The drawtube can easily be set to 2 mm. when focusing, and as the image is over 20 cm. from the objective in all cases, the resulting error in intensity due to focusing is not greater than 2 per cent. This corresponds to 1° C. in temperature, showing that an error of even 5 mm. in focusing the drawtube will not produce an appreciable error in temperature estimation.

Often, in use, the distance of the instrument from the objects studied needs to be changed considerably, and in rapid work it is not always convenient to refocus; a change in this distance of a fourth of its value, i.e., from 120 cm. to 150 cm., will produce an apparent change in intensity of only 9 per cent, or about 5° C. in temperature. That these errors of focusing are so small when interpreted into temperatures, showing that no unusual precautions are needed, is evidently of great convenience in the use of the instrument.

The nonmonochromatism of the red glass in the eyepiece produces no considerable error in temperature measurement up to 1600° C., although if this glass is not very nearly monochromatic the differences in hue in the two adjacent photometric fields — from the comparison lamp and other sources — are very troublesome, and the strain on the eye in matching them is considerable. For the best work at high temperatures a better glass than is usually furnished with the instrument must be used (see page 335).

There remains to be considered the error introduced due to uncertainty in the knowledge of the coefficient of absorption of the absorbing glasses. If an observation (N') is taken with, and then one (N) without, an absorption glass, we have

$$k = \left(\frac{N'}{N}\right)^2,$$

so that the accuracy in determining k depends directly upon the precision of setting and reading the cat's-eye opening. Errors of over 5° at 1000° C. can hardly occur from this cause, although the determination of k is the most difficult and uncertain of all the operations in optical pyrometry.

Modifications of the Le Chatelier Pyrometer. — For use in technical works and other places where there are sure to be strong drafts of air causing unsteadiness of the flame of the oil comparison lamp, the Le Chatelier pyrometer might be improved by the substitution of an electric incandescent lamp of low voltage (six) placed before a uniformly ground diffusing glass screen, which, illuminated by the incandescent lamp, becomes the constant-comparison source. The electric lamp may be mounted in a vertical arm which serves at the same time as a handle, and then the instrument becomes nearly as portable as an opera glass. The reliability of such a method of producing a comparison light of invariable intensity will be discussed when describing the Wanner instrument. Other modifications will be discussed under the Féry and Wanner optical pyrometers.

The Shore Pyroscope. — In this instrument (Figs. 112, 112 A) the principle used is similar to that of the Le Chatelier optical pyrometer, the parts being arranged in a slightly different manner. The temperature is read directly off a scale controlled by the diaphragm; the telescope is movable about a horizontal axis, and the lenses are protected by easily removable cover glasses. In taking an observation, the diaphragm is turned until the object sighted upon and the flame, viewed by reflection, are of the same brightness.

Féry Absorption Pyrometer. — This is similar to Le Chatelier's instrument, except that a pair of absorbing-glass wedges p, p' replaces the iris diaphragm; and the 45° mirror G, with parallel faces. is silvered over a narrow vertical strip, giving a photometric field of form shown at ab, when looking at a hot crucible. The instrument also has a fixed angular aperture, so that no correction has to be made for focusing or for varying distance from furnace. The comparison light L plays the same rôle as in Le Chatelier's pyrometer, and the range of the instrument may be similarly extended by the use of auxiliary absorbing glasses A, A'. Féry has in addition made his instrument movable about a horizontal axis, which is a convenience in sighting.

The *calibration* is equally simple. If x is the thickness of the

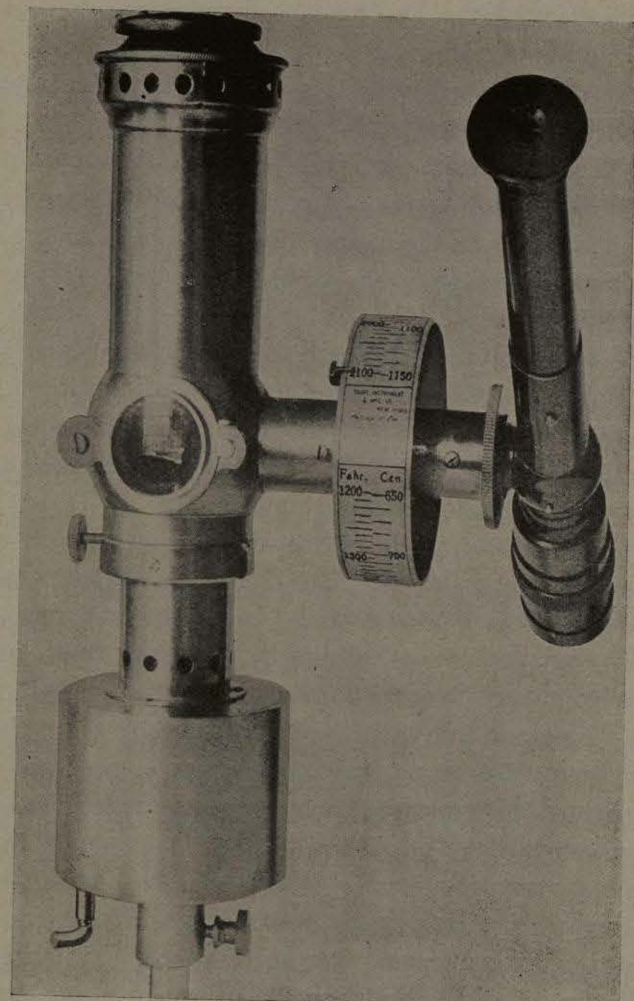

Fig. 112. Shore Pyroscope.

wedges, read off on a scale, when the light from the comparison lamp and furnace is of the same brightness, then the relation between brightness I and thickness of wedge is

$$I = c\epsilon^{kx},$$

where k is the coefficient of absorption of the glass of the wedges for the red light used and c is a constant.

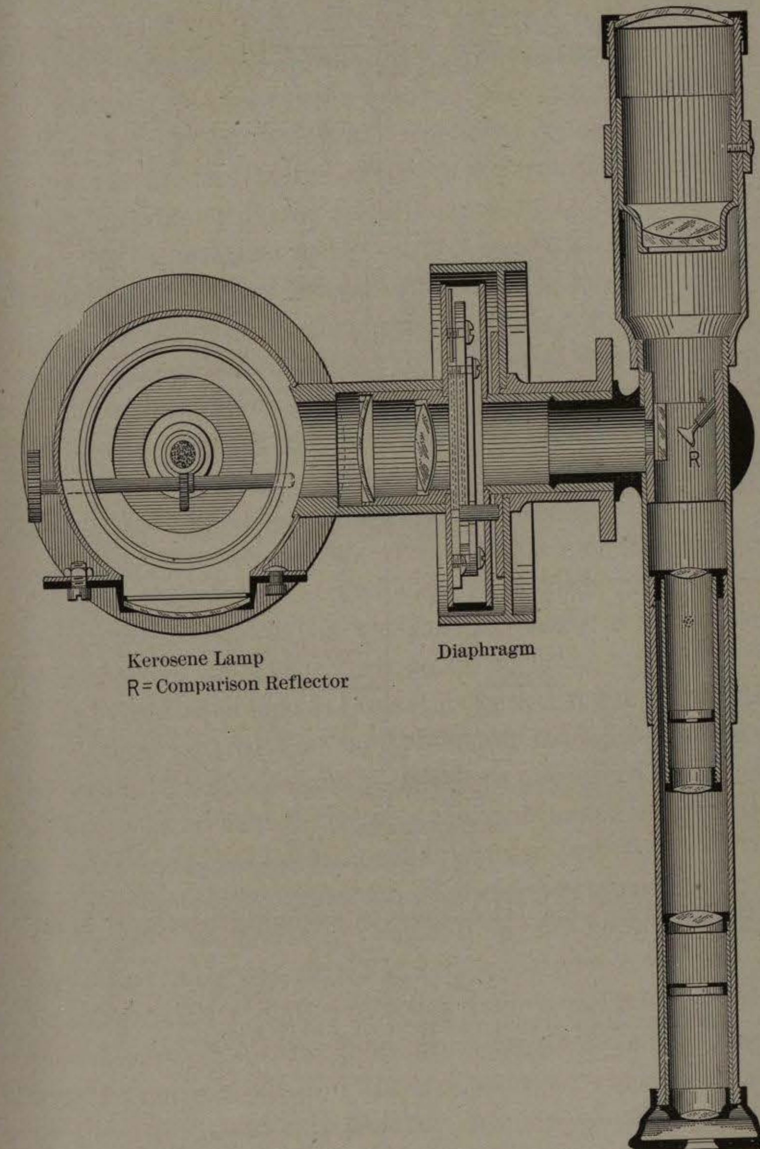

Fig. 112 A. Shore Pyroscope, Section.

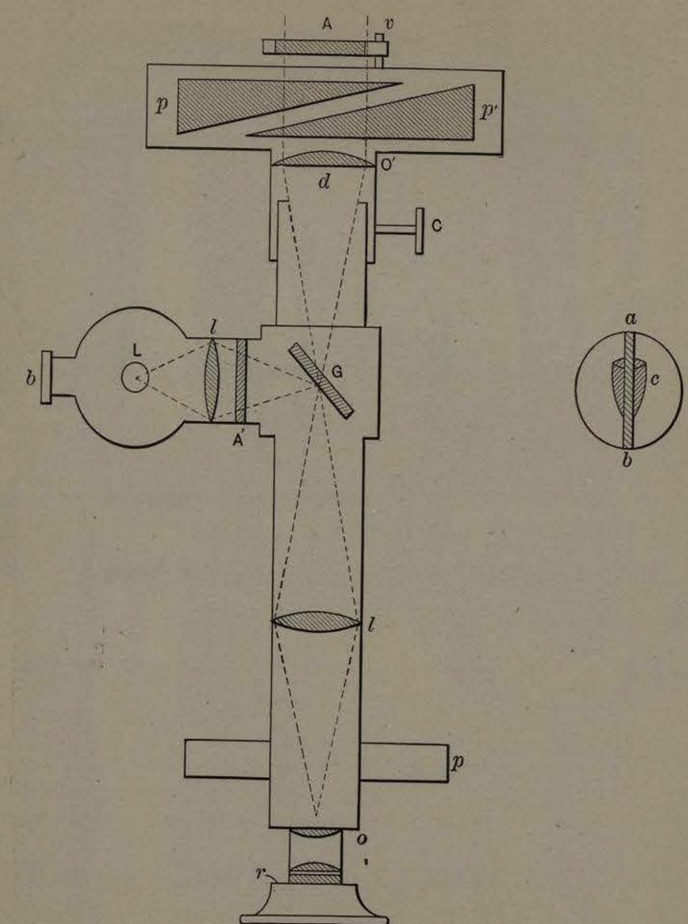

Fig. 113. Féry Absorption Pyrometer.

But by Wien's law III (page 251), assuming it to apply here,

$$I = A\epsilon^{-\frac{B}{T}},$$

or combining these two equations we have

$$c\epsilon^{kx} = A\epsilon^{-\frac{B}{T}},$$

whence

$$kx + C = \frac{-B}{T}.$$

Thus it follows that the thickness of the wedge is inversely proportional to the absolute temperature, so that the calibration

may be effected by finding the thickness of wedge for two temperatures only and plotting a straight line and constructing a table giving I and T respectively in terms of x.

It is questionable if there is any gain in substituting the wedge for the cat's-eye in the desire to extend the range over which the instrument may be used without employing the auxiliary absorbing glasses, for thereby the sensibility is somewhat reduced, and, more important still, the wedge instrument cannot be used at such low temperatures as the original Le Chatelier form, nor is there any gain in simplicity of calibration and ease of manipulation. The shape of the photometric field, the use of an aperture of constant angle, and making the instrument movable about a horizontal axis, however, are improvements over the Le Chatelier instrument; and the Féry instrument enjoys the further advantages that it may more conveniently be sighted on small objects, and fewer absorption glasses are needed.

Wanner Pyrometer. — Wanner, making use of the polarizing principle discarded by Le Chatelier, has brought out a photometer pyrometer which is a modification, suited to temperature measurements, of König's spectrophotometer.

The comparison light is a 6-volt incandescent lamp, illuminating a glass matt surface; monochromatic red light is produced by means of a direct-vision spectroscope and screen cutting out all but a narrow band in the red, and the photometric comparison is made by adjusting to equal brightness both halves of the photometric field by means of a polarizing arrangement.

The slit S_1 is illuminated by light from the comparison source, a small 4-volt electric lamp (Fig. 115), not shown in the Fig. 114, reaching S_1 after diffuse reflection from a right-angled prism placed before S_1. Light from the object whose temperature is sought enters the slit S_2. The two beams are rendered parallel by the lens L_1, and each dispersed into a continuous spectrum by the direct-vision prism P. Each of these beams is next separated by a Rochon prism R into two beams, polarized in planes at right angles. Considering only the red light, there would now be four images formed by the lens L_2 and distributed about the slit S_4. In order to bring two red images oppositely polarized exactly before this slit, a bi-prism B is interposed whose angle is such as to effect this for two images only, at the same time increasing the number of images to eight. There is now in the field of view before the Nicol analyzer, A, two contiguous red fields composed of light oppositely polarized, the light of one coming from S_1 alone, and of the other from S_2 alone. All the other images are cut off from the slit S_4. If the analyzer is at an angle of 45° with the plane of polarization of each beam, and if the illumination of S_1 and S_2 is of the same brightness, the eye will see a single red circular field of uniform brightness. If one slit receives more light than the other, one-half of the field will brighten, and the two may be brought to equality again by turning the analyzer carrying a graduated scale, which may be calibrated in terms of temperature.

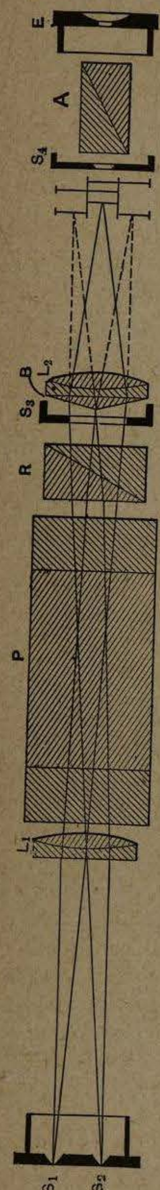

Fig. 114. Wanner Pyrometer, Section.

If the analyzer is turned through an angle ϕ to bring the two halves of the field to the same brightness, the relation between the two intensities from S_1 and S_2 is

$$\frac{I_1}{I_2} = \tan^2 \phi.$$

Calibration.—Since monochromatic light is used, and the comparison beam and that from the object examined undergo the same optical changes, Wien's law III may form the basis of the calibration.

As constructed and generally used, the 45° position of the analyzer when setting on the standard corresponds most conveniently to some intermediate arbitrarily chosen position on the graduated scale (Fig. 115) of the instrument. This reference position or "normal point" is the scale reading to which the instrument must be adjusted, by varying the current through the comparison lamp or its distance from the slit S_1, when sighting upon the standard amyl-acetate flame. The positions of the flame and pyrometer are fixed mechanically (see Fig. 115). The flame height must be carefully adjusted and the lamp should burn some ten minutes before standardizing.

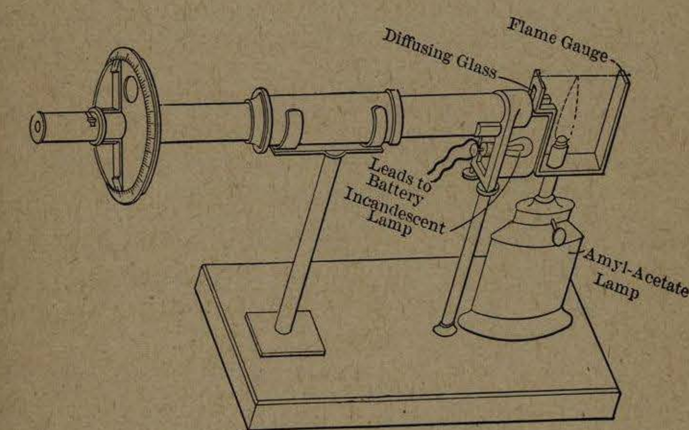

Fig. 115. Wanner Pyrometer.

If I_0 is the intensity of light from the standard amyl-acetate lamp, T_0 the corresponding equivalent temperature absolute, and ϕ_0 the reading in degrees on the scale of the instrument for the "normal point," and I, T, and ϕ are the intensity, apparent temperature, and scale readings when sighting upon the object whose temperature is sought, we have

$$\frac{I_0}{I} = \frac{\tan^2 \phi_0}{\tan^2 \phi}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (a)$$

assuming the circle to be uniformly graduated and the optical parts in adjustment. Also Wien's law III (page 251) gives us

$$\log_{10} \frac{I_0}{I} = \frac{c_2 \log \epsilon}{\lambda} \left(\frac{1}{T} - \frac{1}{T_0} \right). \quad . \quad . \quad . \quad . \quad . \quad (b)$$

Since the constant $c_2 = 14{,}500$ for a black body and $\lambda = 0.656\ \mu$ as the instrument is usually constructed, a knowledge of the apparent black-body temperature of the standard source, together with the reading of the analyzer scale at the normal point when $I = I_0$, for such an instrument, is all the data required for its calibration, as any temperature may then be calculated by means of equations (*a*) and (*b*) in terms of the scale readings. The apparent temperature T_0 of the amyl acetate may be taken as 1673° abs. or 1400° C. This instrument may also, of course, be empirically calibrated in terms of the readings of a thermocouple, using a black body to sight upon (see p. 241).

The actual computation involved in a calibration is very simple, and is readily done graphically in a manner similar to that suggested for the Le Chatelier optical pyrometer. From equations (*a*) and (*b*) above we have

$$\log \tan \phi = a + b \cdot \frac{1}{T}, \quad . \quad . \quad . \quad . \quad . \quad (c)$$

so that if $\log \tan \phi$ is plotted in terms of $\frac{1}{T}$, we have a straight line of which b is the tangent and a the intercept on the $\log \tan \phi$ axis. If a and b are known for the type of pyrometer used, a single calibration temperature suffices, otherwise two observations of T and ϕ are required to completely solve (*c*). It is safer, however, to take several temperatures and draw the line best representing the observations according to (*c*). A table or a curve of $\phi\ vs\ t\ (= T - 273)$ may then be constructed for practical use.

It is evidently necessary to be able to always reproduce exactly the standard intensity I_0. Now, the brightness of an electric lamp will vary with the current through it, so it is necessary to check frequently the constancy of illumination of the slit S_1 against a standard source of light. The amyl-acetate lamp and ground-glass diffusing screen are placed before the slit S_2, thus reproducing the standard light required. The analyzer is then set at the previously determined normal point and the distance of the electric lamp from S_1 adjusted or the current through the lamp changed by a rheostat, until the two fields appear of the same brightness.

In the latest form of this instrument the details of its mechanical construction have been improved, and it has been made direct-reading by providing a second scale on the instrument graduated in temperatures, corresponding, of course, to a definite normal point and for a source approximating a black body.

The amyl-acetate standardizing lamp may be eliminated wholly or in part in the use and calibration of the Wanner pyrometer. If the electric comparison lamp be fixed in position, the reading of the instrument sighted on a black body at a single temperature, as the gold point (adjusting the scale to a conveniently located "normal point"), or better, at a series of known temperatures, may be taken, for a definite current through the comparison lamp. If this same current is always maintained in the use of the instrument, this calibration will hold as long as the lamp does not change nor the optical parts of instrument become deranged. This last method of use is preferable in exact work where calibrating apparatus is available. The normal point, however, may still be that given by the amyl acetate if so desired. Or, the amyl-acetate standard with its corresponding normal point may be retained, but used only occasionally for checking and adjusting the constancy of the pyrometer, whose uniformity of indications is maintained in the meantime by keeping the current constant in the comparison lamp when taking measurements, and keeping the comparison lamp in a fixed position.

According to Nernst and Wartenberg, it may also be necessary to correct the circle readings by a constant fraction; thus they found that for a certain Wanner instrument the ratio $\frac{\tan^2 \phi_1}{\tan^2 \phi_2}$, taken over the scale by means of a sector disk, was not constant, but that the expression $\frac{\tan^2 m\phi_1}{\tan^2 m\phi_2}$ was constant, where m is nearly unity.