On a Method for Increasing the Resolution of Atmospheric Pressure Measurements

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ABSTRACT

It is known that conventional methods for determining atmospheric pressure by measuring the length–height of the mercury column in Torriceli's Tube (TT) give resolution up to 1 Pa. A method is presented in this note for determining atmospheric pressure by measuring mercury column mass in TT which facilitates measurement with a resolution up to 0.01 Pa; this is approximately 100 times the resolution afforded by conventional methods.

The application of this method requires measurement equipment available in a large number of laboratories worldwide, and it may be used in different areas of scientific research, using various measurement techniques and in experimental physics.

1. Introduction

Because of the increased accuracy of physical measurements in different areas of the pure and applied sciences, increased resolution of atmospheric pressure measurements such as given by the proposed method, is becoming increasingly important.

The method for atmospheric pressure measurement proposed in this note is based on measurement of the mass of the mercury column in Torriceli's Tube, TT (which equilibrates the mass of the air column whose pressure is being measured), with modern single-pan analytical balances of mass measurement with a resolution up to 0.1 mg, giving atmospheric pressure measurement with a resolution up to 0.01 Pa. The conventional methods for determining atmospheric pressure by measuring the length–height of the mercury column give a resolution of only up to 1 Pa. Therefore, the method proposed herein for atmospheric pressure measurement provides resolution approximately 100 times higher than conventional methods.

2. Measurement procedure

The proposed method for atmospheric pressure measurement requires the performance of two mass measurements with a single-pan analytical balance.

a. First measurement

A glass tube (opening by plug P) is fixed under the balance pan by a nylon thread with one end immersed in a vessel containing mercury (see Fig. 1), which moves the balance from its reference–equilibrium position. Then, by introduction of balance weights of mass $(m^*)'$ and density ρ^*, the balance is reset to its reference–equilibrium position. On the basis of Archimedean rule, the following equation may be written:

$$m_n\left(1-\frac{\rho_0}{\rho_n}\right)+m_g'\left(1-\frac{\rho_0}{\rho_g}\right)+m_g''\left(1-\frac{\rho_{\mathrm{Hg}}{}^t}{\rho_g}\right)+E=(m^*)'\left(1-\frac{\rho_0}{\rho^*}\right) \quad (1)$$

where

- m_n nylon thread mass
- m_g', m_g'' mass of the glass tube in air and mercury, respectively
- $(m^*)'$ mass of included weights (mass indication on (the balance) during the first (′) measurement
- ρ_n, ρ_g densities of the nylon thread and the glass tube, respectively
- ρ_0 surrounding (ambient) air density
- $\rho_{\mathrm{Hg}}{}^t$ mercury density at temperature t
- E effects related to surface tension during immersion of the glass tube into the vessel containing mercury
- ρ^* 8000 kg m^{-3}—conditional (conventional) density of balance weights (1).

b. Second measurement

The empty glass tube (closed by plug P) from the first measurement (′) is filled with mercury and immersed into the vessel containing mercury (see Fig. 2), moving the balance from its reference–equilibrium position. By the introduction of balance weight mass $(m^*)''$, the balance is reset to its reference–equilibrium position. On the basis of Archimedean Rule, the following equation may be written:

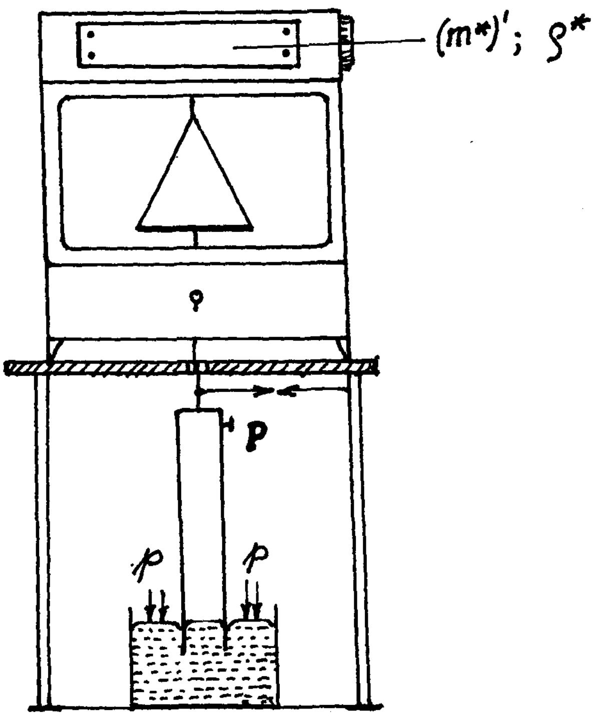

FIG. 1. Conceptual arrangement for first (′) measurement.

$$m_n\left(1-\frac{\rho_0}{\rho_n}\right)+m_g'\left(1-\frac{\rho_0}{\rho_g}\right)+m_g''\left(1-\frac{\rho_{Hg}{}^t}{\rho_g}\right)$$
$$+m_{Hg}\left(1-\frac{\rho_0}{\rho_{Hg}{}^t}\right)+m_v\left(1-\frac{\rho_0}{\rho_v}\right)+Ep_v\frac{S_2}{g}+E$$
$$=(m^*)''\left(1-\frac{\rho_0}{\rho^*}\right) \quad (2)$$

where

$(m^*)''$	mass of included weights (balance mass indication) during the second measurement (″)
m_v, V_v and ρ_v	mass, volume and density of the vapor of mercury in the glass tube above mercury
p_v	vapor pressure of mercury
S_2	TT cross-section area
g	local acceleration of the earth's gravity
V_v	V—volume of glass tube above mercury level.

The effects related to surface tension E in the second measurement [Eq. (2)] may be considered to be approximately equal to those related to the surface tension E in the first measurement [Eq. (1)].

3. Determination of atmospheric pressure

On the basis of Eqs. (1) and (2), a formula may be derived for determination of atmospheric pressure on the basis of mass measurement with single-pan modern analytical balances.

If the left- and right-hand sides of Eq. (1) are subtracted from the left- and right-hand sides of Eq. (2), the following formula is obtained:

$$m_{Hg}\left(1-\frac{\rho_0}{\rho_{Hg}{}^t}\right)+(\rho_v-\rho_0)V+p_v\frac{S_2}{g}$$
$$=[(m^*)''-(m^*)']\left(1-\frac{\rho_0}{\rho^*}\right) \quad (3)$$

Multiplication of the left- and right-hand sides of Eq. (3) by g/S_2 yields measured atmospheric pressure p_a in the form of the following expression:

$$p_a=\frac{\left[m_{Hg}\left(1-\frac{\rho_0}{\rho_{Hg}{}^t}\right)+(\rho_v-\rho_0)V\right]g}{S_2}+p_v$$
$$=\frac{[(m^*)''-(m^*)']\left(1-\frac{\rho_0}{\rho^*}\right)g}{S_1(1+\beta\cdot\Delta t)}, \quad (4)$$

or in an approximate form:

$$p_a=p_{Hg}+p_v=\frac{[(m^*)''-(m^*)']g}{S_1} \quad (5)$$

where

$p_{Hg}=\dfrac{m_{Hg}\cdot g}{S_1}$	pressure of mercury column in TT
p_v	vapor pressure of mercury

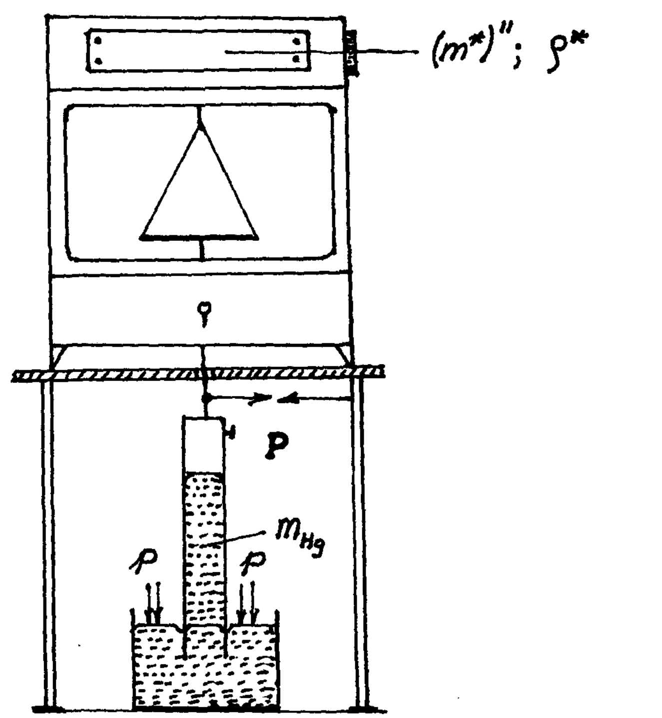

FIG. 2. Conceptual arrangement for second (″) measurement.

m_{Hg}	mass of mercury column in TT
$[(m^*)'' - (m^*)']$	difference of included weight masses (differential of balance mass indications) during the second (″) and first (′) measurement
$S_2 = S_1(1 + \beta \cdot \Delta t)$	TT cross-section area
$\beta = 2\alpha$; α	coefficient of linear expansion of the glass tube, K^{-1} (or $°C^{-1}$) (2)
$\Delta t = t_2 - t_1$	increase of temperature
g	local acceleration of the Eart is gravity.

Therefore, according to Eq. (5), the measured atmospheric pressure p_a is directly dependent on the difference between the masses of weights included (differential of mass indications on the balance) during the second (″) and first (′) measurement at a specified surface area S_1 and local acceleration g.

4. Conclusion

Use of the proposed method for atmospheric pressure measurement requires a modern single-pan analytical balance, glass tube and vessel containing mercury-measuring equipment that are readily available in a great number of laboratories worldwide.

The method enables approximately 100 times higher resolution than that of conventional methods.

The method may find broad application for atmospheric pressure measurement in laboratories of various types as well as for producing standards for calibration and verification of atmospheric pressure measurement instrumentation.

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