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AN OPTICAL LEVER MANOMETER.

BY J. E. SHRADER AND H. M. RYDER.

SYNOPSIS.—To meet the demand for a gauge which will measure vapor pressures in the range between that which can be measured by the Knudsen Gage (.001 mm.) and the ordinary mercury manometer, a new type of gage has been devised. This consists of a rather large mercury manometer in one arm of which a small optical lever is so adjusted that it measures small changes in level due to differences of pressure. The range of the instrument for accurate work is from .001 mm. to 3 or 4 mm. The instrument can also be used as a differential gage with the same accuracy. In use the changes in pressure can be observed by the deflection of a beam of light and may be recorded by a photographic device. Curves are given from a photographic record of the action of the gage during the release of CO_2 and water vapor which had been frozen out in a trap with liquid air. Attention is called to the rapidity with which this gage responds to changes of pressure.

THE McLeod gage has long served as a means of measuring pressures of several millimeters or mercury down to the order of 10^{-5} mm. There are two fundamental cases, however, to which this gage is not applicable in this range, that is, when vapors are to be measured, and where there is a rapidly changing pressure to be recorded. In the first of these cases the McLeod gage becomes useless, due to the fact that Boyle's Law is not applicable to vapors. In the second case the McLeod gage, in its most favorable form, may be much too slow moving, and has no recording feature.

At the present time, when many pumps are on the market which enable more or less leaky systems to be maintained at low pressures, it has become desirable to determine accurately vapor pressure of many substances at pressures below those usually recorded. One of the writers[1] has reported a method of obtaining low vapor pressures accurately, which in a simplified and refined form is capable of operation down to the lower limits of the McLeod gage, but which is applicable to only a certain class of substances, namely those which can be distilled within range of tem-

[1] Ryder, Journal Franklin Institute, Vol. 186, No. 1, July, 1918.

peratures available in the laboratory for such work, and which is not suitable for rapid determinations. The ability to observe rapidly changing pressures, or to record them, would mean, too, the facilitating of a number of operations in the laboratory or shop.

One of the writers[1] has given a preliminary report of a gage designed to provide for the particular requirements suggested in the foregoing. It is the object of this paper to describe the essential details of this gage, and to give a few examples of its actual performance.

The principle of this gage is shown in Fig. 1. A mercury U-tube manometer is formed in the usual manner, except that the surfaces of the mercury are so arranged as to be of relatively large area. Above one

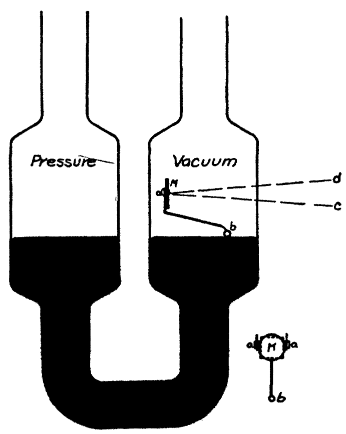

Fig. 1.
Optical Lever Manometer.

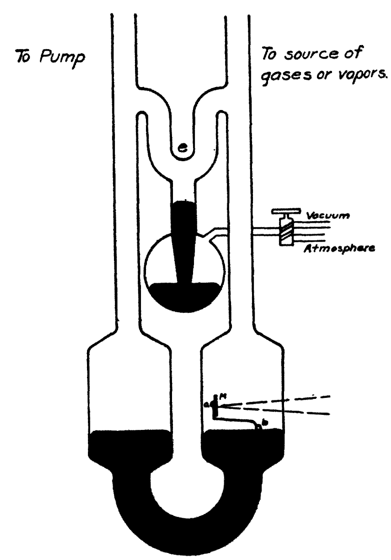

Fig. 2.
System for Manometer.

of the surfaces, within the tube, is arranged an optical lever, as shown in the figure. This lever is supported by two knife edges, *a–a*, which rest on loops of wire, which in turn are sealed into the glass walls of the tube, a glass bead *b*, fused to the end of the lever arm acts as a float on the mercury surface, and in this way transmits the motion of the mercury surface to the lever arm. A mirror *M* attached at the position shown acts in the usual manner to reflect a beam of light from the lamp *c* to the scale *d*, if the gage is to be arranged as an indicating instrument. If the gage is to be used for recording variations in pressure, the scale may be replaced by a photographic device such as is used in oscillographic work.

[1] Shrader, Pittsburgh Meeting, American Physical Society, December, 1917.

Fig. 2 shows a convenient method for connecting this gage in a system. The cross connection *e* provides an easy means of evacuating the whole system with one pump located as shown. With this stop-cock or mercury cutoff open, a zero reading can be easily obtained, after which this connection may be closed and the gases or vapors introduced for measurement. This system provides also for the measurement of small variations in pressure, with an original pressure of any desired value, this value in no way affecting the absolute sensibility of the gage.

The gage as shown is a primary instrument, since the pressure corresponding to any deflection on the scale may be calculated from dimensions which may be readily determined. The lowest pressure which may

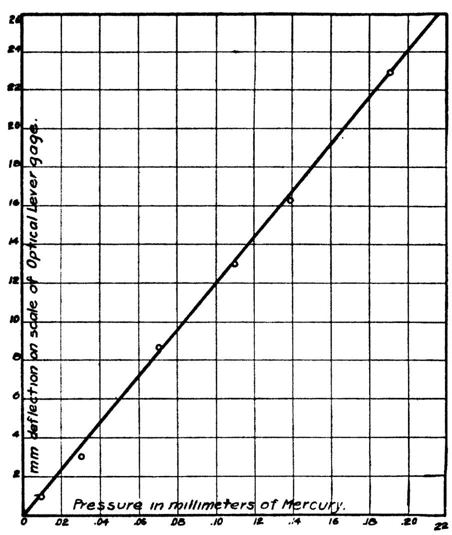

Fig. 3.

Calibration curve for an Optical Lever Gage.

be observed with the gage is that which gives the minimum appreciable movement of the mercury, and has been determined by experience to be approximately one thousandth of a millimeter of mercury in a properly designed gage. The upper limit, is, of course, determined by the dimensions of the gage, and is easily made to overlap the lower accurate readings of an ordinary U-tube manometer. The only source of error which need be considered is that due to the adhesion of the mercury to the walls of the tube, the deflection being therefore less than the actual value. If the mercury is very clean, and the glass in good condition a large mercury surface reduces this error to a negligible quantity. Mercury surfaces of from 5 cm. to 10 cm. diameter are in use. Some gages have had a window of plane glass at the point of transmission through the tube of the beams of light, to prevent any possibility of a refraction of the beams due to the curvature of the glass.

Fig. 3 shows a check curve plotted between scale readings of this "optical lever" gage as ordinate and the actual pressures, as measured by a McLeod gage (hydrogen being the gas used). It will be seen that with this gage, up to the limit of this curve, .2 mm., a straight line relation exists. Above this point, the line is slightly curved, due to the flat scale used, and to the angular movement of the lever arm. This curve shows, too, the variations from the true value which may be expected from consecutive readings. The relative variation of this curve from its calculated position depends principally on the accuracy of the calculation. A convenient method of obtaining accurately the lever arm ratio consists in mounting the lever in a vessel of known cross sectional area

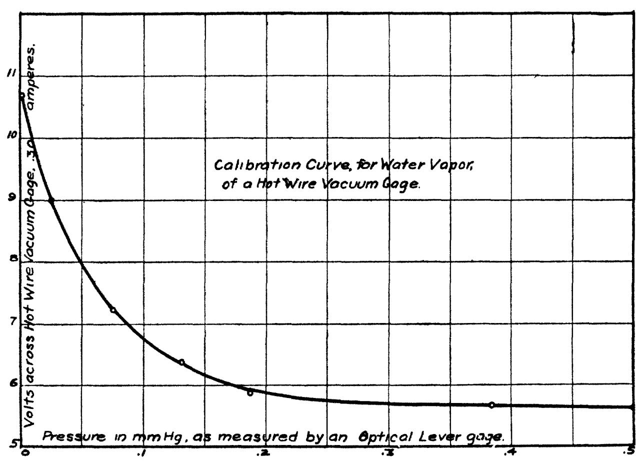

Fig. 4.

Use of Optical Lever Gage as a Primary Instrument.

with the float resting on mercury, in its normal position. When small known amounts of mercury are added, the movement of the beam of light on a properly placed scale may be observed, and the lever arm ratio calculated.

By means of this gage as a primary instrument the use of the hot wire gage[1] may be extended to the measurement of vapor pressures. Fig. 4 is a calibration curve for the hot wire gage for water vapor, the pressure being determined by the "optical lever" gage.

Fig. 5 is a reproduction of a graphic chart obtained by using the

[1] Pirani, Verh. I. Deutsch Phys. Gesell., 24, p. 686, 1906.

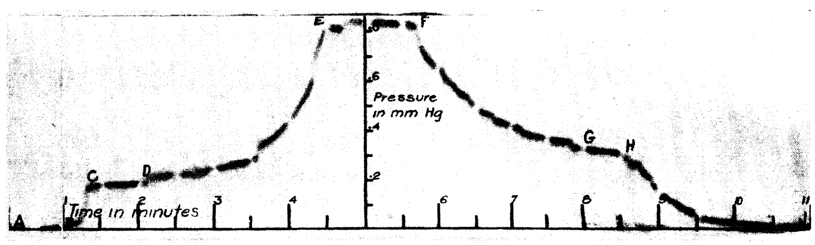

Fig. 5.

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"Optical lever gage." The apparatus used was that shown in Fig. 2 with the addition of a tube arranged for immersing in liquid air, connected to the right leg of the U-tube. At the point *A* on the chart, all gases have been removed from the system except some water vapor and CO_2 which are held frozen in the tube immersed in liquid air. With the cross connection closed, the liquid air is removed. At *B* active vaporizing starts. At *C* the CO_2 has been released, at *D* water vapor is coming off, and at *E* this vaporization is complete. At *F* solid CO_2 is applied and the water starts to freeze out again, this freezing out becoming complete at *G*. At *H* the solid CO_2 is replaced by liquid air and freezing out of the CO_2 begins. This is completed at *J*, the gage being thus brought back to zero reading. This chart is shown merely to give an idea of the possibilities of the "optical lever" gage in this direction. Many problems of diffusion, gas evolution, etc., immediately present themselves for solution with the aid of this device.

Some idea of the maximum rapidity of pressure variation which the optical lever gage will record may be gained from Fig. 6 which shows a

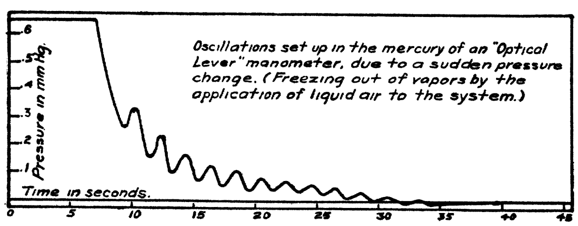

Fig. 6.

record of the freezing out of water vapor by means of liquid air. The oscillations are due to the original sudden pressure drop, and have a period of slightly more than two seconds (approximately 1,000 grams of mercury in the gage). The design of the gage may be such that this period may be materially reduced.

To summarize, a primary vacuum gage, consisting of the optical lever principle applied to a mercury U-tube manometer has been devised for indicating or recording pressures, including pressure variations, of vapors as well as gases, the pressure range being from several millimeters of mercury to approximately one thousandth of a millimeter. All errors of any consequence may be eliminated. By the use of this gage with the addition of a standard photographic device, charts may be obtained showing accurately pressure changes due to such phenomena as vaporization, freezing, diffusion, etc.

Westinghouse Research Laboratory,
East Pittsburgh, Pa.,
January, 1919.

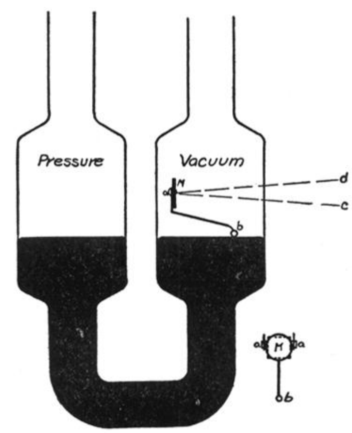

Fig. 1.

Optical Lever Manometer.

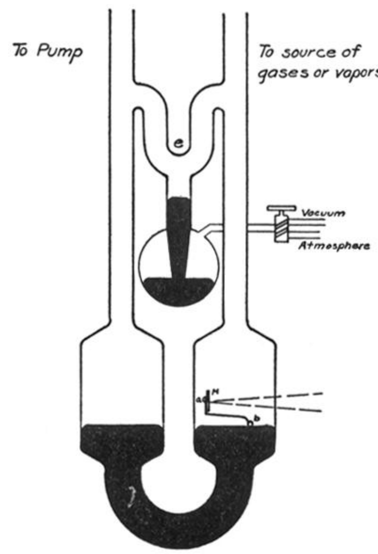

Fig. 2.

System for Manometer.

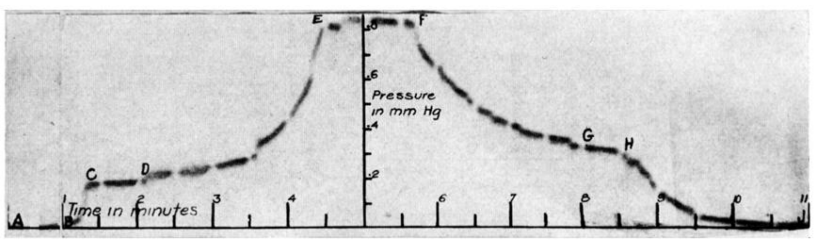

Fig. 5.