Ministry of Health of Ukraine
Ukrainian Medical Stomatological Academy

It is approved
on meeting of department of
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Methodical instructions
for students' self-preparation work at preparation for a practical lesson
at home and at the classroom

Subject matter	**Medical and biological physics**
The unit	1. Fundamentals of higher mathematics and biological physics
Theme of lecture:	**Liquid viscosity. Methods of the determination of viscosity of a fluids.**
Year	1
Faculty	Medical
Speciality	Medicine

Poltava - 2020

The topic significance: the topic «Viscosity coefficient determining» is very important for future doctors in their professional activity, positively influences the students in their attitude to the future profession, forms professional skills and experience as well as taking as a principle the knowledge of the subject learnt.

Specific targets:

1. To have general knowledge of the topic studied;
2. To understand, to remember and to use the knowledge received;
3. To form the professional experience by reviewing, training and authorizing it;
4. To be able to carry out laboratory work.

Basic knowledge, experience, skills necessary for studying the topic in connection with other subjects:

Disciplines	Obtainable skills
Previous (providing disciplines): Physics, anatomy	To know concepts: role of viscosity in liquid behavior.
The subsequent disciplines: Normal physiology	To know change of viscosity in different parts of circulation system: causes of this effect and it role; change of viscosity at different organism states and patologies.

Materials for the before-class self-preparation work:

List of main term, parameters, characteristics, which student have to learn at preparation to class:

Term	Definition
Viscosity	A measure of the resistance of a fluid to deform under either shear stress or extensional stress
Ideal liquid	It is imaginary liquid without viscosity and thermal conduction
Real liquids	Viscous liquids.
Newtonian liquid	Real liquid complies with the Newton's formula
Non-Newtonian liquid	Complex liquids (which consist of particles with various shapes and sizes, for example, solutions of macro-molecules), do not comply with the Newton's formula.
Dynamic viscosity	Viscosity coefficient that determines dynamics of incompressible Newtonian fluid.
Volume viscosity	Viscosity coefficient that determines dynamics of compressible Newtonian fluid.

Theoretical questions to class:
1. Definition of liquid viscosity.
2. The Newton's formula. Explain it.
3. Newtonian and non-Newtonian liquids.
4. Methods of the blood viscosity measurement.
5. Explain principle of Hess' viscometer works.

Practice work executed at class. **Measurement of blood viscosity with Hess' viscometer use.**

Principle and design of Hess' viscometer. The Hess' viscosimeter is designed for the blood viscosity measurement. It consists of two identical capillaries 1 and 2 mounted on a common plate (Fig.2). Both capillaries are converted into wide tubes; they have scales measured in units of volume. Identical narrow parts of capillaries create main part of hydraulic resistance; them geometrical parameters are identical; pressure difference is the same for both capillaries.

One of capillaries has cock (tap). The capillaries are connected by bifurcation to rubber tube and tip (mouthpiece). Fluids velocity in identical capillaries depends on viscosities of fluids.

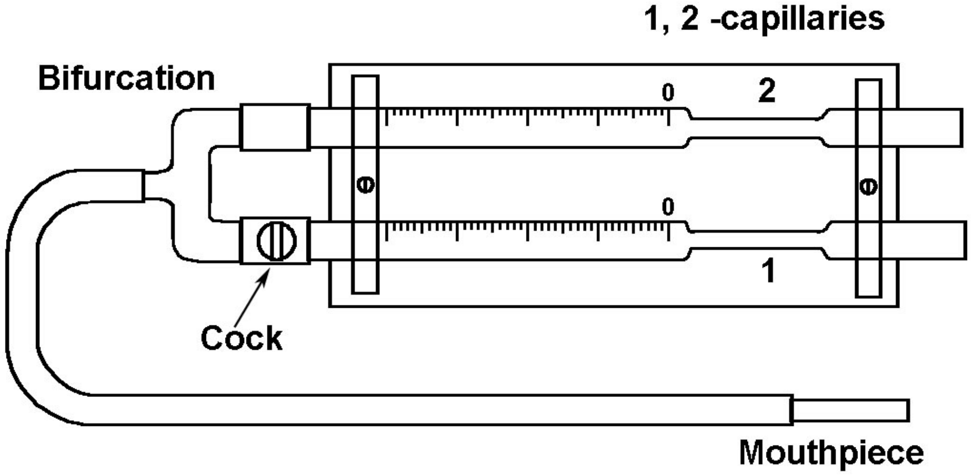

Fig.1. Hess' viscosimeter.

To measure viscosity:

- open cock , dip tube 1 into distilled water, fill tube 1 with distilled water up to mark «0» on the scale pulling air in through the tip with your mouth (or using rubber pump on mouthpiece);

- close cock and do the same with the studied liquid and tube 2;

- put the device onto a desk, open cock and pull in air with your mouth, while the water in tube 1 reaches the top mark h_0 on the scale;

- register the position h_x of the studied liquid in scale of tube 2.

The viscosity of studied liquid is equal:

$$\eta_x = \eta_0 \frac{h_0}{h_x},$$

where η_0 is the viscosity of distilled water; h_0 and h_x are volumes filled by the distilled water and the liquid under study respectively.

Recommendations

1. Open cock 4, dip tube 1 into distilled water, fill tube 1 with distilled water up to mark «0» on the scale pulling air in through the tip 5 with your mouth;
2. Close cock 4 and do the same with the studied liquid and tube 2;
3. Put the device on a table, open cock 4 and pull in air with your mouth, while the water in tube 1 reaches the top mark h_0 on the scale;
4. Register the position h_x of the studied liquid in scale of tube 2.
5. The viscosity of studied liquid is equal:
   $\eta_x = \eta_0 \frac{h_0}{h_x}$, where η_0 is the viscosity of distilled water; h_0 and h_x are lengths passed by the distilled water and the liquid under study respectively;
6. Put data on the table:

N	The viscosity of water, η_0, cP	The length passed by water h_0, cm	The length passed by blood h_x, cm	The viscosity of blood, η_x, cP
1				
2				
3				

7. Calculate average value of blood viscosity.
8. Make conclusion.

The contents of the topic:

Viscosity is a measure of the resistance of a fluid to deform under either shear stress or extensional stress. It is a measure of fluid friction and commonly perceived as resistance to flow.

Ideal liquid (or **inviscid fluid)** is imaginary liquid without viscosity and thermal conduction. It is model which are used for estimate in some condition when real liquid properties can be neglected.

Real liquids are viscous liquids. In a real liquid, forces of internal, or viscous friction arise from the relative movement of layers. When real liquid flows its speed in various points of the stream is different (Fig.2). But there are parts where velocity of any point is the same; such part is called ***liquid layer.*** The existence of viscous friction forces in the flow of a real liquid is referred to as *liquid viscosity*. The internal friction is caused by the interaction of molecules of adjoining layers.

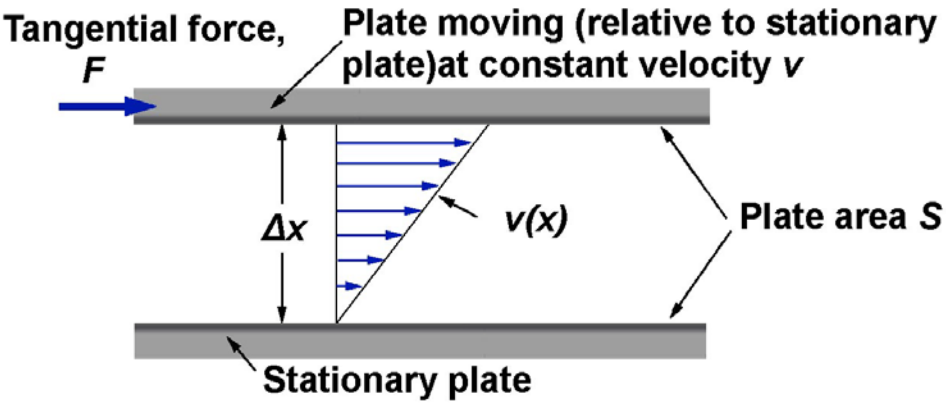

Fig.2.

The conception of *viscosity* as a physical characteristic of liquid (physical quantity) is introduced in hydrodynamics by a ***Newton's formula** (1687) for the viscous friction force,* which reads:

$$F = \eta \frac{dv}{dx} S \, ,$$

where: ***F*** is the force of viscous friction between ***the liquid layers*** appearing as a result of their relative shift;

v is the velocity of the liquid layer movement,

x is the coordinate perpendicular to the ***layer contact*** boundary;

$\frac{dv}{dx}$ is a ***velocity gradient absolute value,*** which ***dx*** characterizes the degree of change in the velocity of the liquid flow in transfer from one layer to another;

– ***S*** is the area of the liquid layers contact surface;

– η is the proportionality factor, called ***coefficient of viscosity*** *(or **dynamic viscosity)*** of the liquid. The coefficient of viscosity characterizes the layer displacement resistance. The coefficient of viscosity in the metric *SI* is measured in ***Pascal-seconds*** *(Pa·s),* non system unit is ***Poise*** *(P).* 1 Pa·s = 10 P. For example, water at 20°C has the viscosity of $1{,}005 \cdot 10^{-3}$ Pa·s ≈ 1 mPa·s ≈ 1cP. The viscosity of human blood usually ranges from 4 to 6 mPa·s or from 4 to 6 cP.

When the liquid flows through a cylindrical pipe, the considered layers are coaxial cylinders, one inside another, ***S*** being the area of the cylinder side surface, and direction ***x*** at any point of the stream coinciding with the direction of the cylinder section radius at this point.

Numerous inhomogeneous complex liquids (which consist of particles with various shapes and sizes, for example, solutions of macro-molecules), do not comply with the Newton's formula. That is why real liquids are subdivided into ***Newtonian*** and ***non-Newtonian liquids*** with respect to their viscosity properties.

Dynamic viscosity is viscosity coefficient that determines dynamics of incompressible Newtonian fluid. **Volume viscosity** is viscosity coefficient that determines dynamics of compressible Newtonian fluid.

In Newtonian liquids, coefficient of viscosity depends only on the kind of liquid and its temperature: when the temperature increases, then the coefficient of viscosity decreases. In non-Newtonian liquids, however, the viscosity coefficient value also depends on the values, characterizing the conditions of the liquid flow, for example, on the speed gradient. That is why it is possible to refer to the coefficient of viscosity of non-Newtonian liquids only taking into account the conditions of liquid flow. Usually, referring to the viscosity of non-Newtonian liquids, the term *"apparent viscosity"* is used.

Blood viscosity is 0,4–0,5 Pa·s in norm; it changes from 0,17 to 2,29 Pa·s at pathologies. Erythrocyte sedimentation rate (ESR) change correspondingly at that. Venous blood has more viscosity than arterial blood. Hard physical work increases blood viscosity.

Viscosity measurement is called ***viscosimetry*****,** and the instruments for measuring of viscosity are referred to as ***viscosimeters.***

In **Stockes'** viscosimetry method small ball fallen in an investigated liquid is used. After short period of accelerated falling, movement of the ball is uniform with friction force equal to weight. **Stockes'** law describes dependence between ball mass and radius, liquid viscosity and ball velocity: $F_{fr} = 6\pi\eta rv$. Here r – ball radius, v – ball movement velocity, η – liquid viscosity. Ball volume – $V = 4/3\pi r^3$, ball mass – $\rho_b V$, ball weight – P = mg. $mg = 4/3\pi r^3\rho_b$; $F_{arch} = 4/3\pi r^3\rho_l$. ρ_l – liquid density.

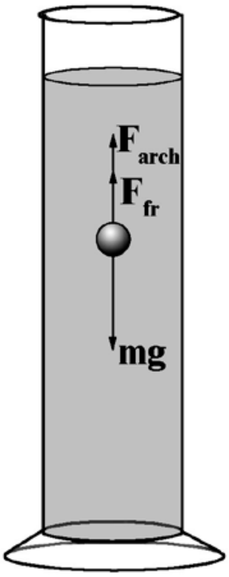

Fig3. Stockes' method.

Correspondingly, adjusted for Archimedean principle, $4/3\pi r^3\rho_l g = 4/3\pi r^3\rho_b g + 6\pi\eta rv.$

Consequently, $\eta = 2(\rho_l-\rho_b)r^2g/(9v)$, *where* ρ and ρ_0 – ball and liquid densities.

Requirements to the liquid are: the transparency and the density close to a ball density, but a few smaller. But large volume of investigated liquid is necessary in this method; it is impossible in medicine.

At **rotary viscosimetry** liquid is in a gap (chink – separation distance) between two coaxial cylinders. One cylinder wheels, other is motionless. If angular velocity of revolving cylinder is constant, viscosity is calculated by moment of force applied to the motionless cylinder (or conversely).

Capillary viscosimetry is based on Poiseuille's law. Liquid flows through capillary under the influence of gravity at fixed pressure difference. Time of certain mass flowing is measured, next viscosity is calculated.

Poiseuille's law: $\frac{dV}{dt} = \frac{\pi\Delta PR^4}{8L\eta}$ or $Q = \frac{\pi R^4}{8\eta}\cdot\frac{\Delta P}{L}$.

Here ***Q=dV/dt is*** volume flow rate, R is radius of vessel, L is it length, ΔP is the pressure difference from one side of the pipe to the other, η (Greek letter "eta") is the viscosity index.

Self-control material:

A. Questions and statements to be answered:

1. What is stationary (steady) flow?
2. What is Bernoulli equation?
3. What type of liquids is blood by viscosity characteristics?
4. Blood viscosity does not depend on …
5. Dependence of linear liquid rate on distance from a tube center is:
6. Equation of continuity of stream (flow) is:
7. Flow is stationary (steady flow), if…
8. For determining of internal friction force of Newtonian liquid it is not necessary to know:
9. How to use the Reynolds number for identification of a flow of a viscous Newtonian fluid on a smooth-wall tube?
10. Hydrodynamic resistance of one smooth-wall cylindrical tube is X. Calculate common hydrodynamic resistance of two such tubes bridged sequentially.
11. Specify a Newtonian fluid flow for which the Poiseuille formula is valid.
12. Term more general law of the classical mechanics, which special case of a statement is the formula of continuity of a stream in hydrodynamics:

13. The diagram of dependence of viscosity of a whole human blood on a hematocrit at stationary values of rate gradients and temperature:
14. The friction force at free falling of ball in liquid is:
15. The internal friction force of Newtonian liquid between two parallel layers is:
16. What is apparent viscosity?
17. What is the profile of allocation of the linear rates on a cross-section of the cylindrical capillary for a laminar flow of a viscous Newtonian fluid?
18. What is tube of current?
19. What are parameters of liquid that are determined by viscosity coefficient?
20. How does dynamic viscosity of blood change in different vessels?
21. What is meaning of Rheynold's number?

B.Tasks to be done.

At stationary (steady) flow …

1. Liquid rate does not depend on a cross-section are;
2. Liquid rate gradually decreases;
3. Liquid rate in all points does not depend on a time
4. Liquid rate gradually increases;
5. Liquid rate does not depend on a distance from center if tube;

Ideal liquid feature is:

1. in this liquid only normal pressure forses act
2. internal friction does not exist
3. in this liquid viscosity index does not depend on character of movement
4. in this liquid tangential forces exist
5. viscosity index depends on concentration

For determining of internal friction force of newtonian liquid it is not nesessary to know:

1. rate gradient
2. pressure differense between ends of tube
3. tube diameter
4. tube length
5. liquid viscosity

The internal friction force of newtonian liquid between two parallel layers is:

1. $f = \rho g + \frac{dp}{dx}$
2. $F = 6\pi r\eta v$
3. $F = S\left(\rho gh + \rho\frac{v^2}{2}\right)$
4. F = ma
5. $F = \eta S\frac{dv}{dr}$

The friction force at free falling of ball in liquid is:

1. $F = \eta S\frac{dv}{dr}$
2. $f = \rho g + \frac{dp}{dx}$
3. $F = 6\pi r\eta v$

4. $F = S\left(\rho gh + \rho \frac{v^2}{2}\right)$
5. F = ma

Poiseuille's law is:

1. $F = 4/3\pi r^3 \rho_l$
2. $F = 6\pi r \eta v$
3. $Q = \frac{\pi R^4}{8\eta} \cdot \frac{\Delta P}{L}$
4. $F = \eta S \frac{dv}{dr}$
5. F = ma

Dependence of linear liquid rate on distance from a tube center is:

1. $v = \frac{dV}{dt}\frac{1}{S}$
2. $v(r) = \frac{\Delta P(R^2 - r^2)}{4\eta L}$
3. $R_e = \eta S \frac{dv}{dr}$
4. $v(r) = gt/2$
5. $v(r) = v_0 + at$

Bernoulli equation is:

1. $\rho S v = const$.
2. $v(r) = \frac{\Delta P(R^2 - r^2)}{4\eta L}$
3. $p + \rho gh + \frac{\rho v^2}{2} = const$
4. P = 4σ/R.
5. it determines liquid quontity which flows through cross-section S.

Poiseuille equation is:

1. It determines viscous friction force in cylindric pipe.
2. Sum of static pressure, hydrostatic pressure and dynamic pressure is constant.
3. It determines what quantity of liquid flows through cross–section of vessel in time unit.
4. Viscous friction force is product of viscosity factor, area of flat adjoining layers and rate gradient.
5. Fluid volume rate through any cross–section of pipe in close pipe system is constant.

Literature recommended

Main sources.

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