New! Size #3 increases viscosity range to 1000 cp., with tantalum float to 2000 cp.

VISCOSIMETER*

FALLING BALL TYPE

The Falling Ball Viscosimeter has been recognized as one of the most effective and accurate instruments for the determination of viscosity. Now for the first time, a simplified type is available at low cost.

This new instrument utilizes a novel method of releasing the ball and has the following features:

- **The tube is made of high precision bore glass tubing with stabilizing beads.**
- **Two high precision balls, one of glass and one of stainless steel, are supplied with each instrument to extend the range.**
- **The ball release device is made of Teflon® and sealed with a Viton® O-ring.**
- **The remaining plastic parts are made from corrosion resistant delrin.**
- **The ball is observed against a white background with red lines permanently fused into the glass.**
- **Available in three sizes to cover a wide range of viscosity.**
- **Tantalum ball may be purchased separately to double range.**

* Reference: Gilmont, R. Inst. & Control Systems *36*, 121, (1963).

VISCOMETERS, FALLING BALL

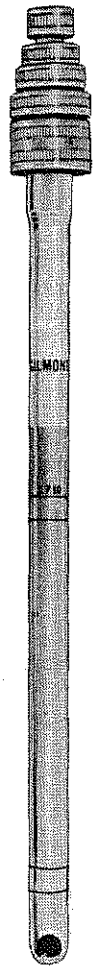
Size No.	Range in cp.	Approx. K	Cat. No.	Price
1	0.2 - 10	0.3	V-2100	108.00
2	2 - 100	3.3	V-2200	108.00
3	20 - 1000	35	V-2300	108.00

Maximum cp. for each size may be doubled using Tantalum ball, see Spare Parts List.

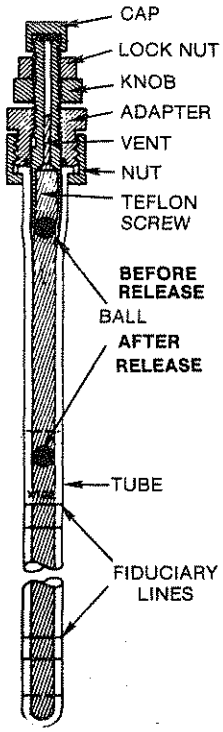
SPARE PARTS LIST

Description	Cat. No.	Price
Glass Tube size #1	V-2101	76.00
Glass Tube size #2	V-2201	76.00
Glass Tube size #3	V-2301	76.00
Release Mechanism	V-2102	42.00
Nut	V-2111	7.75
Adapter	V-2112	12.00
Knob	V-2113	4.75
Lock Nut	V-2114	4.75
Cap	V-2115	5.00
Teflon Screw	V-2116	7.50
Large Viton O-ring	V-2117	1.70
Large O-ring, pkg/6	V-2117/6	7.75
Large Teflon O-ring	V-2117T	1.70
Large O-ring, pkg/6	V-2117T/6	7.75
Small Viton O-ring	V-2118	1.15
Small O-ring, pkg/6	V2118/6	5.00
Small Teflon, O-ring	V-2118T	8.00
Small O-ring, pkg/6	V-2118T/6	36.00
Glass Ball	F-1332	2.90
S.S. Ball	V-2119S	2.40
Tantalum Ball	F-1332-T	28.00

NOTE: The same diameter (1/4") ball is used in all 3 sizes.



OVERALL SIZE
10" LONG x 1" DIA.



SEE APPENDIX FOR REPRINT

DIRECTIONS

ASSEMBLY—The viscosimeter is supplied with a glass ball and a stainless steel ball (type 316). A tantalum ball may be ordered separately. The recommended ranges of viscosity for each size and ball are as follows:

Size No.	Range in cp		
	Glass	S.S.	Tantalum
1	0.2 to 2	1 to 10	2 to 20
2	2 to 20	10 to 100	20 to 200
3	20 to 200	100 to 1000	200 to 2000

The proper ball is selected and the instrument is scrupulously cleaned and dried. The ball is added to the tube and the parts are assembled as in the diagram. The position of the knob and lock nut are adjusted so that the Teflon® screw will just prevent the ball from falling when the knob is turned to meet the adapter. Unscrewing the knob should allow the ball to be released. This adjustment should be made with care so as not to over-compress the end of the Teflon® screw which holds the ball.

FILLING WITH LIQUID—The nut and adapter are separated and the cap is removed from the screw. The ball is also removed from the tube. Approximately 5 ml. of the test liquid is required to fill the tube. The liquid should be clear of particles and filtered if necessary. Particles in the liquid will interfere with the motion of the ball and reduce the accuracy of measurement. The liquid is carefully pipetted into the tube until nearly full (approximately 1/4" from the top of the flange). The ball is now carefully added and allowed to drop into the tube. The adapter and screw assembly in the release position is now carefully inserted into the tube and liquid allowed to enter the capillary vent. The nut and adapter are tightened on the flange of the tube until secure. The cap is replaced on the screw.

TAKING A READING—The instrument full of liquid is inverted until the ball enters the Teflon® screw and the knob turned until the closed position is reached. The instrument is restored to its normal vertical position and is ready for taking a reading. For the most accurate work, the viscosimeter tube should be immersed in a constant temperature bath with a transparent window to observe the fiduciary lines. At elevated temperatures the cap should be removed to permit excess liquid to pass through the capillary vent. Air and gas bubbles should also be vented after equilibrium is reached. Then the cap is replaced.

The ball is released by turning the knob to raise the screw. The time of descent between the two sets of fiduciary lines is measured with a stop-watch. Repeat measurements can be made by removing the viscosimeter from the bath and inverting to return the ball to the screw and turning to the closed position. With good technique measurements should be reproducible from 0.2 to 1.0% depending upon the time of descent.

CALCULATING THE VISCOSITY—For a falling ball viscosimeter the viscosity is calculated by the simple formula:

$$\mu = K(\rho_t - \rho)t$$

where μ = viscosity in centipoises (cp)
ρ_t = density of ball (gms/ml)
2.53 for the glass
8.02 for stainless steel
16.6 for tantalum
ρ = density of liquid (gms/ml)
t = time of descent (minutes)
K = viscosimeter constant

The viscosimeter constant is obtained by measuring the time of descent for a standard liquid (e.g. water for size no. 1, water-glycerol mixture for size no. 2 and 3):

$$K = \frac{\mu}{(\rho_t - \rho)t}$$

For the most accurate work, the standard liquid should have, physical properties as close to that of the unknown liquid as possible.

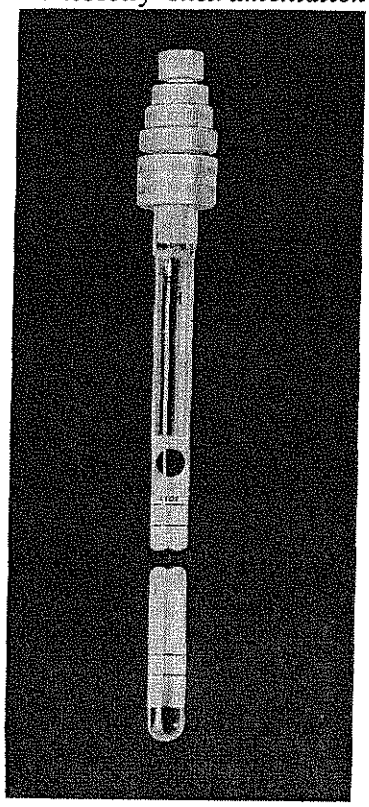


FIG. 1. FALLING-ball viscometer.

A Falling-Ball Viscometer

ROGER GILMONT
Roger Gilmont Instruments, Inc.

This falling-ball viscometer can be used readily in conventional temperature baths to measure viscosity from 1 to 300 cp. Theoretical limits for this type of instrument are 0.01 to 1 million cp.

FALLING-BALL VISCOMETERS have been used widely to measure viscosity. To avoid variances due to the ball not being centered in the tube, the tube is normally used in a slightly inclined position; thus the instrument is often referred to as a rolling-ball viscometer. As the ball rolls down the tube the fluid passes through a crescent-shaped orifice between the ball and the tube. The usual method of releasing the ball is to turn the tube end for end. The time to traverse a prescribed distance is observed. Temperature control is obtained with a thermostated jacket.

Two features were desired in developing a falling-ball viscometer: first, the precision tube should be absolutely vertical when in use; second, a simple ball-release mechanism should be provided. The advantage of the vertical position is that errors due to non-vertical alignment are negligible. The purpose of the release mechanism is to allow the tube to be employed in a conventional temperature-controlled bath, without a complex jacket and tilting mechanism. In order to obtain accurate and reproducible results with a vertical tube it was necessary to incorporate a beaded wall to assure centering of the ball. The ball-release mechanism, made of Teflon, utilizes the ease of distortion and the recovery memory of this material.

Theory

In the development of formulas for rotameters with spherical floats, the flow of fluid past the ball is treated as if the ball were falling in the tube at terminal velocity.* Terminal velocity is exactly the form of motion in a falling-ball viscosimeter and the same theory may be applied.

Equation 10 of this article* gives the volumetric flow in terms of a rotameter orifice coefficient as follows:

$$q = 59.8\, C_R R \left[\frac{R}{100} + 2 \right] D_t \sqrt{\frac{W_f (\rho_f - \rho)}{\rho_f \rho}} \qquad (1)$$

where q = flow (cc/min)

C_R = rotameter coefficient

$R = \frac{D_t - D_f}{D_f} \times 100$

D_t = diameter of tube (inches)

D_f = diameter of float (inches)

W_f = weight of float (gm)

ρ_f = density of float (gm/cc)

ρ = density of fluid (gm/cc)

The rotameter coefficient (C_R) is a generalized function of a Stokes-modified Reynolds number ($S\text{-}R_n$). The modified Reynolds number is defined by equation 15 of the above-mentioned paper* as follows:

*"A Generalized Equation for Rotameters with Spherical Floats," Roger Gilmont, Paul W. Maurer, *Instruments and Control Systems*, Vol. 34, No. 11, Nov. 1961, p. 2071.

Reprinted from the September 1963 issue of *Instruments & Control Systems*

$$S\text{-}R_n = \frac{1.042\ W_f(\rho_f - \rho)\rho R^3}{\mu^2\rho_f} \qquad (2)$$

where, in addition to the terms defined above, μ = viscosity of the fluid (centipoise).

One interesting fact of this generalized correlation is especially appropriate for use in viscometry. The coefficient C_R reduces to a simple function of the Stokes-modified Reynolds number when the latter is less than 5:

$$C_R = k\sqrt{S\text{-}R_n} \qquad (3)$$

where $k = 0.0852$ for spherical float rotameters.

For viscometry measurements limited to the region where the dimensionless quantity $S\text{-}R_n$ is less than 5, it is possible to combine equations 1, 2 and 3 to give:

$$q = 61.05k\ \frac{D_f W_f\ (\rho_f - \rho)}{\rho_f \mu}\ R^{5/2}\left[\ 2 + \frac{R}{100}\right] \qquad (4)$$

The value of k has been omitted intentionally because, for viscometry, the precision is of a higher order of magnitude and individual calibration is required, as will be explained.

Theory Applied to Viscometer

As the ball falls through the cylindrical tube at terminal velocity, it displaces a given volume of fluid that flows through the annular space between the ball and the tube. If the ball falls a given distance in a certain time, the volumetric flow would then be:

$$q = \frac{L}{t}\ \frac{\pi}{4}\ (2.54D_f)^2 \qquad (5)$$

where L = distance (cm), t = time (min), and the conversion factor 2.54 is necessary to give the flow in consistent units.

By equating the volumetric flow of equations 4 and 5, the following solution is obtained for the viscosity:

$$\mu = 103.3k\ \frac{D_f^2}{L}\ R^{5/2}\left[\ 2 + \frac{R}{100}\right](\rho_f - \rho)t \qquad (6)$$

The usual falling-ball viscometer constant can be defined as:

$$K = 103.3k\ \frac{D_f^2}{L}\ R^{5/2}\left[\ 2 + \frac{R}{100}\right] \qquad (7)$$

Substituting K in equation 6 will give the familiar relationship:

$$\mu = K\ (\rho_f - \rho)t \qquad (8)$$

The value of k from the generalized flowmeter correlation can be substituted in equation 7:

$$K = 8.82\ \frac{D_f^2}{L}\ R^{5/2}\left[\ 2 + \frac{R}{100}\right] \qquad (9)$$

Although equation 9 is not sufficiently exact for absolute use in viscometry work, it does allow one to design the physical dimensions of the instrument for any specified range of measurement. The value of K can be predicted to within 20% of the correct value by equation 9, but it is necessary to determine the exact value from equation 8 by observing the time of fall with a fluid of known viscosity and density.

In order to improve prediction of K so that it may be suitable for absolute measurement, the theory must be developed further to account for the precise effect of the stabilizing beads required in the tube, and the possible variation of k as a function of R. Preliminary studies indicate that in the region of suitable measurement k may be a function of the fourth root of R.

Equation 8 may be simplified further when applied to special cases, such as the rising bubble viscometer, and measurement of gas viscosities. In the case of the rising bubble, the density of the float may be neglected, reducing the equation to:

$$\mu/\rho = K\,t \qquad (10)$$

The minus sign has been omitted to indicate that the float, which is the rising bubble, moves in the opposite direction. Equation 10 is the familiar expression showing that kinematic viscosity is proportional to the time of rise.

In measuring the viscosity of a gas, the density of the gas can be neglected, giving:

$$\mu = K\rho_f t \qquad (11)$$

Thus, for gases the viscosity is directly proportional to the time of fall, and independent of the gas density.

Design

The improved falling-ball viscometer consists of a high-precision bore glass tube with three stabilizing beads to insure concentricity between the ball and tube during descent. The inside diameter of the tube is held to a precision of better than ± 0.0002″ and the diameter of the ball to better than ± 0.0001″.

The ball-release mechanism is essentially a Teflon screw with a tubular opening that engages the ball. When screwed against the shoulder of the tube the ball is held. Upon unscrewing, the tubular opening enlarges and the ball falls down the tube. Two sets of fiduciary lines and a white background are fired permanently into the tube for ease of determining the exact time of descent. The construction allows convenient use in a constant-temperature bath with a transparent window.

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ADDENDUM TO ASSEMBLY INSTRUCTIONS
VISCOMETER BALL-RELEASE MECHANISM

The ball release mechanism is adjusted for proper operation as follows:

With the tube dry and clean:

1 Ensure the ball easily enters and exits the teflon screw. If not, remove the ball release assembly from the tube and swage the opening to the screw with a suitable tool (a classic Bic pen cap works well).

2 With the screw retracted, assemble the ball release mechanism to the tube. Separate the locknut and knob on the threaded portion.

3 Holding the cap, advance the screw until the tip is close to being compressed by the tapered portion of the glass tube.

4 While tilting the assembly back and forth to allow the ball to enter and exit the screw, advance the screw slightly until the end is compressed just enough to retain the ball.

5 While holding threaded portion stationary, run knob down clockwise until it stops against the adapter. Ensure the threaded portion is not being advanced, as this will cause the teflon screw to deform.

6 Tighten the locknut against the knob to act as a jam nut.

7 When properly assembled, turning the knob will advance and retract the screw. When advanced until the knob meets the adapter, ball will be held in screw assembly. A 1/4 turn retraction of the screw assembly should release the ball.