**Physics 05-07 Viscosity, Poiseuille’s Law, and Turbulence**

**Viscosity**
- Fluid _______________
- Laminar Flow
  - Smooth flow in ____________ that don’t _______________
- Turbulent Flow
  - Has ____________ and ____________ that have ________________ layers of fluid
  - Turbulent flow is ____________ than laminar flow

How viscosity is measured
- Two ____________ with fluid between
- Top plate ____________
- ____________ causes the fluid to move

\[ \eta = \frac{FL}{vA} \]

**Laminar flow in tubes**
- Difference in ____________ causes fluids to ________________
  \[ Q = \frac{P_2 - P_1}{R} \]
- \( P_1 \) and \( P_2 \) are pressures; \( R \) is resistance

Since flow rate depends on ____________
- Higher pressure difference, higher ____________
- Higher resistance, higher ________________ to maintain ____________
- In blood vessels this is a ____________ with ________________ on artery walls

**Poiseuille’s law for resistance**
\[ R = \frac{8\eta l}{\pi r^4} \]
- \( \eta \) is viscosity; \( l \) is length of tube; \( r \) is radius of tube

**How to tell if laminar or turbulent flow**
- ____________ speed with smooth, streamlined object → ____________
- ____________ speed or rough object → ____________

Reynolds number
- Below 2000 → ____________
- Above 3000 → ____________
- Between 2000 and 3000 ________________

\[ N_R = \frac{2\rho vr}{\eta} \]

A hypodermic syringe is filled with a solution whose viscosity is \( 1.5 \times 10^{-3} \) Pa \( \cdot \) s. The plunger area of the syringe is \( 8.0 \times 10^{-5} \) m\(^2\), and the length of the needle is 0.025 m. The internal radius of the needle is \( 4.0 \times 10^{-4} \) m.

The gauge pressure in a vein is 1900 Pa (14 mmHg). What force must be applied to the plunger, so that \( 1.0 \times 10^{-6} \) m\(^3\) of solution can be injected in 3.0 s?
Is the flow laminar if the density is 1000 kg/m³?

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**Homework**

1. When paddling a canoe upstream, it is wisest to travel as near to the shore as possible. When canoeing downstream, it may be best to stay near the middle. Explain why.

2. Doppler ultrasound can be used to measure the speed of blood in the body. If there is a partial constriction of an artery, where would you expect blood speed to be greatest, at or nearby the constriction? What are the two distinct causes of higher resistance in the constriction?

3. What force is needed to pull one microscope slide over another at a speed of 1 cm/s, if there is a 0.500-mm-thick layer of 20°C water between them and the contact area is 8.00 cm²? (OpenStax 12.30) \(1.61 \times 10^{-5}\) N

4. A glucose solution being administered with an IV has a flow rate of 4.00 cm³/min. What will the new flow rate be if the glucose is replaced by whole blood having the same density but a viscosity 2.50 times that of the glucose? All other factors remain constant. (OpenStax 12.31) \(1.60\) cm³/min

5. A small artery has a length of 1.1 \(\times\) 10⁻³ m and a radius of 2.5 \(\times\) 10⁻⁵ m. If the pressure drop across the artery is 1.3 kPa, what is the flow rate through the artery? (Assume that the temperature is 37°C.) (OpenStax 12.33) \(8.7 \times 10^{-2}\) mm³/s

6. The arterioles (small arteries) leading to an organ, constrict in order to decrease flow to the organ. To shut down an organ, blood flow is reduced naturally to 1.00% of its original value. By what factor did the radii of the arterioles constrict? Penguins do this when they stand on ice. When paddling a canoe upstream, it is wisest to travel as near to the shore as possible. When canoeing downstream, it may be best to stay near the middle. Explain why.

7. Angioplasty is a technique in which arteries partially blocked with plaque are dilated to increase blood flow. By what factor must the radius of an artery be increased in order to increase blood flow by a factor of 10? (OpenStax 12.36) \(1.8\) \(r_1\)

8. (a) Suppose a blood vessel’s radius is decreased to 90.0% of its original value by plaque deposits and the body compensates by increasing the pressure difference along the vessel to keep the flow rate constant. By what factor must the pressure difference increase? (b) If turbulence is created by the obstruction, what additional effect would it have on the flow rate? (OpenStax 12.37) \(1.52\)

9. Verify that the flow of oil is laminar (barely) for an oil gusher that shoots crude oil 25.0 m into the air through a pipe with a 0.100-m diameter. The vertical pipe is 50 m long. Take the density of the oil to be 900 kg/m³ and its viscosity to be 1.00 \((\text{N/m}^2)\) \cdot s\) (or 1.00 \(\text{Pa} \cdot \text{s}\)). (OpenStax 12.51) \(1990\)

10. Calculate the Reynolds numbers for the flow of water through (a) a nozzle with a radius of 0.250 cm and (b) a garden hose with a radius of 0.900 cm, when the nozzle is attached to the hose. The flow rate through hose and nozzle is 0.500 L/s. Can the flow in either possibly be laminar? (OpenStax 12.53) \(35100, 127000\)

11. A fire hose has an inside diameter of 6.40 cm. Suppose such a hose carries a flow of 40.0 L/s starting at a gauge pressure of \(1.62 \times 10^6\) N/m². The hose goes 10.0 m up a ladder to a nozzle having an inside diameter of 3.00 cm. Calculate the Reynolds numbers for flow in the fire hose and nozzle to show that the flow in each must be turbulent. (OpenStax 12.54) \(7.90 \times 10^5\)

12. At what flow rate might turbulence begin to develop in a water main with a 0.200-m diameter? Assume a 20°C temperature. (OpenStax 12.56) \(3.16 \times 10^{-4}\) m³/s

13. A blood vessel is 0.10 m in length and has a radius of 1.5 \(\times\) 10⁻³ m. Blood \((\eta = 4 \times 10^{-3} \text{ Pa} \cdot \text{s})\) flows at a rate of \(1.0 \times 10^{-7}\) m³/s. Determine the difference in pressure that must be maintained between the two ends of the vessels. (Cutnell 11.70) \(20\) Pa