to which platinum thermometers of the type he approves have frequently been exposed without any apparent ill effect. The preference expressed by Holborn and Wien for thermo-electric methods thus perhaps carries less weight than it might seem to deserve at first sight. It would certainly appear, as pointed out by Mr. Griffiths in *NATURE*, vol. liii. p. 390, that the determinations of the melting point of copper, about 1080°C ., by Heycock and Neville, with a variety of different platinum thermometers, agree considerably better amongst themselves than the corresponding results obtained by Holborn and Wien with thermo-couples.

Be this as it may, there can be no doubt that thermo-couples are very convenient instruments for high temperature measurements, and they have had hitherto a considerably wider use than platinum thermometers.

The physical quantity whose variations in the thermo-couple give temperature variations, is the total electromotive force in a circuit. The mainly active part of the circuit consists of two metals, one of whose common junctions is usually kept at a known fixed temperature, the other being exposed to the temperature it is desired to measure. The most widely used couple of late years has been Le Chatelier's, in which one metal is platinum, the other an alloy of platinum with rhodium (10 per cent. rhodium). The substitution of iridium for rhodium is not

¹ Described in various memoirs in the Reichsanstalt's *Wissens. Abhandl.* and in the *Zeitschrift für Instrumentenkunde*.

uncommon. Holborn and Wien have compared the Le Chatelier couple with the air thermometer at the Reichsanstalt up to 1450°C . In *Wied. Ann.* vol. lvi. p. 364, they say that the readings of different thermo-elements may be expected to agree within $\pm 5^{\circ}$ at 1000°C , while different observations with the same instrument agree better than this. They also say that properly prepared thermo-elements have remained unaltered for years, whether unemployed or subjected to frequent temperature changes, always provided they are not exposed to certain sources of contamination.

In their more recent low temperature work, already referred to, Holborn and Wien made further use of thermo-couples, but the metals chiefly employed were apparently iron and constantan.

In translating measurements of E.M.F., E , into air temperature, t , Holborn and Wien employ an ordinary algebraic formula

$$t = aE - bE^2 + cE^3.$$

Here, as usual, a , b , c denote constants, which may be determined by observations at three fixed temperatures.

The question of the most suitable type of formula to be applied to thermo-electric data is discussed very fully by Prof. S. W. Holman in the *Phil. Mag.* for June 1896. The three types he advances as most deserving of notice are

$$E = (\tau - \tau_0)\{a + b(\tau + \tau_0)\},$$

$$E = m(\tau^n - \tau_0^n),$$

$$E = m\tau^n.$$

In all E represents E.M.F., m and n constants to be determined by reference to fixed points, τ and τ_0 temperatures of hot and cold junctions measured from absolute zero, t ordinary Centigrade temperature of hot junction (the cold junction being supposed in ice). The first or algebraic type, in a special form, is usually associated in this country with the name of Prof. Tait. The second type is called by Prof. Holman the *exponential*, and the third the *logarithmic* (as lending itself readily to logarithmic calculation). The three types are applied by Prof. Holman to what he regards as the most notable series of recent observations. In addition to the high temperature observations of Holborn and Wien, already referred to, he considers a number of comparisons of platinum and platinum-iridium couples with constant-pressure air thermometers made by Barus in America, and less extensive series by other observers in France and Germany. Of the three types of formulæ, the algebraic proved the least suitable for application to a wide temperature range.

In a later paper in the *Phil. Mag.* (vol. xlii., 1896, p. 37), Prof. Holman, with Messrs. Lawrence and Barr, apply the three above specified formulæ to observations of their own with couples of platinum and platinum-rhodium at the melting points of aluminium, silver, gold, copper and platinum. The constants in the formulæ were determined from the same three fixed points, viz. the ice point, the boiling point of sulphur at standard pressure, and the melting point of gold. For the second point Callendar and Griffiths' value $444^{\circ}\cdot 53^{\circ}\text{C}$. was accepted, and for the third point Holborn and Wien's mean result 1072°C .

Observations were taken at the boiling points of water and naphthalin, as well as at the melting points of the several metals. The temperatures calculated from the three formulæ agree closely for the copper point—which lies near the gold point—and fairly closely for the silver point. For the naphthalin point the calculated values differed from the true air scale temperatures by from 4° to 12° , and the errors in the calculated values for the steam point were fully as large. If the authors are correct in their opinion, "so far . . . as constant or variable instrumental errors are concerned, it is believed that no error beyond $0^{\circ}\cdot 5$ to 1°C . exists in the results," we must conclude that further inquiry into thermo-electric methods is highly desirable.

Thermo-electric methods lend themselves fairly readily to the study of gradual temperature changes, the spot of light reflected by the mirror of the galvanometer measuring the E.M.F. being thrown either on a screen or on a photographic plate actuated by clockwork. Prof. Roberts-Austen (*Roy. Soc. Proc.*, vol. xlix., 1891, p. 347) has inaugurated investigations by this method¹ into

¹ Since this article was written there has appeared in the *Phil. Mag.* for July 1898, an interesting paper by Mr. A. Stansfield, describing improvements in Prof. Roberts-Austen's recording pyrometer, and discussing thermo-electric results. Mr. Stansfield obtains $E = a\tau + b \log \tau + c$, for the relation between E.M.F. and temperature, measured from the absolute zero. His melting points agree well, on the whole, with the determinations of Heycock and Neville.

the phenomena accompanying solidification of metals. Prof. Callendar, on the other hand (*Trans. Roy. Soc. of Canada*, 1897, p. 34), has recently applied the platinum thermometer in the continuous registration of the changes of earth, water and air temperatures; and, unless my memory deceives me, bare wire resistances have been used previously for the last-mentioned purpose.

Thermo-electric and electrical resistance methods are also specially applicable to the measurement of minute temperature differences. As examples of this application, we may take the bolometer of Langley and the radio-micrometer of Boys (*Phil. Trans.*, 1889, p. 159). The former instrument in its most approved shape—as in use at the Astrophysical Observatory at Washington—has been described very recently by Prof. Langley himself (*The Smithsonian Institution*, 1846-96, pp. 419-442, Washington, 1897). Its main use at Washington is in mapping out the infra-red spectrum and determining the intensity of the solar radiation at different wave-lengths. It is simply an electrical resistance thermometer, the resistance being that of a "metallic tape usually about $\frac{1}{8}$ -inch long, but narrower and far thinner than a human hair . . . this, at present, may be arranged to record changes of temperature as small as one-millionth of a degree." Prof. Langley has devised the means of producing a uniform relative motion of the bolometer and solar spectrum, and obtaining an exact photographic record of the varying heating effect; and in this way he has apparently enormously reduced the labour of mapping the spectrum.

The radio-micrometer, on the other hand, consists essentially of a thermo-electric circuit—the principally effective junction being that of bismuth and antimony—which is suspended by a quartz fibre and is capable of rotation in an intense magnetic field. It is especially suitable for measuring the radiation from a distant or feeble source of heat, the radiation being received on a metal surface in immediate connection with the bismuth antimony junction. The delicacy of the instrument varies greatly with the shape of the circuit and the fineness of the quartz fibre suspension. According to Mr. Boys, it would be possible with the most approved pattern to detect with certainty "a temperature difference of less than one two-millionth of a degree Centigrade." Whether this has been realised in practice, I do not know.

A *differential* radio-micrometer was employed some years ago by Mr. W. E. Wilson and Mr. P. L. Gray (*Phil. Trans. A*, 1894, p. 361) in experiments in which solar radiation was balanced against the radiation from a strip of platinum heated to various known temperatures. The object of the research was to determine the mean effective temperature of the sun. The method is one which would seem capable of numerous useful applications.

As already stated, thermo-electric and electrical resistance methods are by no means the only ones, in addition to gas thermometry, for which high accuracy is claimed in high temperature measurements. There is, however, only one other method to which I shall refer here, viz. the expansion of solids. This is, of course, a very old method, and is generally employed only for commercial purposes for which high accuracy is not aimed at. In 1891, however, Dr. Joly applied the principle in a new special form of instrument, the *meldometer*, for which high accuracy is apparently claimed as a means of determining melting points. The essential part of the instrument is a thin strip of platinum, kept stretched by a spring and heated as required by an electric current. A minute quantity of the substance under examination is placed on the strip, whose temperature is raised until the substance melts. There is delicate means of measuring the lengthening of the strip, and the corresponding temperature is deduced with the aid of a preliminary calibration, based on observations at two or three known melting points. The *meldometer* has been used by Prof. Ramsay and Mr. Eumorfopoulos (*Phil. Mag.*, vol. xli., 1896, p. 360) in determining the melting points of a large number of salts, and these observers seem to think highly of it. A *meldometer* strip was also the source of heat, whose radiation was compared with that of the sun in the experiments of Messrs. Wilson and Gray already referred to. Having had no personal experience of the *meldometer*, I can only say that I should hardly expect it to rival in accuracy either the thermo-couple or the electrical resistance thermometer; but the smallness of the quantity of material required, is unquestionably a recommendation to its use in determining the melting points of rare or precious substances.

C. CHREE.