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An Optical Recording Rotameter for Measuring Blood Flow.*

ROBERT E. SHIPLEY AND E. C. CRITTENDEN, JR.† (Introduced by D. E. Gregg.)
From the Department of Medicine, Western Reserve University, Cleveland, Ohio.

The rotameter, described in a previous communication,[1] is a simple and reliable instrument with which measurements of average rate of blood flow may be made in acute experiments. The instrument is a variable area type meter and consists of a vertical tube having a tapering bore in which a freely movable metal "float" varies in its vertical position with the rate of blood flow through the tube.

Depending upon the flow range to be covered, the capacity and sensitivity of the same rotameter may be modified by using "floats" of different shapes, diameters, specific gravities or weights. For more extreme blood flow ranges, tubes with bores of different diameters or degrees of taper may be used.

While the commercially available rotameters have been found satisfactory for measuring blood flow from as low as 0.5 cc/min. to at least 1200 cc/min., they were designed primarily for industrial use. Consequently certain features in design were modified in preliminary models to permit more advantageous use of the rotameter in physiological work. The regular precision bore Pyrex glass rotameters are considerably longer than necessary and, although quite rugged, are still subject to accidental breakage. These disadvantages were overcome by making the rotameter tubes of ½-inch to ⅝-inch Lucite rod with an over-all length of 6-10 cm. The central hole was reamed with a standard taper-pin reamer, the size of which was chosen to give the instrument the desired sensitivity and range. The surface was finished by polishing with magnesia. Metal "floats" of appropriate size and shape were turned on a lathe. The threaded or tapered fittings at the ends of the tube were constructed to accommodate cannulæ attachments. An arbitrary scale of millimeter graduations was cut into the Lucite for notation and calibration of the height of the "float."

Although these earlier instruments were quite satisfactory from the standpoint of being accurate, convenient, and relatively unbreakable, they still required visual notation of the height of the float and periodic calibration of several points during prolonged experiments to correct for any major change in blood viscosity. These objections were circumvented by developing further changes and additions. In the most recent design, the tapered portion of the tube was shortened to 11-12 mm. The shape of the "float" was modified so as to eliminate almost entirely shifts in calibration due to changes in blood viscosity. An electrical unit was developed with which the height of the "float" could be determined and blood flow automatically and optically recorded on sensitized paper. With the use of this unit, a continuous recording of blood flow could be made simultaneously with blood pressure, ECG, or other tracings. The electrical unit is small, can be made from standard radio parts, and is described in a companion paper.[2] The instrument has been used thus far to record coronary and peripheral arterial blood flow as well as venous flow.[3] In Fig. 1 is a photograph of an original record of coronary flow obtained with the recording rotameter.

A sectional view of the rotameter proper is shown in Fig. 2. The body of the instrument is made from ½-inch Lucite and is constructed in 3 pieces which are screwed together. The lumen of the lower piece is tapered as shown. The lumen of the central (cross hatched)

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† Department of Physics, Case School of Applied Science, Cleveland, Ohio.

1 Gregg, Donald E., Shipley, R. E., Eckstein, R. W., Rotta, A., and Wearn, J. T., PROC. SOC. EXP. BIOL. AND MED., 1942, **49**, 267.

2 Crittenden, E. C., Jr., and Shipley, R. E., *Rev. Scient. Inst.*, in press.

3 Gregg, Donald E., and Shipley, R. E., *Amer. Jour. Physiol.*, in press.

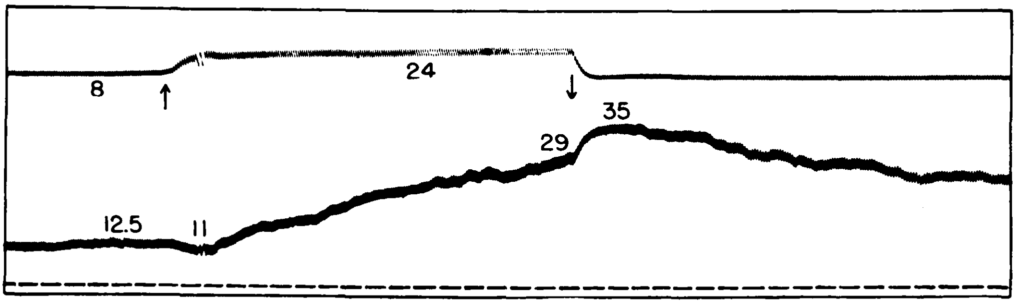
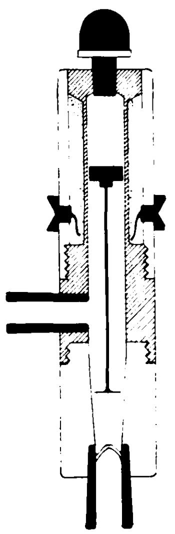


FIG. 1.
Photograph of original record showing the effect of mean right ventricular pressure elevation on right coronary inflow (perfusion pressure kept constant). Upper curve, mean right ventricular pressure with values in mm Hg. indicated by numbers adjacent to curve. Lower curve, mean right coronary inflow as measured by the recording rotameter unit with values in cc/min. indicated by numbers adjacent to curve. (↑) Pulmonary artery constricted, (↓) pulmonary artery released. Time, 5 seconds. (For interpretation of experiment, see reference.[3])



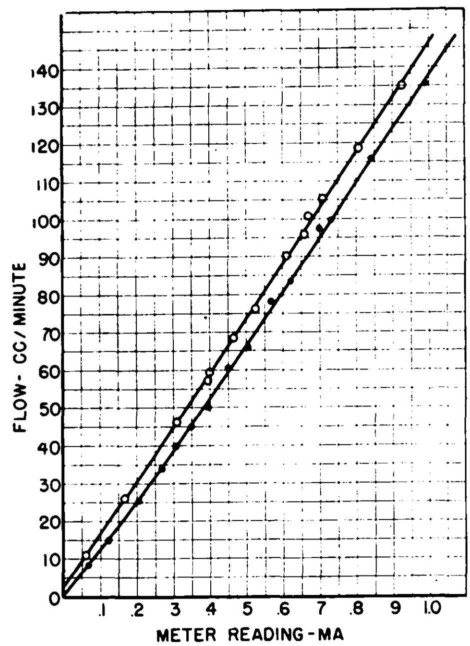


FIG. 2.
Sectional view (actual size) of rotameter unit. Description in text. Graph showing relative linearity of calibrations and comparatively small shift in calibration due to large change in fluid viscosity. Open circles, calibration obtained with water (spec. visc. = 1). Closed circles, calibration obtained with acacia solution having a viscosity approximating that of blood (spec. visc. = 4.5).

piece is drilled straight and polished. Around its upper part, and separated from the lumen by a thin shell of Lucite .020 inches thick, is wound .0025 inches enameled copper wire with decreasing number of turns from top to bottom. Over the upper part of the rotameter is fastened a Lucite sleeve which adds rigidity and protects the coil. Melted paraffin may be forced under the sleeve to give further mechanical and electrical protection to the wire. Slightly hollowed contacts fixed to the outer sleeve serve as the external terminals of the coil as well as the supporting points for the unit when in use (*cf.* Fig. 3).

The "float" is a soft iron cylinder connected to a phosphor-bronze wire, at the bottom of which is soldered a thin (.007-inch) brass disc, all of which are chrome plated.

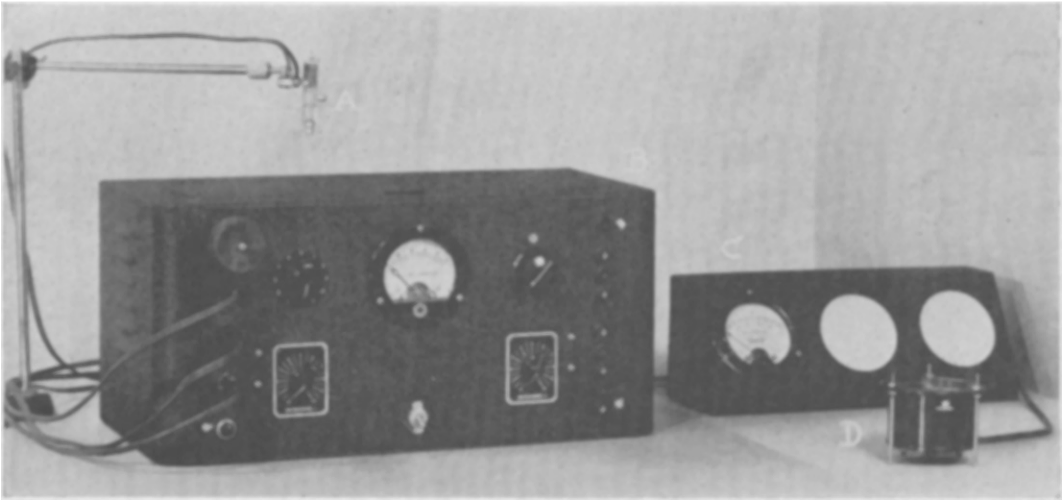


FIG. 3.
Photograph of apparatus. A, rotameter unit held in support as used. B, cabinet containing electrical unit with which balancing, sensitivity, and recording adjustments are made. Monitor meter mounted in cabinet face. C, portable monitor meter with long lead connection. D, recording meter (0-7.5 MA) mounted on 3 adjustable legs. Hole cut from side of meter to permit reflection of light beam from 3 mm x 3 mm mirror mounted to counterbalance end of meter hand.

A "stop," soldered to the tapered cannula fitting at the bottom, establishes the zero position of the "float." A tapered plug at the top of the rotameter can be removed to allow the escape of air during filling.

During operation, the vertical position of the "float" varies directly with the rate of flow. This relationship is essentially linear with the new type "float" and is affected relatively little even with very large changes in viscosity (*cf.* Fig. 2). When connected to the electrical unit, the inductance of the rotameter coil varies with the axial position of the iron cylinder within the coil. The inductance change is measured by an AC bridge circuit, the output of which is amplified and ultimately read on a milliammeter. Optical recording is made by reflecting a beam of light from a small mirror fastened to the hand of another series connected milliammeter. (See Fig. 3.)

With a given rotameter, a wide range of sensitivities are available by appropriate adjustments of controls on the electrical unit. Because of minimal interference from changes in blood viscosity, periodic calibrations are not necessary. The entire apparatus is sufficiently stable so that one set of calibrations, made at all (11) gain settings (to obtain different sensitivities), may be used in subsequent experiments to translate, with negligible error, meter readings or recorded deflections in terms of blood flow. In actual practice, one or more calibration points are always taken *in vivo* to verify this relationship. Although the rotameter is primarily a mean flow recorder, the cyclic pulses are not completely damped out and heart rates may be subsequently determined from the photographic record.

Summary. A rotameter and electrical unit have been described with which permanent recordings of blood flow may be made in acute experiments. No special training or technical knowledge is required for its use. Continuous recording of blood flow is possible without any attention from the operator. Tests have shown that the instrument measures blood flow accurately with 5% or less variation and is not significantly altered by changes in blood viscosity or flow pattern over a wide physiological range.