Recap: Static Fluids

- **Archimedes' principal** states that the **buoyant force** acting on an object is **equal** to the **weight** of fluid displaced.
- If the **average density** of object is **greater** than density of fluid displaced, then the **weight** of object will **exceed buoyant force** and it will **sink** (and vice versa).
- A balloon will **rise** until its **average density** equals that of the **surrounding air** (just like a submarine floating in water).
- **Buoyancy force** is due to **pressure difference** between **top** and **bottom** of submerged object (as pressure increases with depth).
- **Buoyancy is a very useful force**:
  - Ship floatation; cargo transport.
  - Balloon flights
  - Density determination (Archimedes' original goal).

Fluids in Motion (Chapter 9)

- Have you ever wondered why water seems to **speed up** or **slow down** in a stream?
- Fluid motion is affected by:
  - Width / depth of stream
  - Viscosity of fluid (friction within fluid)
  - Type of flow (laminar or turbulent)

Rate of flow

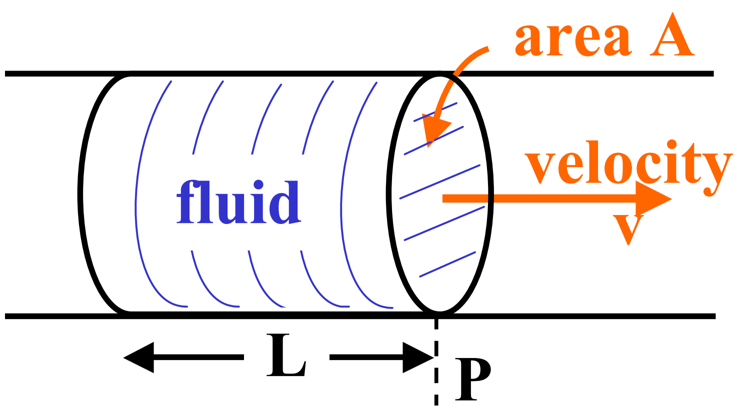
- In many instances of **continuous flow**, the amount of fluid **entering** and **leaving** a system is **conserved**.

E.g. The **same amount** of water that **enters** a stream at some upper point **leaves** the stream at a lower point.

Called: “**Continuity of flow**”.

- If **no continuity** of flow then get **collection** or **loss** at some point in system.

Flow Rate



- Consider flow of liquid down a pipe past point P.
- **Rate of flow** = $\frac{\textbf{volume}}{\textbf{time}}$ liter /sec (gal / min)

$$\text{Volume} = A\,.L \quad \text{and} \quad \text{speed } v = \frac{L}{t}$$

Thus rate of flow = $\frac{A.L}{t}$ or $\boxed{\textbf{Flow rate} = v\,.A}$

Result (assuming continuous flow):

"The **rate** at which a fluid moves (e.g. through a pipe) is equal to its **speed** times its **cross-sectional area**."

i.e. The **greater speed** and **larger area**, the **greater** the flow rate.

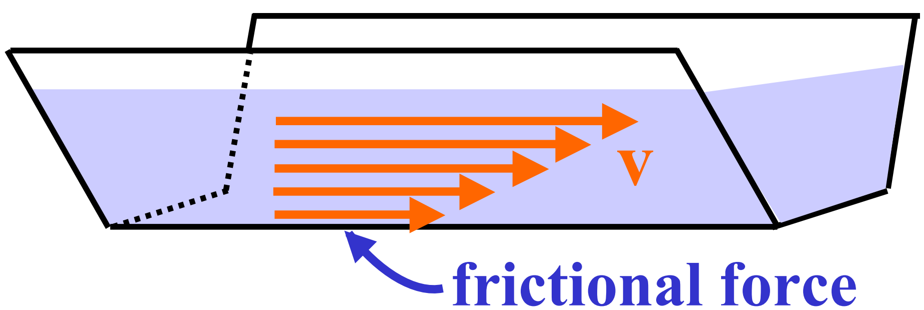
- Valid for **any** fluid.

Consequences of Continuous Flow (= v .A)

- If **area increases**, the **velocity decreases**, e.g. wide, deep streams tend to flow **slowly** (e.g. Amazon river).
- As **area decreases**, the **velocity increases**, e.g. a narrowing in a stream creates faster flow; or: a **nozzle** on a hose pipe creates a **fast jet** of water!

Viscosity

- Viscosity of a fluid results in a **variation** in **speed** across its **cross-sectional area**.
- Viscosity is due to **frictional forces** between "**layers**" of fluid and between the **fluid** and **walls of container**. (Large viscosity => large friction).



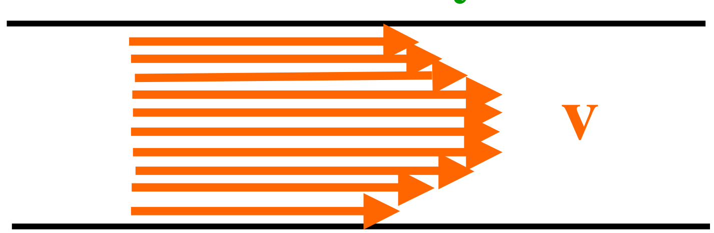
- Each **layer** of fluid flowing in trough **moves more slowly** than the layer above it.

- Net effect of viscosity is that the velocity of flow **increases** as get **farther** from the **edges of container**.
- E.g. In a **pipe** the fastest flow is at its **center**; or in a **river** fastest flow is in the center and slowest near banks.

Unexpected consequences:

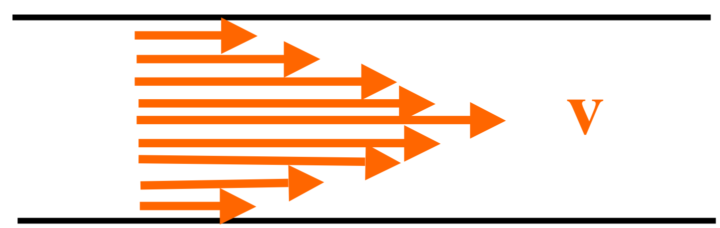
- At the **edge** of pipe there exists a **thin layer of fluid** (liquid or gas) that is **stationary**… which causes:
  - **Dust** to build up on **moving objects** such as fan blades, car windows etc! – where least expected!
- **Viscosity** of different fluids varies **significantly**, e.g. honey, thick oils have much larger viscosities than water.

low viscosity



low friction

high viscosity

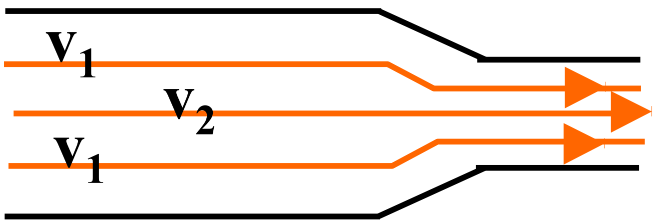


high friction

- Viscosity of **liquids** is much **larger** than **gases** and is highly **temperature sensitive.**

Two Types of Fluid Flow

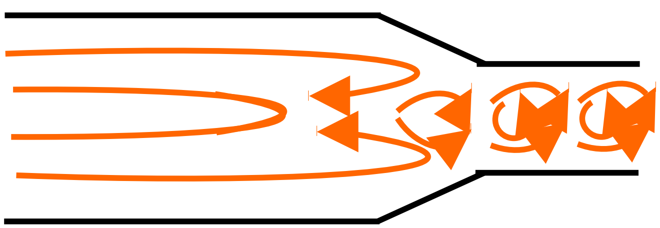
a) Laminar flow:



- **Laminar flow** is described by "**streamlines**" that are **roughly parallel** and **smooth**.

- Net effect is that the **speeds of different layers** may be **different** but one layer moves **smoothly** past another.
- **Laminar flow** is usually associated with **low speed** flow.

b) Turbulent Flow:



- If rate of flow is **increased**, the **laminar flow** pattern is replaced by a **complex turbulent one.**

- **Turbulent flow** can consist of **rope-like twists** that can become distinctive **whorls** and **eddies**.

- Turbulent flow greatly **increases resistance** to flow of fluid and is usually undesirable, e.g. modern car design **reduces** turbulent flow to get **better** gas consumption. (Fuel economy)
- Although the **density** of fluid and the **cross sectional area** play a role we usually consider the **transition** from **laminar** to **turbulent** flow as function of:

  - Average fluid speed
  - Fluid viscosity.

- Higher **fluid speeds** are more likely to be **turbulent**.
- But higher **viscosity inhibits** turbulent flow.

Examples:

- Water flowing from a tap: **laminar near tap** where **flow rate is low**, but as water **accelerates** under gravity it becomes **turbulent flow**!
- **Weather patterns** on Earth are subject to **turbulent flow** (order in chaos?!).
- **Red Spot** on Jupiter is a **giant stable vortex**… with associated **whorls** and **eddies**.

Red Spot –
Hundreds of Years Old Storm

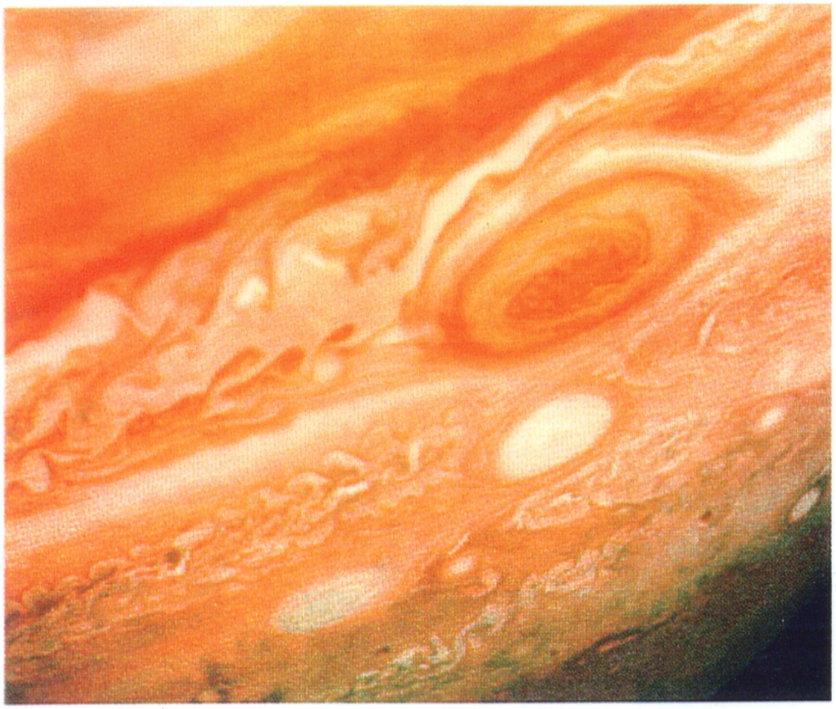


Figure 13-5 R I V U X G

Turbulence Around the Great Red Spot Atmospheric turbulence around the Great Red Spot is clearly seen in this *Voyager 2* image. When this picture was taken in 1979, the Great Red Spot was about 20,000 km long and about 10,000 km wide. For comparison, the Earth's diameter is 12,756 km. The prominent white oval south of (below) the Great Red Spot has been observed since 1938. (NASA/JPL)

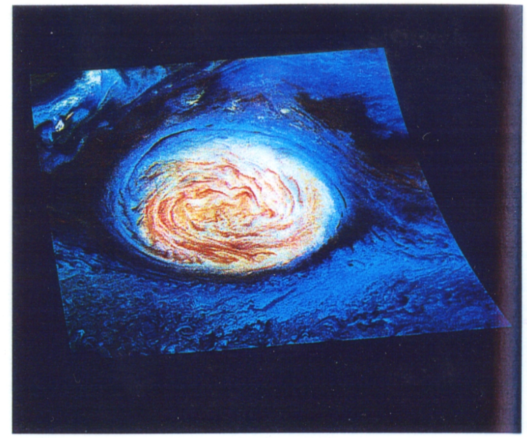


Figure 13-6 R I V U X G

***Galileo* Views the Great Red Spot** This June 1996 view from the *Galileo* spacecraft is actually a mosaic of images made at different infrared wavelengths, which are reflected preferentially by clouds at different altitudes. The highest clouds, shown in red and white, are found within the Great Red Spot. A green color indicates medium-level clouds, and the blue and black areas around the Great Red Spot denote the lowest clouds. (These are false colors, not the actual colors of the clouds.) (NASA/JPL)

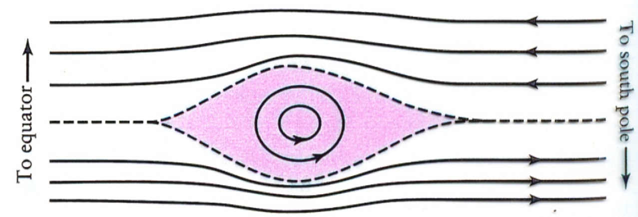
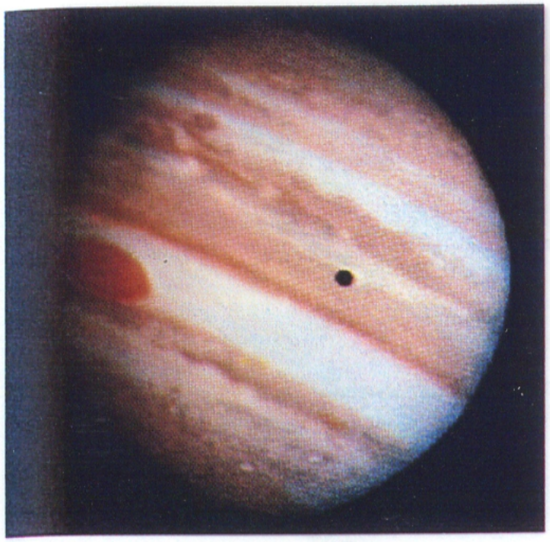
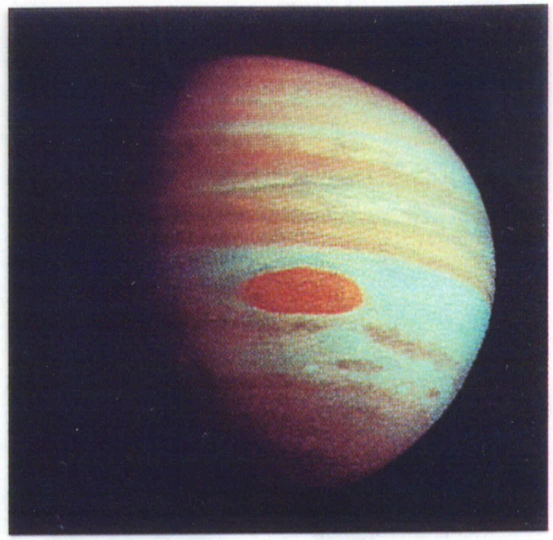


Figure 13-7

Circulation Around the Great Red Spot The winds to the north and south of the Great Red Spot blow in opposite directions. Winds within the Great Red Spot itself spin counterclockwise, completing a full revolution in about six days. (Adapted from A. P. Ingersoll)

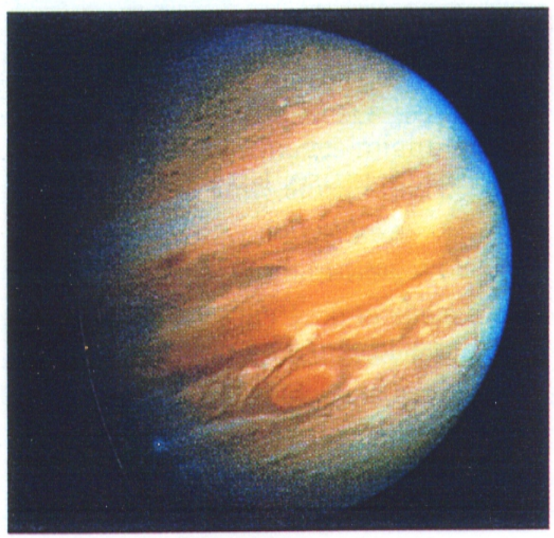


a *Pioneer 10*, December 1973



b *Pioneer 11*, December 1974

c *Voyager 1*, March 1979



d *Voyager 2*, July 1979

e HST, February 1995

VIDEO 13.1

Figure 13-4 R I **V** U X G

Five Views of Jupiter These images show major changes in the planet's upper atmosphere over more than 21 years. Differences are apparent even between the two *Voyager* views (**c** and **d**), made only four months apart. Image (**e**) was taken by the 2.4-m Hubble Space Telescope from

Bernoulli's Principle

Question: What happens when we perform **work** on a fluid?

…**increasing** its **energy**.

Can - Increase its **kinetic energy** (increase velocity)

- Increase its **potential energy** (e.g. pump it up hill)

- **Bernoulli's principle** results from **conservation of energy** applied to flow of fluids.
- For an **incompressible fluid** flowing in a horizontal pipe (or stream) the **work done** will increase the **fluid's KE**.
- To **raise the KE** (i.e. velocity) of fluid there must be a **force** (and acceleration)… to do **work** on the fluid.
- **Force** is due to **pressure difference** in fluid from one point to another, i.e. a difference in pressure will cause accelerated flow from a **high to a low** pressure region.
- Thus, we can expect to find **higher flow speeds** at regions of **low pressure**.

Bernoulli's Principle

❖ "The sum of **pressure** plus **kinetic energy** per unit volume of a flowing fluid is **constant.**"

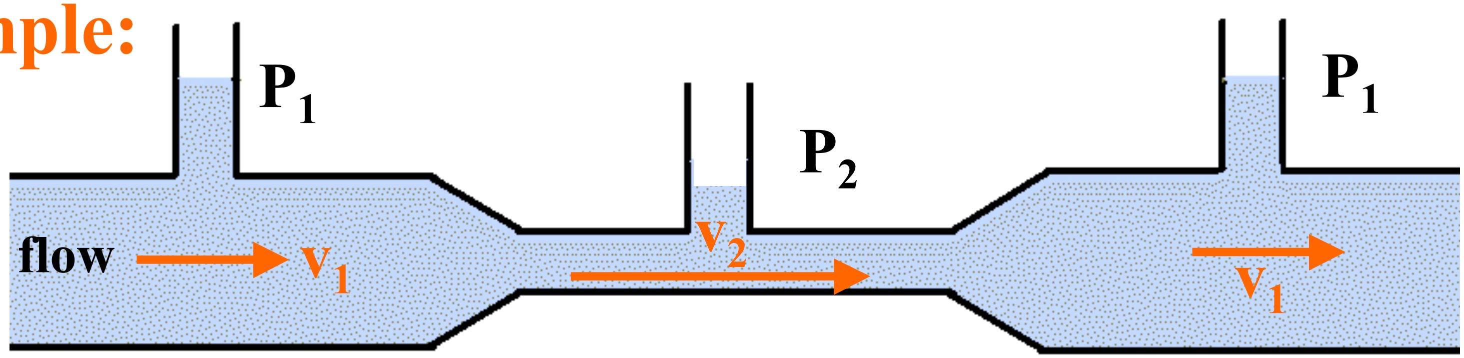
$$\boxed{P + \underbrace{\tfrac{1}{2}\rho v^2}_{\text{K.E. per unit volume}} = \text{constant}}$$

pressure

$\left(\rho = \dfrac{\text{mass}}{\text{vol}}\right)$

Result: Relates pressure variations to changes in fluid speed.

Example:



- Intuitively expect pressure in constriction region to be higher.

Not True – Exact opposite !

- **Speed of liquid is greater in constriction which by Bernoulli's equation indicates lower pressure.**

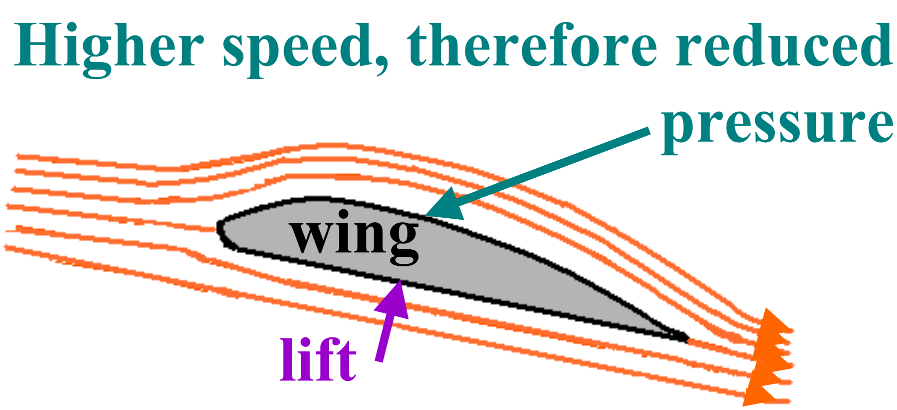
Note: **High pressure** is **not** associated with **high velocity**. (Against intuition).

Example: Garden hose – a restriction causes **velocity** of water to **increase** but pressure at nozzle is **less** than further back in pipe where velocity of flow is lower.

(The **large force** exerted by **water** exiting hose is due to its **high velocity** and **not** to extra **pressure** in pipe).

Bernoulli's Principle and Flight

- Bernoulli's principle applies to an **incompressible fluid** (i.e. density ρ constant)
- However it can be **extended** qualitatively to help explain motion of **air** and other compressible fluids.



Shape /tilt of wing causes the air flow over wing to have **higher speed** than **air flowing** underneath it (greater distance).

- **Reduced pressure** above the wing **results** in a net **upward force** due to pressure change called **"lift".** (Demo: paper leaf)
- A **biker** also has swollen jacket when going fast due to low external pressure!
- In aircraft design have shape of wing and "angle of attack" variations that effect total lift. (wind tunnel tests).
- **Forward speed** is therefore **critical** for aircraft **lift**. This can be affected by turbulence…
- If air flow over wing changes from **laminar** to **turbulent** flow the lift will be reduced significantly!
- In regions of **strong wind shears** lift can also be lost as flow reduces to zero!

Summary:

- A **reduction** in **pressure** causes an **increase** in **flow velocity** (and vice versa).