

The Ideal Fluid(Liquid)

Viscosity of a Liquid

Laminar and Turbulent Flow

Learning Objectives:

1. Describe an ideal liquid (fluid);
2. Define steady and turbulent flow;
3. Use the equation of continuity to solve problems:

$S_1 v_1 = S_2 v_2$ or $v_2/v_1 = S_1/S_2$
where v is velocity of flow



CHARACTERISTICS OF AN IDEAL FLUID

1. The fluid is non viscous – meaning there is no internal friction between adjacent layers.

- Liquid viscosity is basically the measure of stickiness of a fluid.

- It refers to molecular friction caused by pushing of molecules past one another.

- While viscosity of water is low, other liquids such as shampoo or syrup have high viscosity.

Give examples of viscous and non viscous substances you can see in stores and markets.



CHARACTERISTICS OF AN IDEAL FLUID



Lava is an example of a viscous fluid.

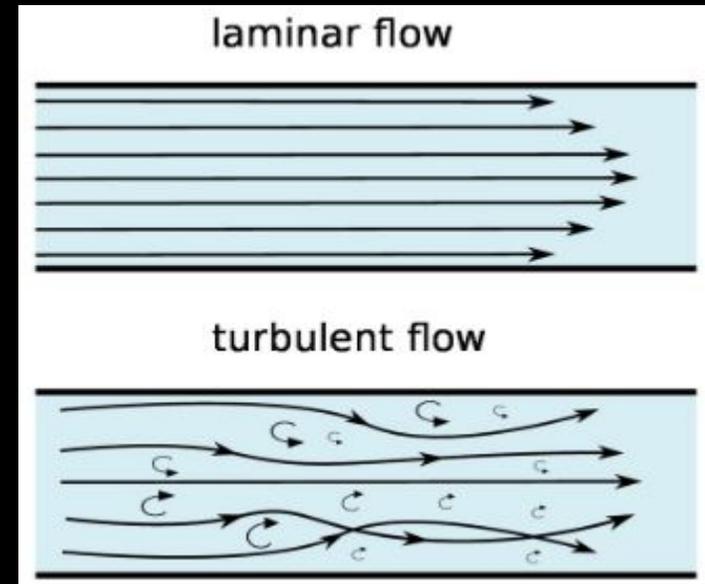
The viscosity decreases with increasing temperature: The hotter the lava, the more easily it can flow.

CHARACTERISTICS OF AN IDEAL FLUID

One factor that affects viscosity is *flow conditions*. The two main flow conditions of a liquid are laminar and turbulent.

- *Laminar* flow is characterized by the smooth flow of the fluid in layers that do not mix.

- *Turbulent* flow, or turbulence, is characterized by eddies and swirls that mix layers of fluid together.



The flow of smoke rising from these incense sticks is laminar up to a certain point, and then becomes turbulent.

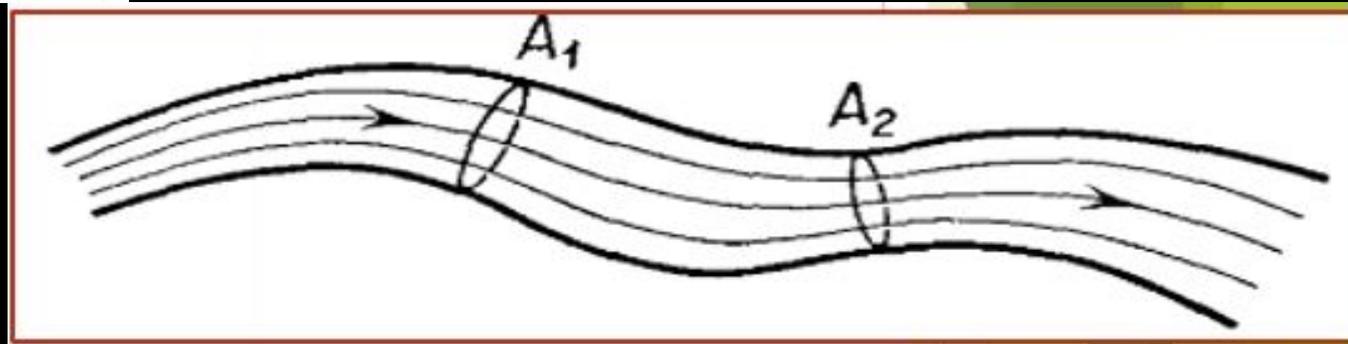
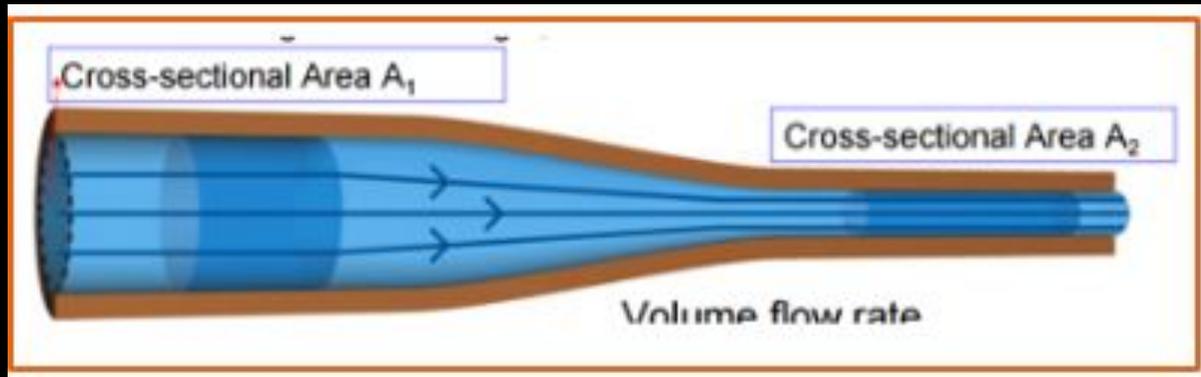


Smoke rises smoothly for a while and then begins to form swirls and eddies. The *smooth flow* is called *laminar flow*, whereas the *swirls and eddies* typify *turbulent flow*. If you watch the smoke (being careful not to breathe on it), you will notice that it *rises more rapidly when flowing smoothly* than after it becomes turbulent, *implying that turbulence poses more resistance to flow.*



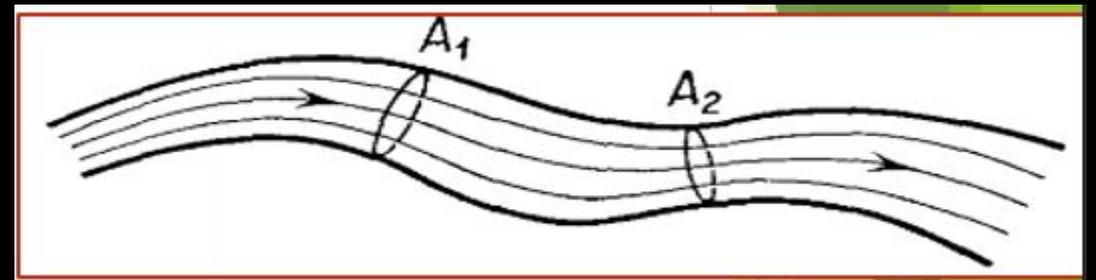
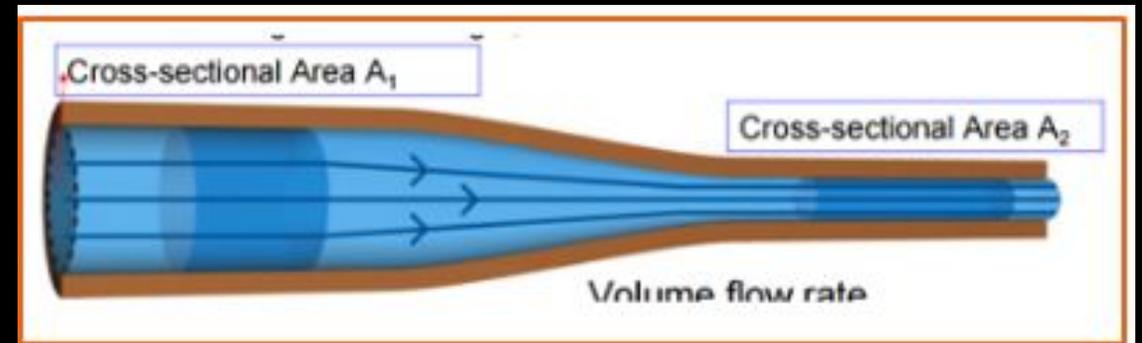
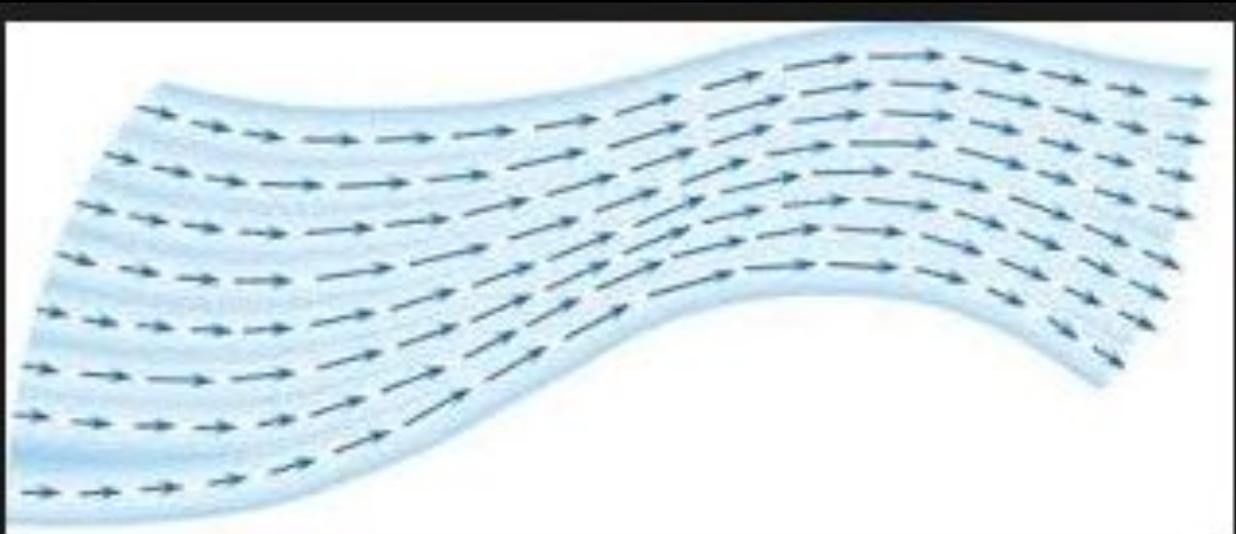
CHARACTERISTICS OF AN IDEAL FLUID

2. The fluid is incompressible – meaning its density is constant as it flows or its volume flows with the fluid velocity.



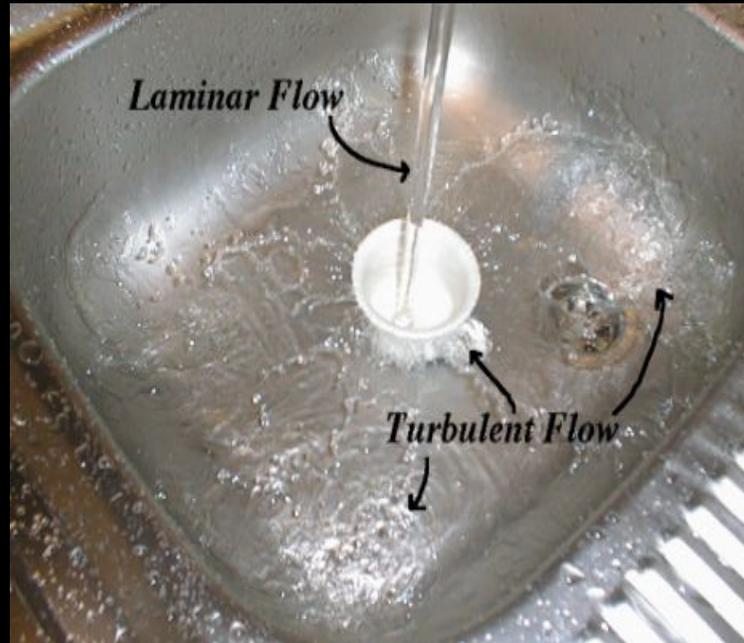
CHARACTERISTICS OF AN IDEAL FLUID

3. The fluid is steady - a flow in which the velocity, density and pressure of the fluid at a particular fixed point does not change with time.



CHARACTERISTICS OF AN IDEAL FLUID

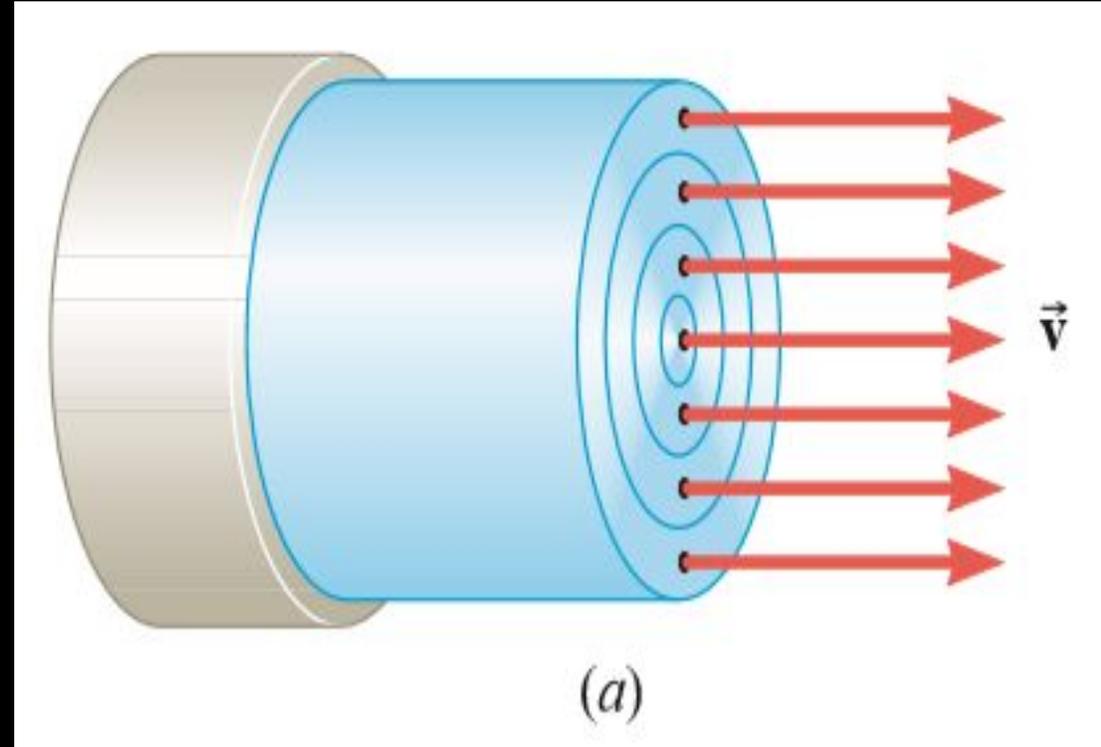
4. The fluid moves without turbulence – meaning the flow is laminar.



*VISCOUS FLOW

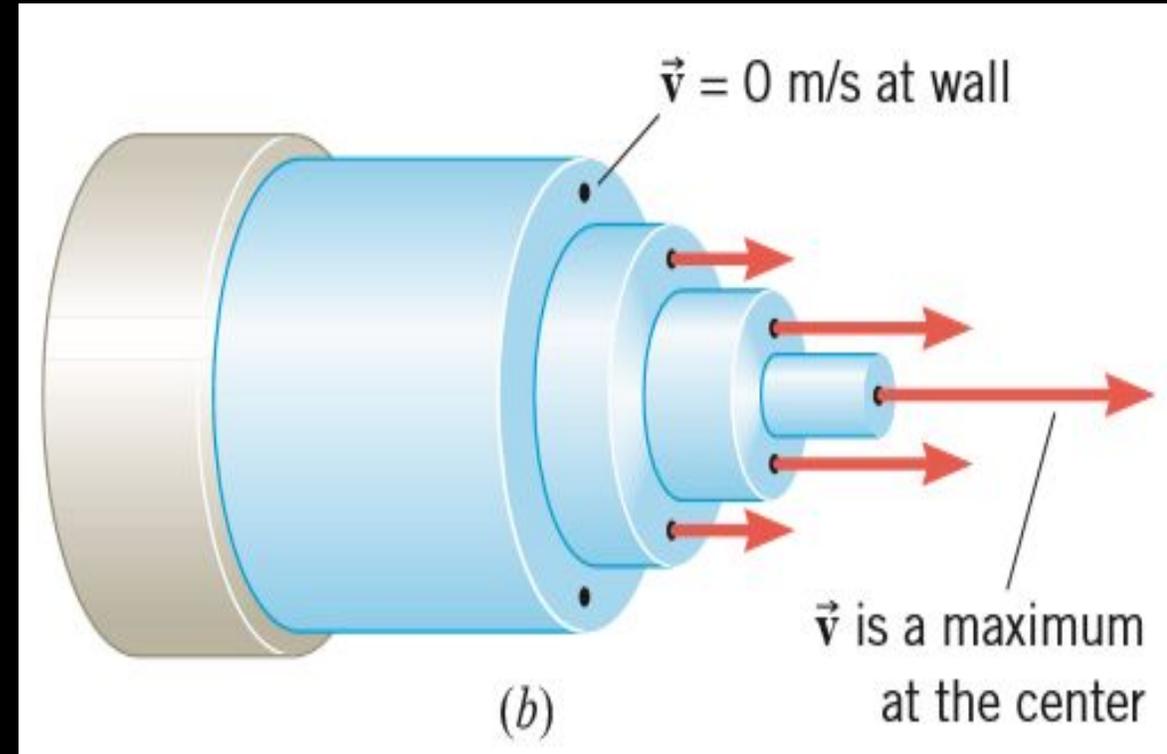
-In an ideal fluid there is no viscosity to hinder the fluid layers as they slide past one another.

-Within a pipe of uniform cross section, every layer of an ideal fluid moves with the same velocity, even the layer next to the wall.

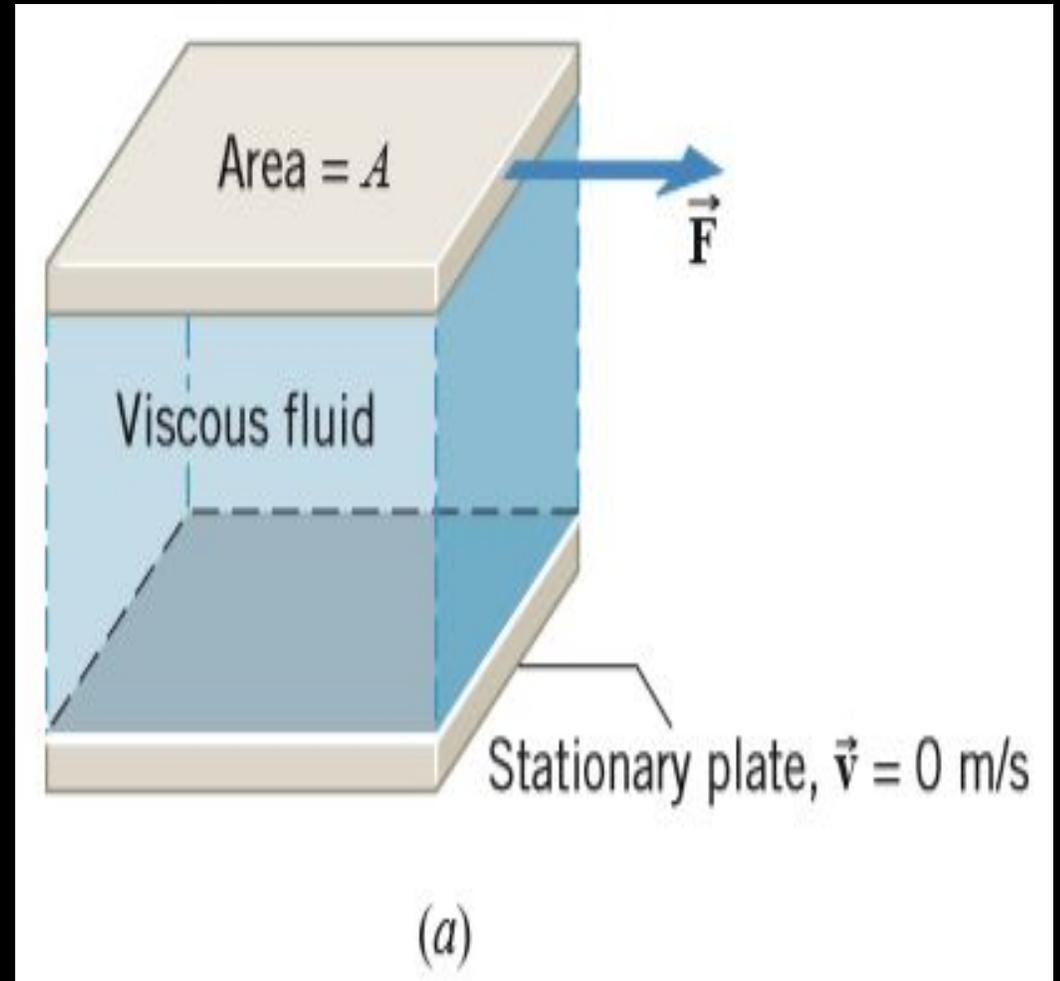


*VISCOUS FLOW

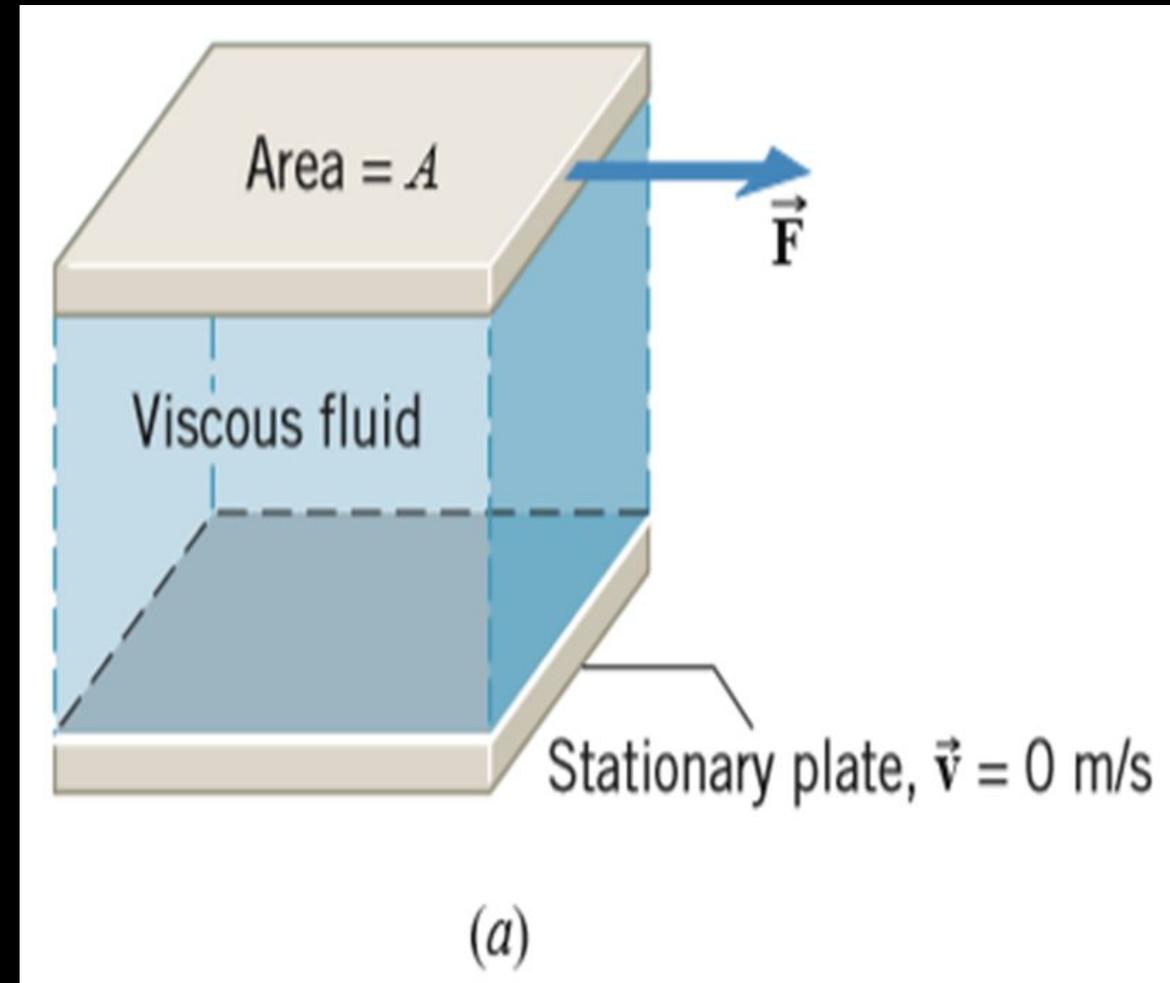
- When viscosity is present, the fluid layers have different velocities.
- The fluid at the center of the pipe has the greatest velocity.
- In contrast, the fluid layer next to the wall surface does not move at all, because it is held tightly by intermolecular forces.



To help introduce **viscosity** in a quantitative fashion, this figure shows a viscous fluid between two parallel plates. The top plate is free to move, while the bottom one is stationary.

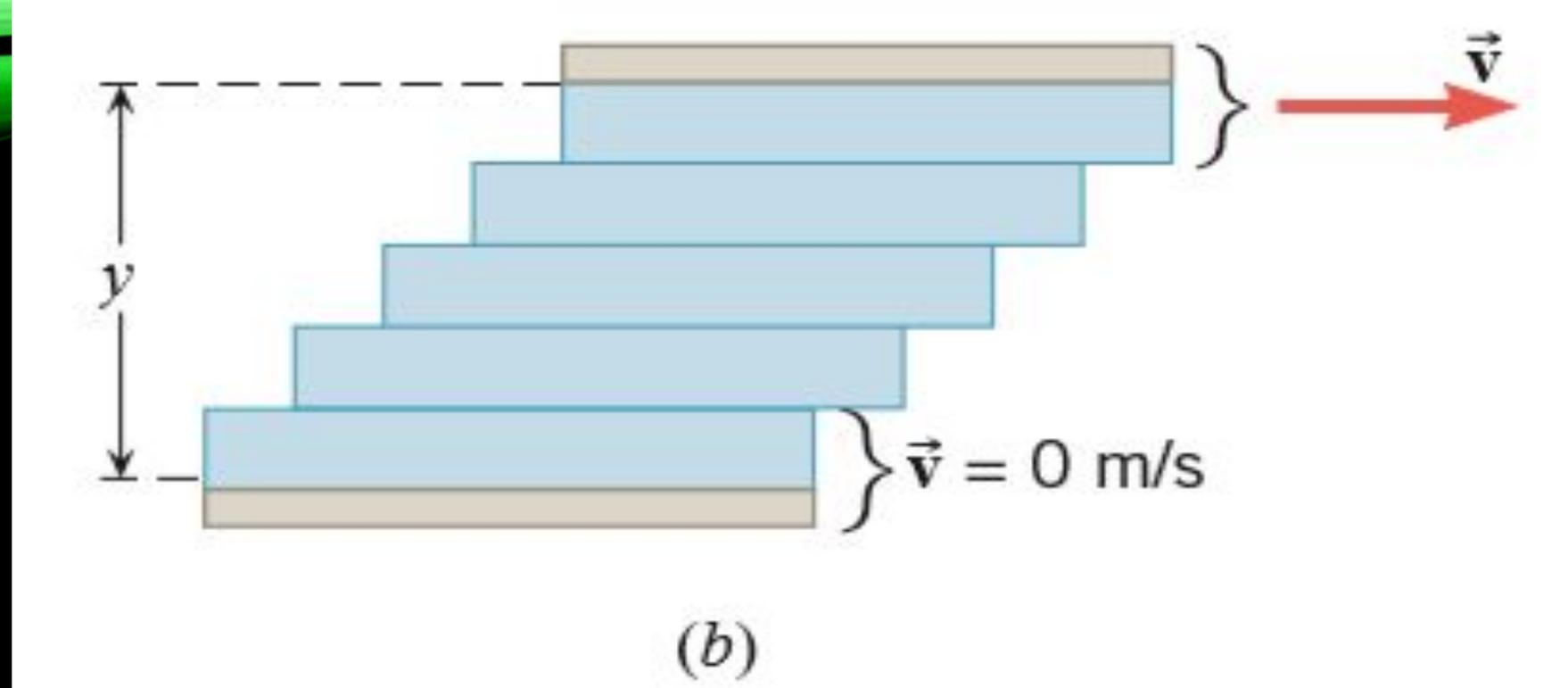


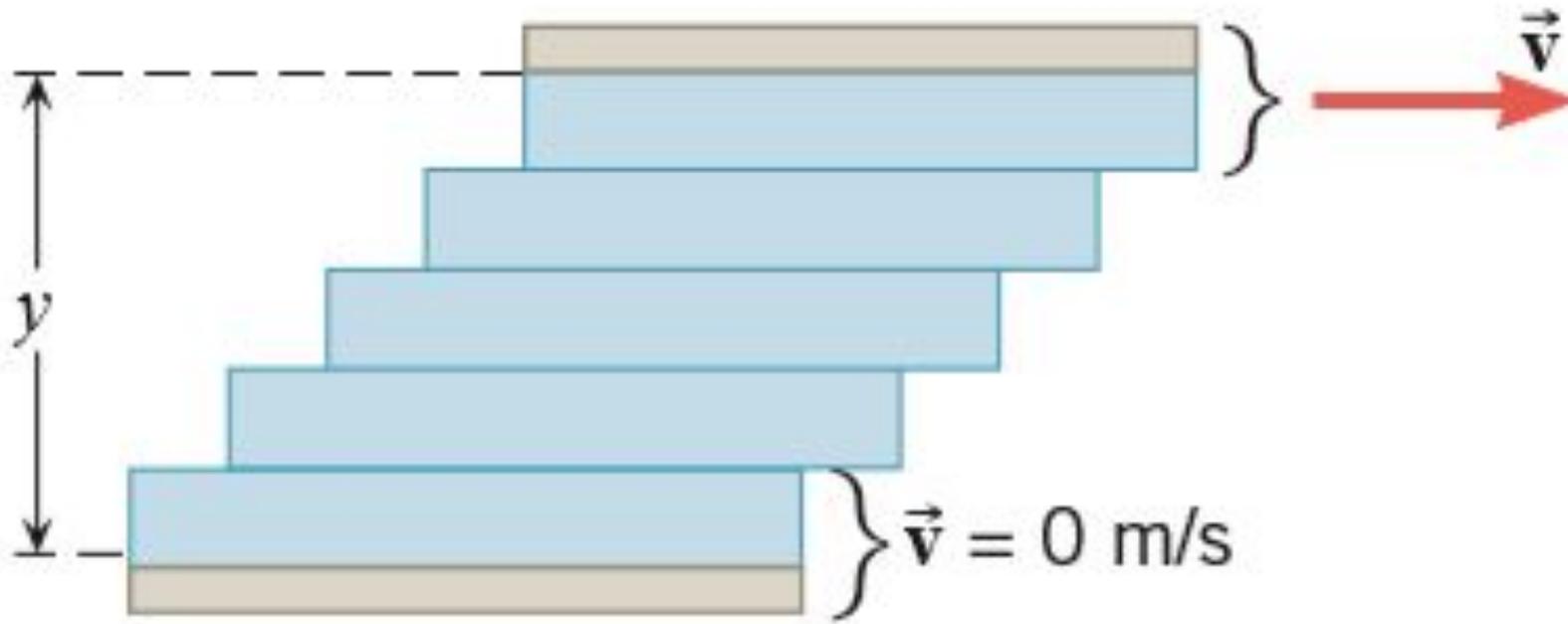
If the top plate is to move with a velocity relative to the bottom plate, a force is required. For a highly viscous fluid, like thick honey, a large force is needed; for a less viscous fluid, like water, a smaller one will do.



This drawing suggests, we may imagine the fluid to be composed of many thin horizontal layers.

When the top plate moves, the intermediate fluid layers slide over each other. The velocity of each layer is different, changing uniformly from at the top plate to zero at the bottom plate.

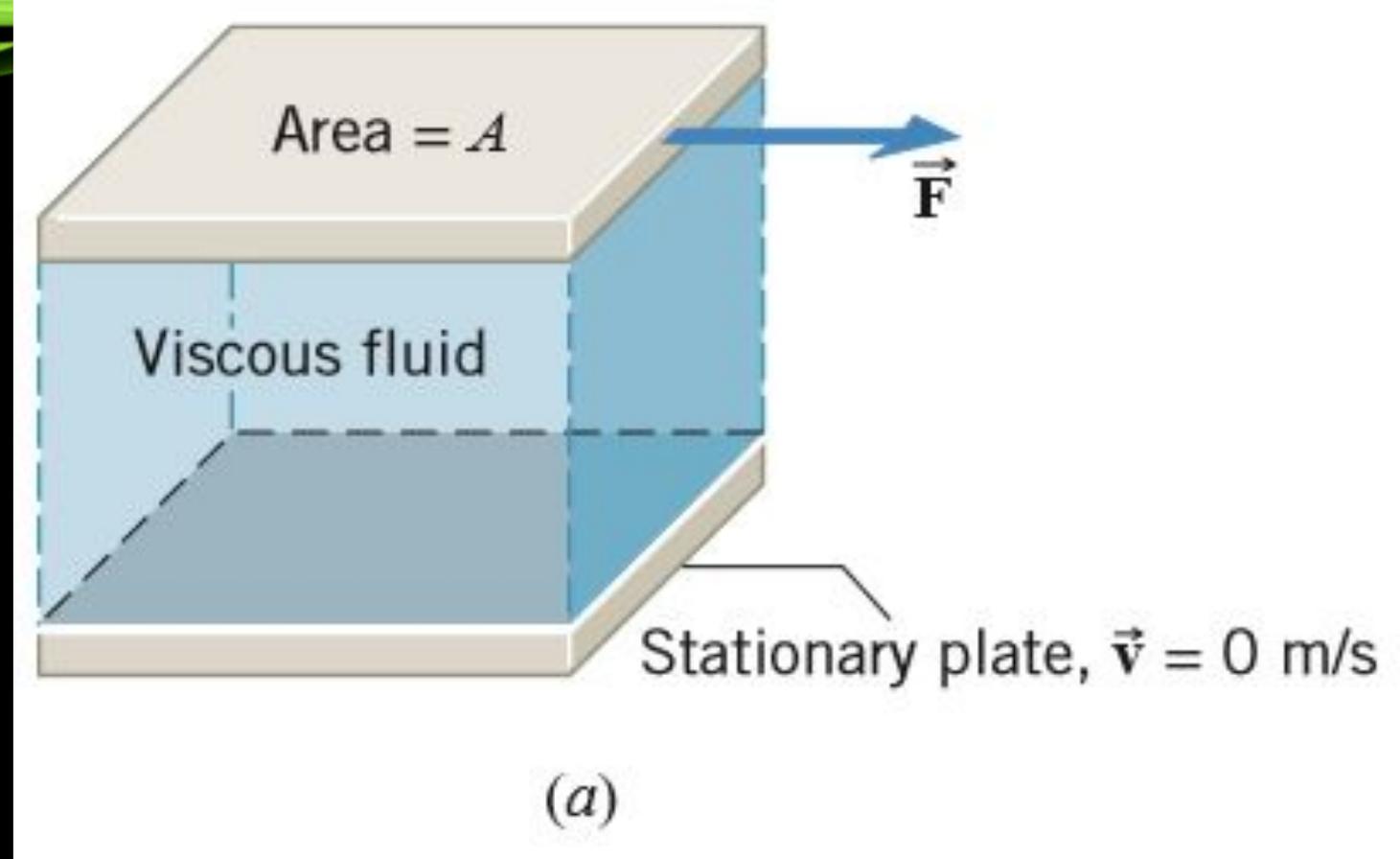




The resulting flow is called *laminar flow*, since a thin layer is often

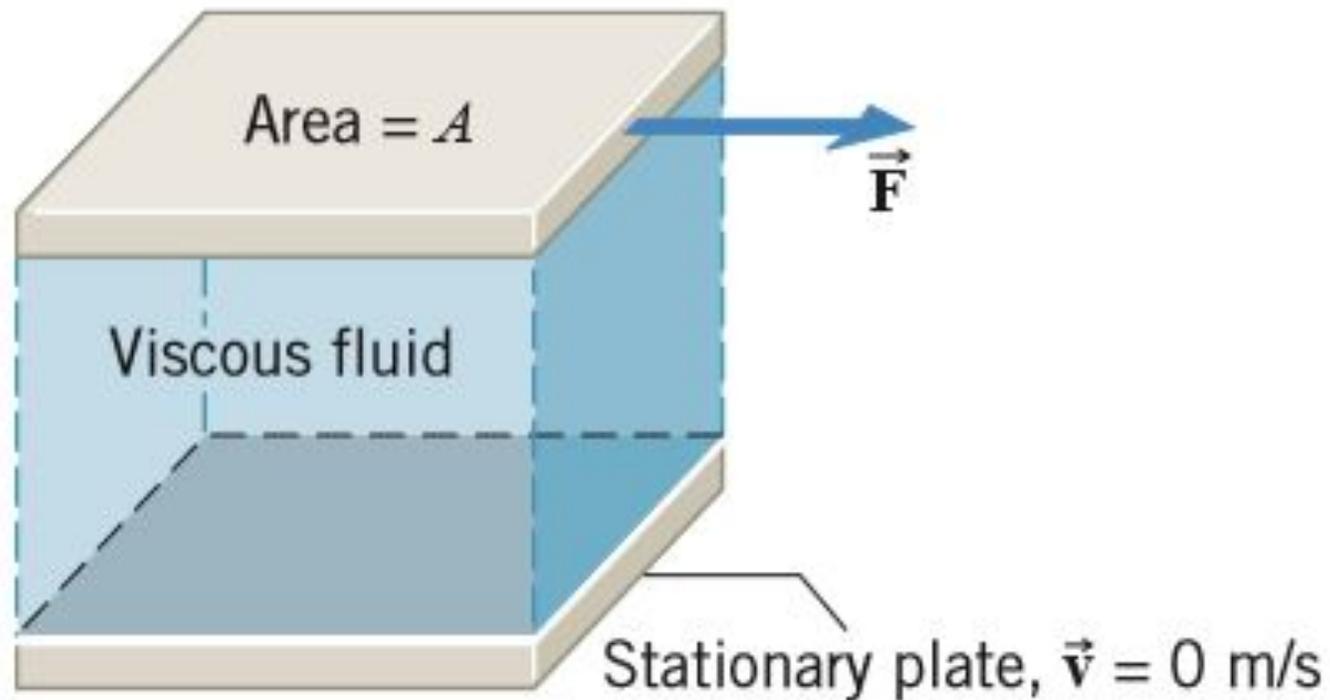
referred to as a *lamina*. As each layer moves, it is subjected to viscous forces from its neighbors.

The amount of force required to move the top plate to a certain velocity depends on several factors. Larger areas A , being in contact with more fluid, require larger forces, so that the force is proportional to the contact area ($F \propto A$).



Q:

How is the force needed to move the plate to a certain velocity related to the area of the plate?

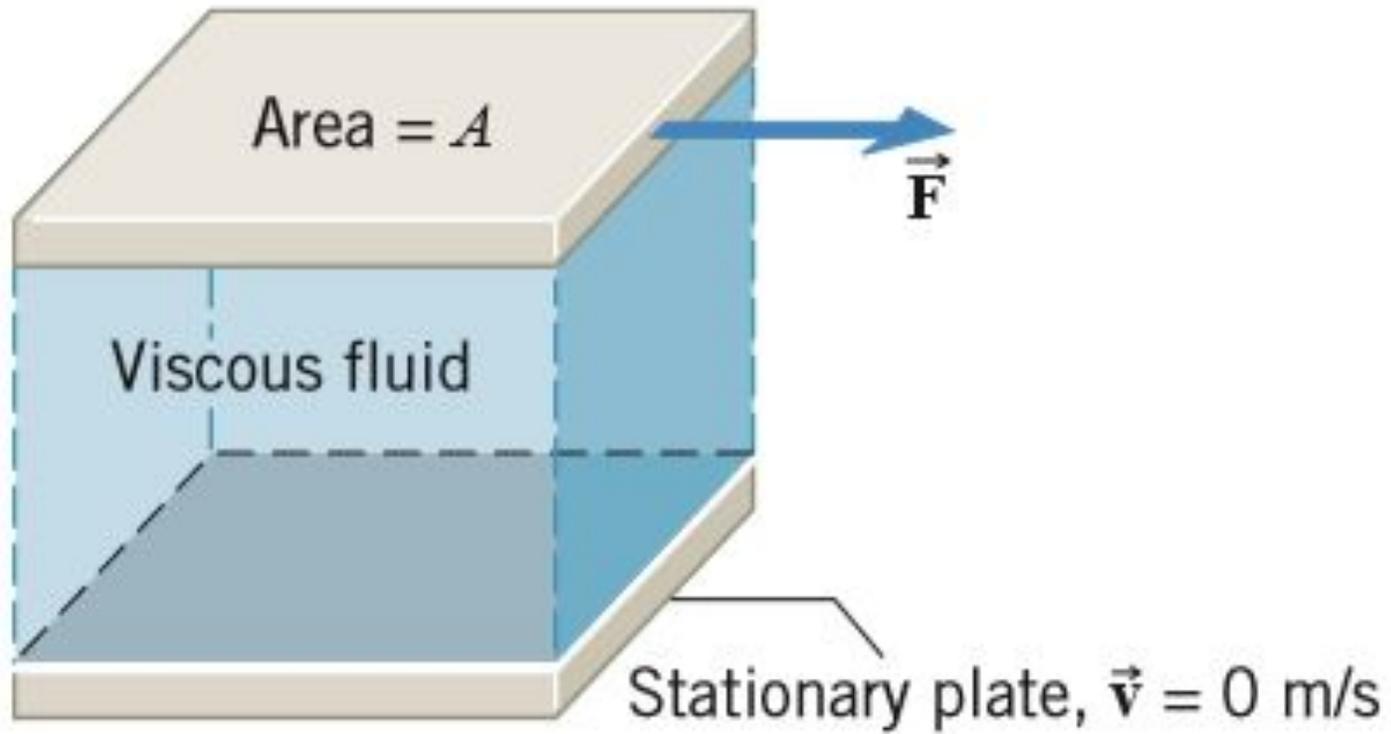


(a)

For a given area, greater speeds require larger forces, with the result that the force is proportional to the speed ($F \propto v$).



How is the force required to move the plate to a certain velocity related to velocity of the fluid?



The force is also inversely proportional to the perpendicular distance y between the top and bottom plates ($F \propto 1/y$).

The larger the distance y , the smaller is the force required to achieve a given speed with a given contact area.

These three proportionalities

$$(F \propto A)$$

$$(F \propto 1/y)$$

$$(F \propto v)$$

can be expressed simultaneously in the following way: $F \propto Av/y$.

$$F = \frac{\eta Av}{y}$$

FORCE NEEDED TO MOVE A LAYER OF VISCOUS FLUID WITH A CONSTANT VELOCITY

The magnitude of the tangential force \vec{F} required to move a fluid layer at a constant speed v , when the layer has an area A and is located a perpendicular distance y from an immobile surface, is given by

$$F = \frac{\eta Av}{y}$$

where η is the coefficient of viscosity.

SI Unit of Viscosity: Pa·s

Common or CGS Unit of Viscosity: poise (P)

$$1 \text{ poise (P)} = 0.1 \text{ Pa} \cdot \text{s}$$



Notes:



- Values of viscosity depend on the nature of the fluid.



- Under ordinary conditions, the viscosities of liquids are significantly larger than those of gases.



- Viscosities of either liquids or gases depend markedly on temperature.

Notes:

- Usually, the viscosities of liquids decrease as the temperature is increased.
- Anyone who has heated honey or oil, for example, knows that these fluids flow much more freely at an elevated temperature.
- In contrast, the viscosities of gases increase as the temperature is raised.



Notes:



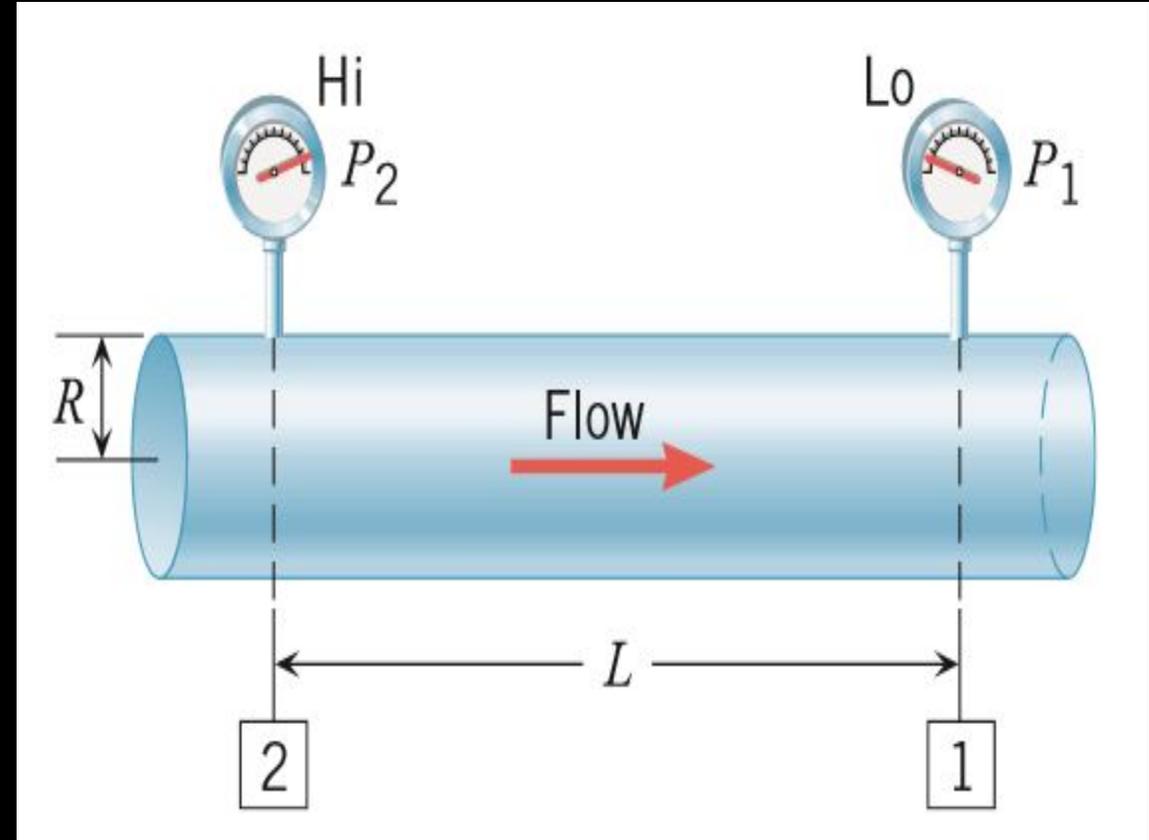
Viscous flow occurs in a wide variety of situations, such as

**- oil moving through a pipeline
or a liquid being forced through**

**-the needle of a hypodermic
syringe.**



For viscous flow, the difference in pressures $P_2 - P_1$, the radius R and length L of the tube, and the viscosity η of the fluid influence the volume flow rate.



Factors that determine the volume flow rate Q (in m^3/s) of the viscous fluid:

1. Difference in pressures $P_2 - P_1$ must be maintained between any two locations along the pipe for the fluid to flow. Q is proportional to $P_2 - P_1$, a greater pressure difference leading to a larger flow rate.



2. A long pipe offers greater resistance to the flow than a short pipe does, and Q is inversely proportional to the length L .

Factors that determine the volume flow rate Q (in m^3/s) of the viscous fluid:

3. High-viscosity fluids flow less readily than low-viscosity fluids, and Q is inversely proportional to the viscosity η .

4. The volume flow rate is larger in a pipe of larger radius, Q being proportional to the fourth power of the radius, or R^4 . For instance, the pipe radius is reduced to one-half of its original value, the volume flow rate is reduced to one-sixteenth of its original value

The mathematical relation for Q in terms of these parameters was discovered by Poiseuille and is known as Poiseuille's law.

POISEUILLE'S LAW

A fluid whose viscosity is η , flowing through a pipe of radius R and length L , has a volume flow rate Q given by

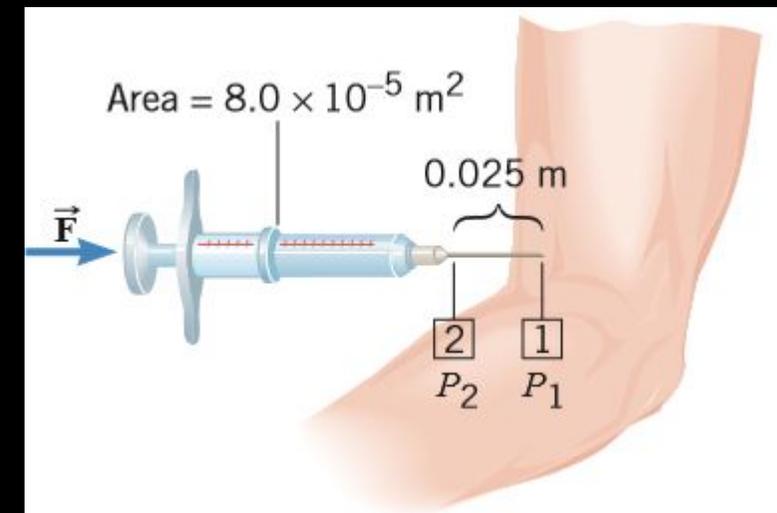
$$Q = \frac{\pi R^4 (P_2 - P_1)}{8 \eta L}$$

where P_1 and P_2 are the pressures at the ends of the pipe.

Example: Giving an Injection

A hypodermic syringe is filled with a solution whose viscosity is 1.5×10^{-3} Pa-s. As the figure shows, the plunger area of the syringe is 8.0×10^{-5} m², 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 mm of mercury). What force must be applied to the plunger, so that 1.0×10^{-6} m³ of solution can be injected in 3.0 s?



Solution The volume flow rate is $Q = (1.0 \times 10^{-6} \text{ m}^3)/(3.0 \text{ s}) = 3.3 \times 10^{-7} \text{ m}^3/\text{s}$. According to Poiseuille's law (Equation 11.14), the required pressure difference is

$$P_2 - P_1 = \frac{8\eta LQ}{\pi R^4} = \frac{8(1.5 \times 10^{-3} \text{ Pa}\cdot\text{s})(0.025 \text{ m})(3.3 \times 10^{-7} \text{ m}^3/\text{s})}{\pi(4.0 \times 10^{-4} \text{ m})^4} = 1200 \text{ Pa}$$

Since $P_1 = 1900 \text{ Pa}$, the pressure P_2 must be $P_2 = 1200 \text{ Pa} + 1900 \text{ Pa} = 3100 \text{ Pa}$. The force that must be applied to the plunger is this pressure times the plunger area:

$$F = (3100 \text{ Pa})(8.0 \times 10^{-5} \text{ m}^2) = \boxed{0.25 \text{ N}}$$

