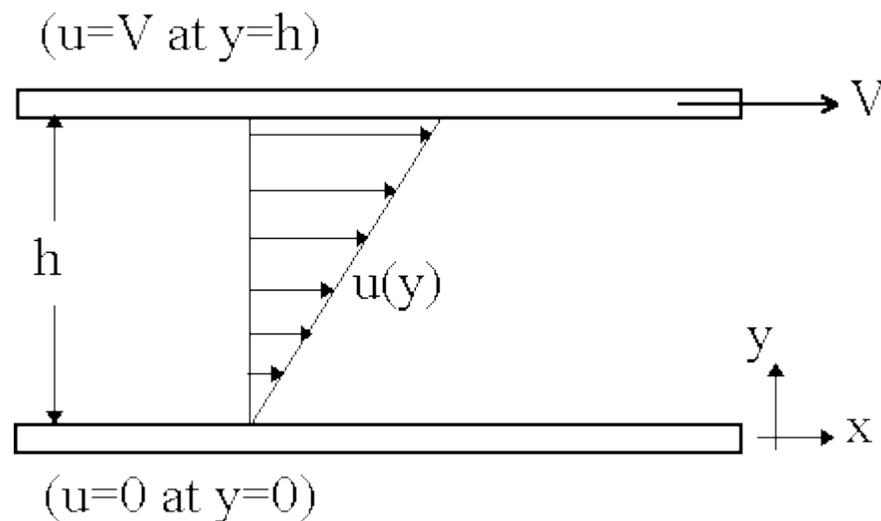


## Fluid Properties (three types)

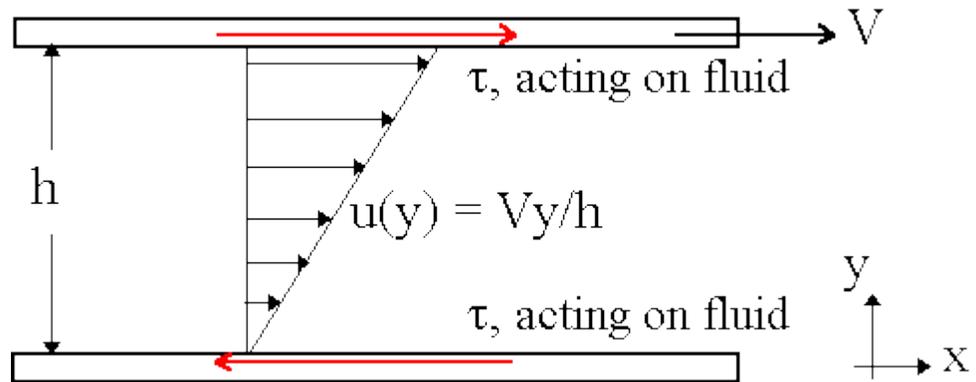
- **Kinematic properties** - properties related to fluid *motion*, like velocity and acceleration.
- **Thermodynamic properties** - properties which describe the thermodynamic state of a fluid. These include temperature, pressure, density, internal energy, specific entropy, specific enthalpy, etc.
- **Miscellaneous properties** - properties which do not fall into either of the above categories.
  - **Viscosity** - a measure of the importance of *friction* in fluid flow. Consider, for example, simple shear between two plates: Consider a fluid in 2-D steady shear between two infinite plates, as shown in the sketch. The bottom plate is fixed, while the upper plate is moving at a steady speed of  $V$ .



It turns out (we will prove this at a later date) that the velocity profile,  $u(y)$  is *linear*, i.e.  $u(y) = Vy/h$ . Also notice that the velocity of the fluid matches that of the wall at both the top and bottom walls. This is known as the ***no slip condition***.

The top plate will experience a friction force to the left, since it is doing work trying to drag the fluid along with it to the right. The fluid at the top of the channel will experience an equal and opposite force (i.e. to the right). Similarly the bottom plate will experience a friction force to the right, since the fluid is trying to pull the plate along with it to the right. The fluid at the bottom of the channel will feel an equal and opposite force, i.e. to the left. In fluid mechanics, shear stress, defined as a

tangential force per unit area, is used rather than force itself. Define (Greek letter "tau") as the friction force per unit area acting on the fluid, as illustrated below:



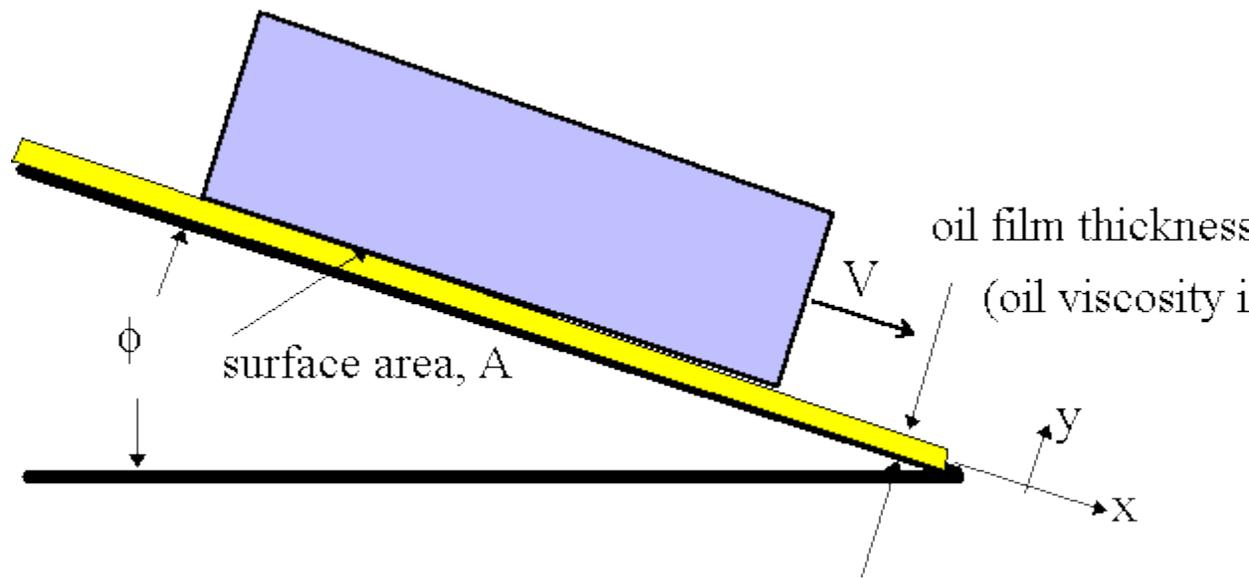
In a simple 2-D shear flow such as this, the shear stress is directly proportional to the slope of the velocity profile. In fact, the constant of proportionality is the coefficient of viscosity itself! Mathematically,

$$\tau = \mu \frac{du}{dy} = \mu \frac{V}{h}$$

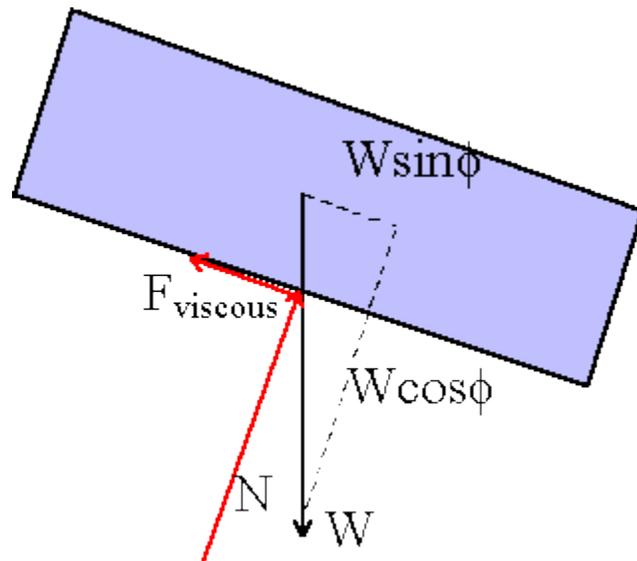
This little equation turns out to be quite useful for a lot of practical engineering problems. For example, consider a block sliding down an incline:

**Given:** A block of weight  $W$  is sliding down an incline at constant speed  $V$  on a thin film of oil of thickness  $h$ , as sketched.

**Find:** Speed  $V$  as a function of the other variables in the problem



**Solution:** Draw a free body diagram of the block. The forces acting on the block are its weight,  $W$ , a normal force,  $N$ , due to pressure of the oil on the bottom surface of the block, and a viscous force,  $F_{\text{viscous}}$ , due to friction on the bottom of the block.



From simple trig, we can sum the forces in both  $x$  and  $y$  and set the net force to zero (this is a statics problem since the block is moving at constant speed). Thus,

$$N = W \cos \phi$$

$$F_{\text{viscous}} = W \sin \phi$$

A magnified view of the oil film reveals that it is locally the same as our simple shear between plates problem. Thus, the x component of velocity,  $u$  is given by  $u(y) = Vy/h$ . We also know that for simple 2-D shear,

$$\tau = \mu \frac{du}{dy} = \mu \frac{V}{h}$$

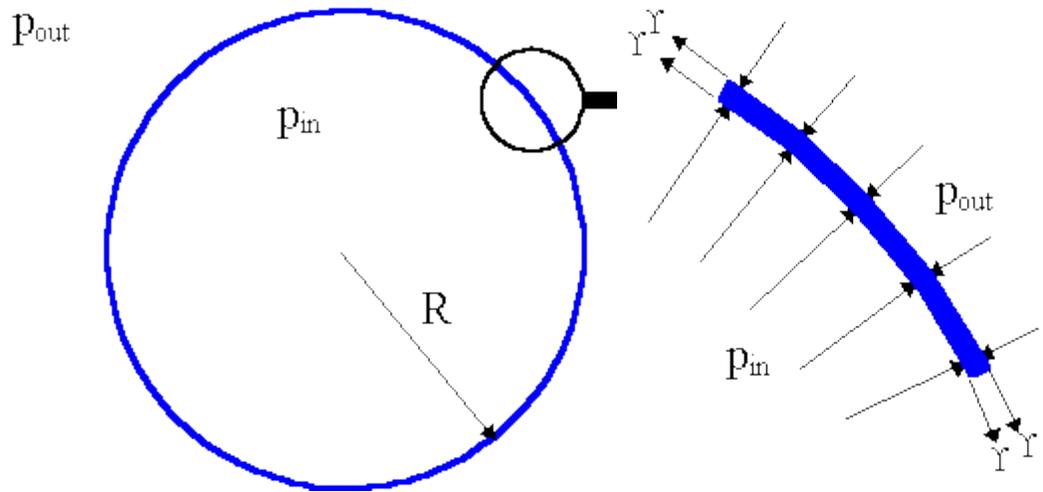
Finally, the total viscous force is equal to the shear stress times the surface area,  $A$ , in contact between the fluid and the bottom surface of the plate. Therefore,

$$F_{\text{viscous}} = \tau \cdot A = \frac{\mu VA}{h} = W \sin \phi, \text{ or}$$

$$V = \frac{Wh \sin \phi}{\mu A}$$

- **Kinematic viscosity** is simply defined as the viscosity divided by density, i.e.  

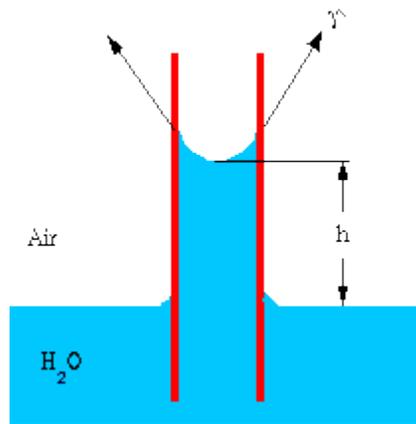
$$\nu = \mu / \rho$$
- **Surface tension** is a property of liquids which is felt at the interface between the liquid and another fluid (typically a gas). Surface tension has dimensions of force per unit length, and always acts parallel to the interface. Surface tension causes the molecules at the interface to repel each other, forming a kind of "skin" under tension at the interface. A good example of surface tension is found in a common soap bubble. A soap bubble is a good example to illustrate the effects of surface tension. How does a soap bubble remain spherical in shape? The answer is that there is a higher pressure inside the bubble than outside, much like a balloon. In fact, surface tension in the soap film acts much the same as the tension in the skin of a balloon. Consider a soap bubble of radius  $R$  with internal pressure  $p_{\text{in}}$  and external (atmospheric) pressure  $p_{\text{out}}$ . If the area shown is magnified, a free body diagram of the soap film can be drawn.



- On the free body diagram, the sum of all forces must be zero, since the soap film segment is not accelerating. Surface tension forces act parallel to any interface. On the free-body diagram of the soap bubble segment, there are four locations where surface tension acts, as shown. Analysis of a soap bubble yields the following,

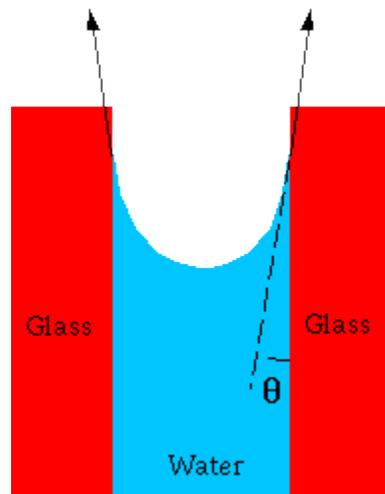
$$\Delta p = p_{in} - p_{out} = \frac{4Y}{R}$$

- **Surface tension** (continued) Surface tension is also important at the interface between a liquid, a gas, and a solid. For example, a **meniscus** occurs when the surface of a liquid touches a solid wall, as most readily noticed when a capillary tube is placed in a liquid. Consider a glass capillary tube inserted into a liquid, such as water. The water will rise up the tube to a height,  $h$ , because surface tension pulls the surface of the water towards the glass, as shown. The meniscus is the curved surface at the top of the water column.

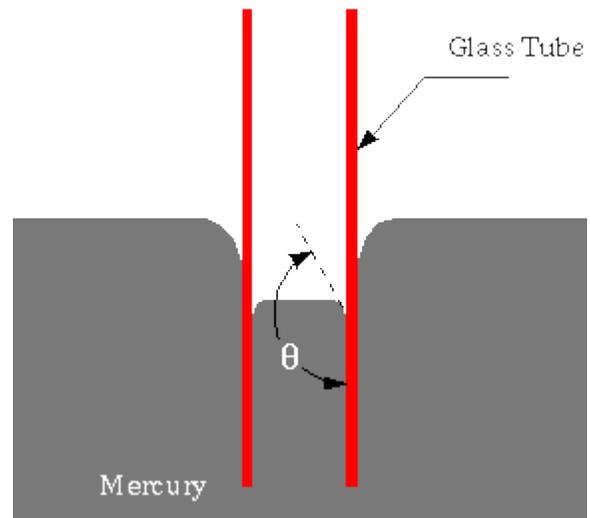


The contact angle is defined as the angle between the liquid and solid surface, as shown in the sketch. Contact angle depends on both the liquid and the solid. If  $\theta$  is less than  $90^\circ$ , the liquid is said to "wet" the solid. However, if  $\theta$  is greater than  $90^\circ$ , the liquid is repelled by the solid, and tries not to "wet" it. For example, water wets glass, but not wax. Mercury does not wet glass.

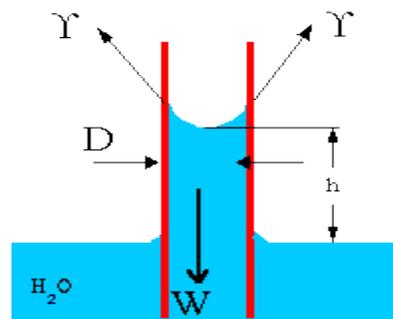
Water wets glass



Mercury does not wet glass



Consider a small glass capillary tube inserted into water. The height of the water column can be found by summing all forces acting on the water column as a free body diagram. (This is a statics problem since there is no acceleration.)



The downward force is due to gravity, i.e. the weight of the water column. The only upward force available to balance the weight is that caused by surface tension (pressure forces all cancel out, as will be

explained in a later lecture). Column height  $h$  can be predicted as follows:

$$W = mg = \rho g V = \rho g \frac{\pi D^2}{4} h$$

$$\text{Surface tension force} = \gamma \cos \theta \cdot \pi D$$

$$\text{Equating these, } h = \frac{4\gamma \cos \theta}{\rho g D}$$

- **Vapor pressure** is defined as the pressure at which a liquid will boil (vaporize). Vapor pressure rises as temperature rises. For example, suppose you are camping on a high mountain (10,000 ft. or roughly 3,000 m in altitude). From Table A.6 the atmospheric pressure at this elevation is about 70. kPa. From Table A.5 it is seen that at a temperature of around 90. °C, the vapor pressure of water is also around 70. kPa. From this it can be stated that at 10,000 ft. of elevation, water boils at around 90 °C, rather than the common 100 °C at standard sea level pressure. This has consequences for cooking. For example, eggs have to be cooked longer at elevation to become hard-boiled since they cook at a lower temperature. A pressure cooker has the opposite effect. Namely, the tight lid on a pressure cooker causes the pressure to increase above the normal atmospheric value. This causes water to boil at a temperature even greater than 100 °C; eggs can be cooked a lot faster in a pressure cooker! Vapor pressure is important to fluid flows because, in general, pressure in a flow decreases as velocity increases. This can lead to **cavitation**, which is generally destructive and undesirable. In particular, at high speeds the local pressure of a liquid sometimes drops *below* the vapor pressure of the liquid. In such a case, **cavitation** occurs. In other words, a "cavity" or bubble of vapor appears because the liquid vaporizes or boils at the location where the pressure dips below the local vapor pressure. Cavitation is not desirable for several reasons. First, it causes noise (as the cavitation bubbles collapse as they migrate into regions of higher pressure). Second, it can lead to inefficiencies and reduction of heat transfer in pumps and turbines (turbomachines). Finally, the collapse of these cavitation bubbles causes pitting and corrosion of blades and other surfaces nearby.

Source:

[http://www.mne.psu.edu/cimbala/Learning/Fluid/Fluid\\_Prop/fluid\\_property.htm](http://www.mne.psu.edu/cimbala/Learning/Fluid/Fluid_Prop/fluid_property.htm)