Viscosity

- Fluid _____

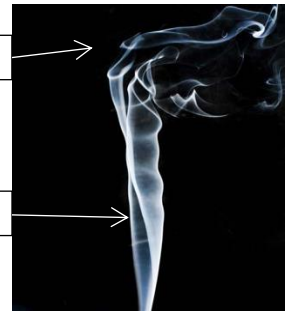**Laminar Flow**

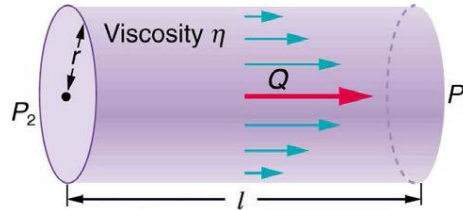- Smooth flow in _____ that don't _____

Turbulent Flow

- Has _____ and _____ that _____ 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 _____

$$Q = \frac{P_2 - P_1}{R}$$

- Q is flow rate; P_1 and P_2 are pressures; R is resistance

Poiseuille's law for resistance

$$R = \frac{8\eta l}{\pi r^4}$$

- η is viscosity; l is length of tube; r is radius of tube

Since flow rate depends on _____

- Higher pressure difference, higher _____
- Higher resistance, higher _____ to maintain _____ Q
- In blood vessels this is a _____ with _____ on artery walls

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 _____

$$N_R = \frac{2\rho vr}{\eta}$$

Table 12.1 Coefficients of Viscosity of Various Fluids

Fluid	Temperature (ºC)	Viscosity η (mPa·s)
Gases		
Air	0	0.0171
	20	0.0181
	40	0.0190
	100	0.0218
Ammonia	20	0.00974
Carbon dioxide	20	0.0147
Helium	20	0.0196
Hydrogen	0	0.0090
Mercury	20	0.0450
Oxygen	20	0.0203
Steam	100	0.0130
Liquids		
Water	0	1.792
	20	1.002
	37	0.6947
	40	0.653
	100	0.282
Whole blood[1]	20	3.015
	37	2.084
Blood plasma[2]	20	1.810
	37	1.257
Ethyl alcohol	20	1.20
Methanol	20	0.584
Oil (heavy machine)	20	660
Oil (motor, SAE 10)	30	200
Oil (olive)	20	138
Glycerin	20	1500
Honey	20	2000–10000
Maple Syrup	20	2000–3000
Milk	20	3.0
Oil (Corn)	20	65

A hypodermic syringe is filled with a solution whose viscosity is 1.5×10^{-3} Pa · s. The plunger area of the syringe is 8.0×10^{-5} m^2, and the length of the needle is 0.025 m. The internal radius of the needle is 4.0×10^{-4} m. The gauge pressure in a vein is 1900 Pa (14 mmHg). What force must be applied to the plunger, so that 1.0×10^{-6} m^3 of solution can be injected in 3.0 s?
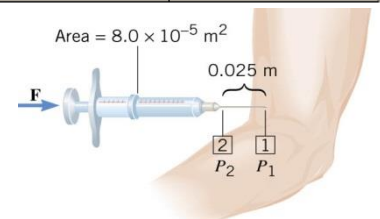
Is the flow laminar if the density is 1000 kg/m³?

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. What force is needed to pull one microscope slide over another at a speed of 1.00 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) 1.61×10^{-5} **N**

3. 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**

4. A small artery has a length of 1.1×10^{-3} m and a radius of 2.5×10^{-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) 8.7×10^{-2} **mm³/s**

5. 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 to reduce the blood flow to their feet. (OpenStax 12.35) $0.316r_1$

6. 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) $1.8r_1$

7. (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**

8. 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 (N/m²) · s (or 1.00 Pa · s). (OpenStax 12.51) **1990**

9. 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**

10. 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 1.62×10^6 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) 7.90×10^5

11. 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) 3.16×10^{-4} **m³/s**

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