Physics 140 – Fall 2007
lecture #24: 29 Nov

Ch 14 topics:

- **ideal fluid** dynamics
- volume flow rate
  (incompressible fluids)
- Bernoulli's equation

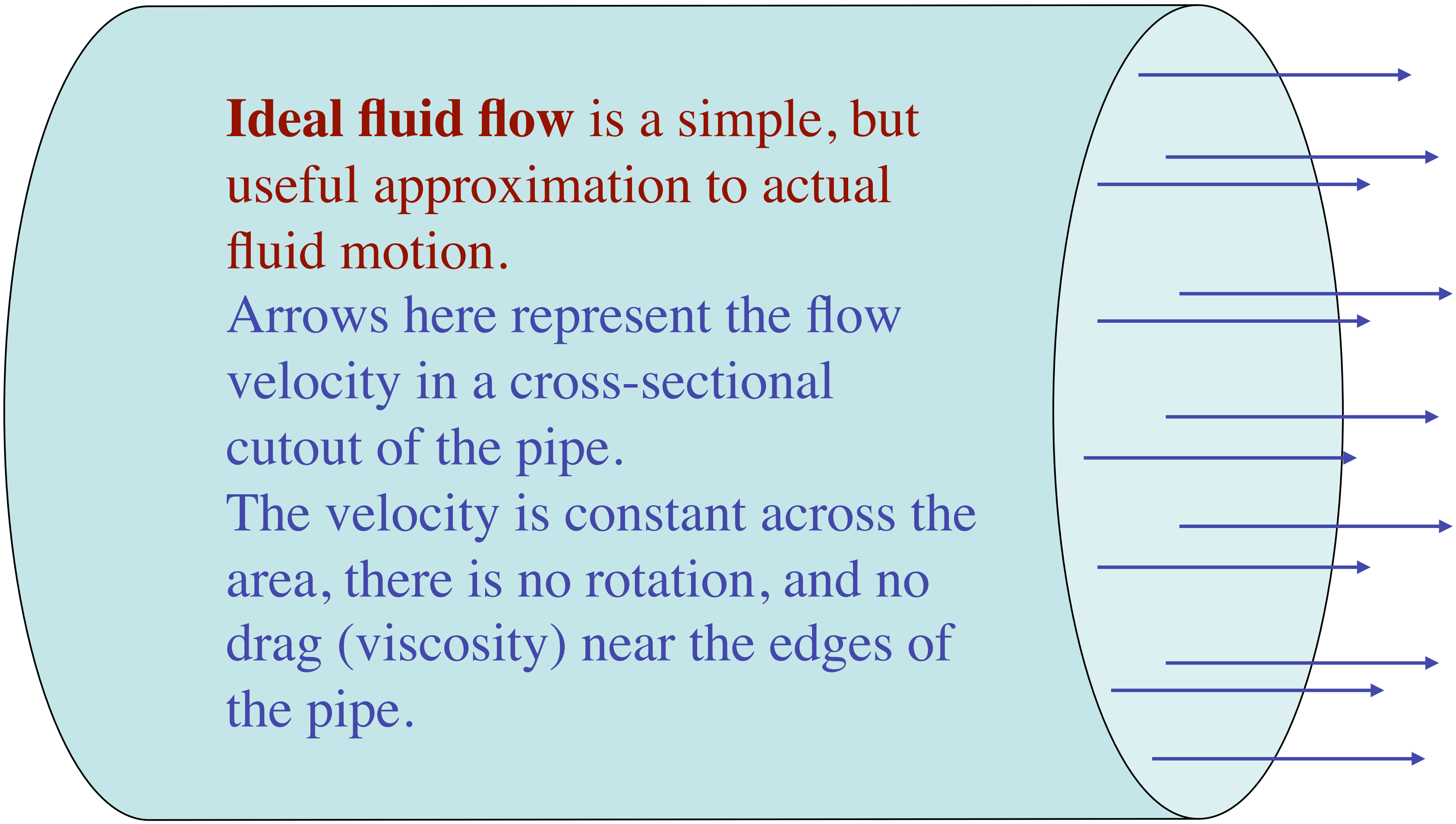
Source: V.van Gogh, Starry Night

Exam #3 tonight
6:00-7:30 pm
Ch 9-12

Ideal fluids

An ideal fluid is defined by the following set of characteristics. The flow of the fluid must be

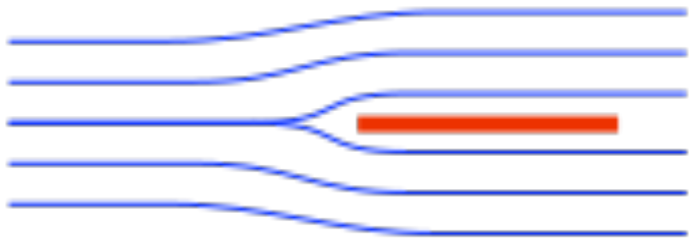
- *steady*
  The velocity at any point in the flow does not change in time.
- *incompressible*
  The density does not change with pressure.
- *non-viscous*
  There are no sources of internal friction that could remove energy from the flow.
- *irrotational*
  An element (small piece) of the flow traces out a straight path aligned with the fluid velocity, not a helical pattern around it.



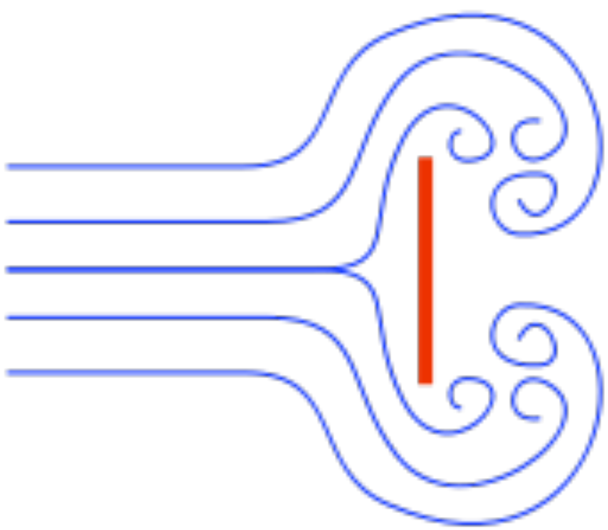
Ideal fluid flow is a simple, but useful approximation to actual fluid motion.

Arrows here represent the flow velocity in a cross-sectional cutout of the pipe.

The velocity is constant across the area, there is no rotation, and no drag (viscosity) near the edges of the pipe.

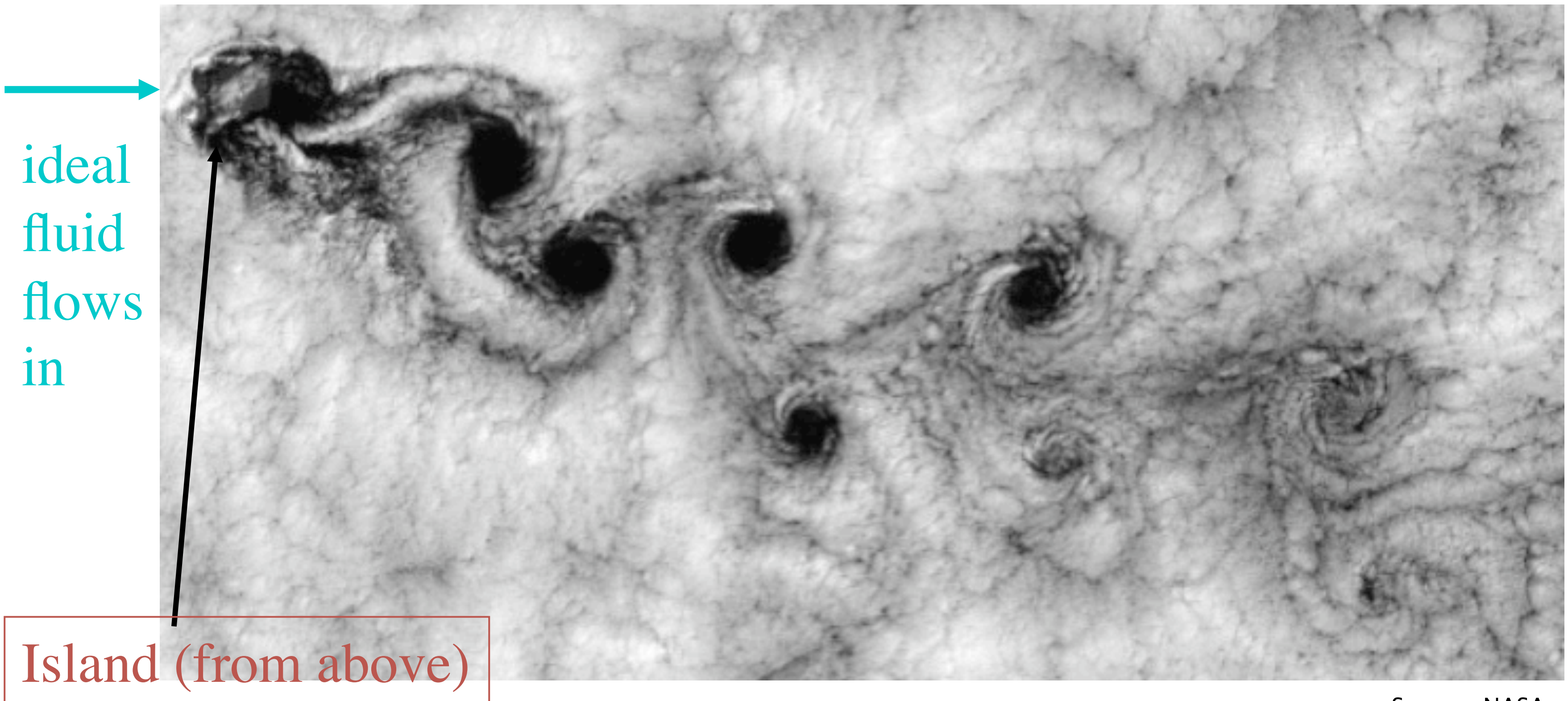


Small drag in streamlined position



Large drag in unstreamlined position

Turbulent flow: `vortex shedding' around an obstacle



Source: NASA

Steady (also called *laminar*) flow to the left of an island becomes unsteady (or *turbulent*) after passing by it. The grey scale image above shows clouds in the atmosphere. Patches of the flow behind the obstacle are spun up to create a series of *vortices* that alternately roll off, or 'shed', from the top and bottom of the tube. The behavior downstream of the tube is one of many examples of *non-ideal* fluid flow.

Conservation of mass for incompressible fluids

For a fluid of density ρ flowing through a pipe of cross-sectional area A at speed v, the amount of mass Δm passing through a joint in the pipe in a time interval Δt is given by

$$\Delta m = \rho\, A\, v\, \Delta t$$

For regions of flow in which there are no sources or sinks of fluid, the requirement that ***mass is neither created nor destroyed*** implies that the product $\rho A v$ is the same at all parts of the flow

$$\rho_1 A_1 v_1 = \rho_2 A_2 v_2$$

Since an *incompressible fluid* has the same density at all points in the flow (ρ=constant), then two locations (1 and 2) of a pipe with different cross-sectional area will have the same *volume flow rate*

$$A_1 v_1 = A_2 v_2$$

Conservation of energy: Bernoulli's equation

Flow in an ideal fluid conserves total energy. When fluid flows in a gravitational field, the energy (per unit volume of fluid) comes in three forms:

- gravitational potential energy density: $\rho g y$
- kinetic energy density: $\rho v^2/2$ (ordered particle velocities)
- internal energy density: P (disordered particle velocities)

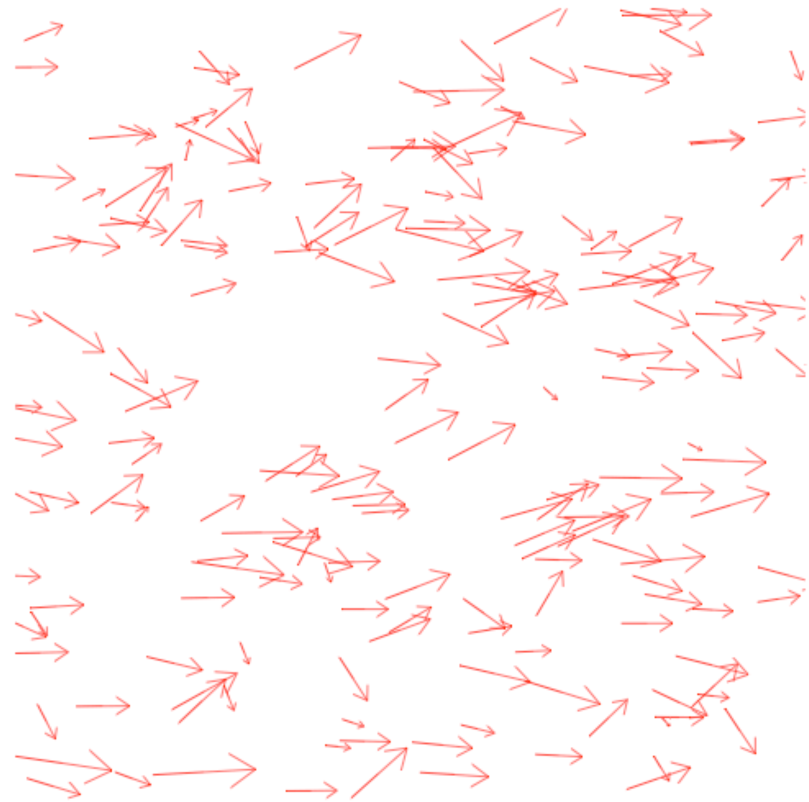
The requirement that the total energy be conserved implies that the sum of these three forms remains constant throughout the flow. The result is *Bernoulli's equation*

$$P + \rho v^2/2 + \rho g y = \text{constant}$$

mostly disordered motion
– high pressure
– low velocity

v ~ 0

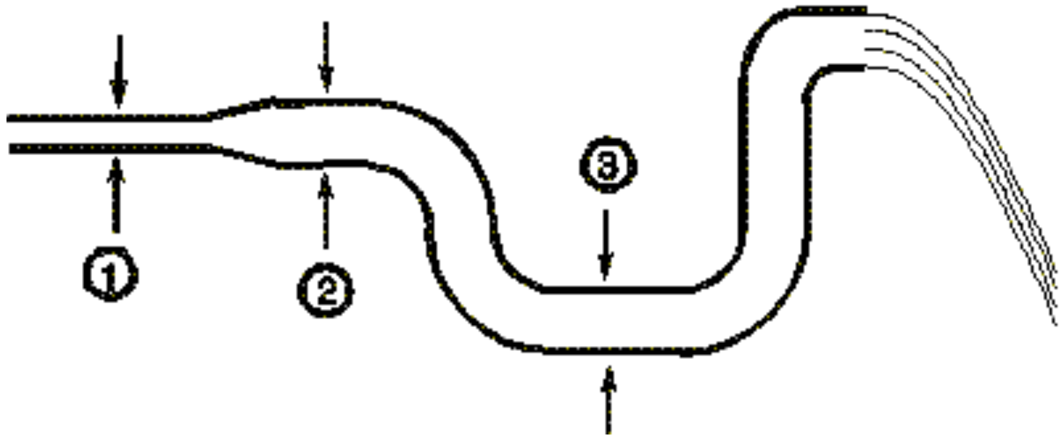
mostly ordered motion
– low pressure
– high velocity



v →

A blood platelet drifts along with the flow of blood through an artery that is partially blocked. As the platelet moves from the wide region to the narrow region, it experiences

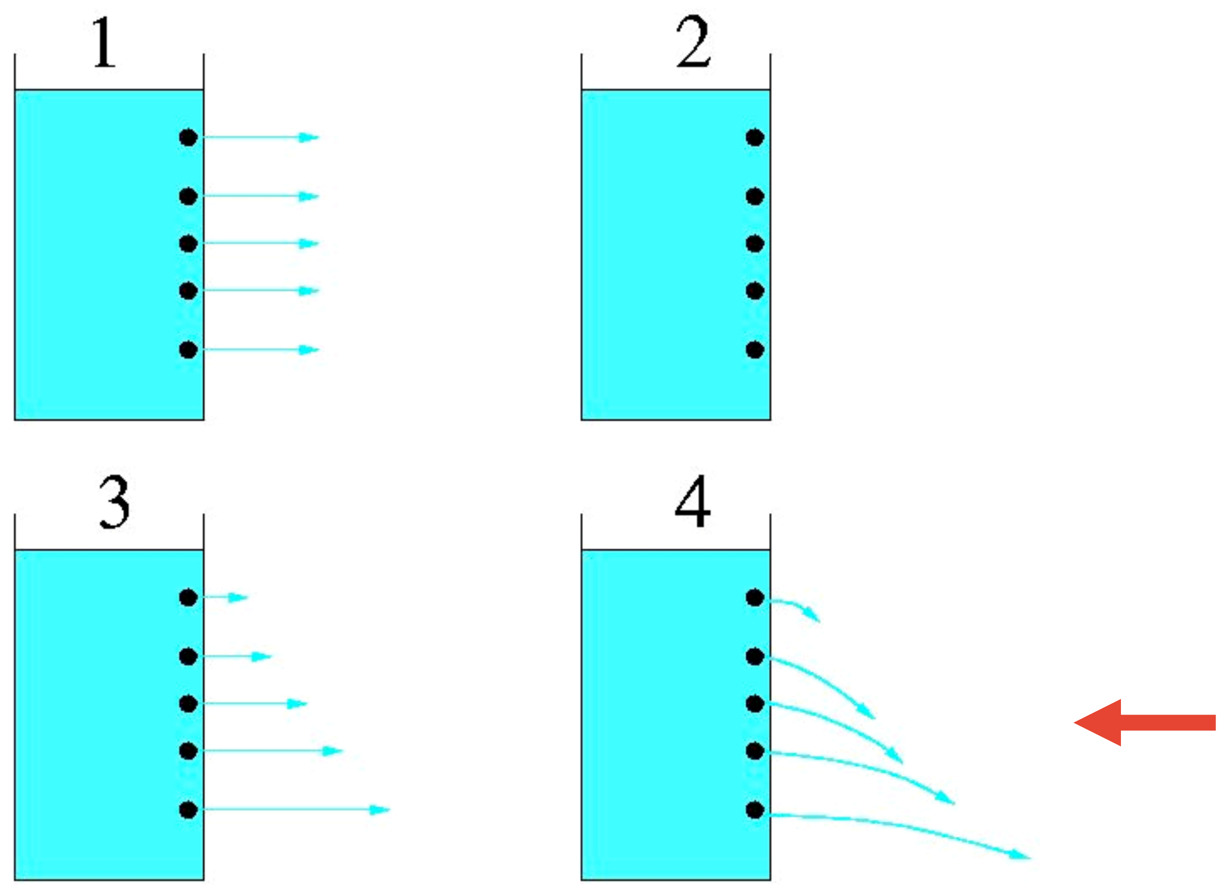
1) an increase in pressure.
2) a decrease in pressure.
3) no change in pressure.



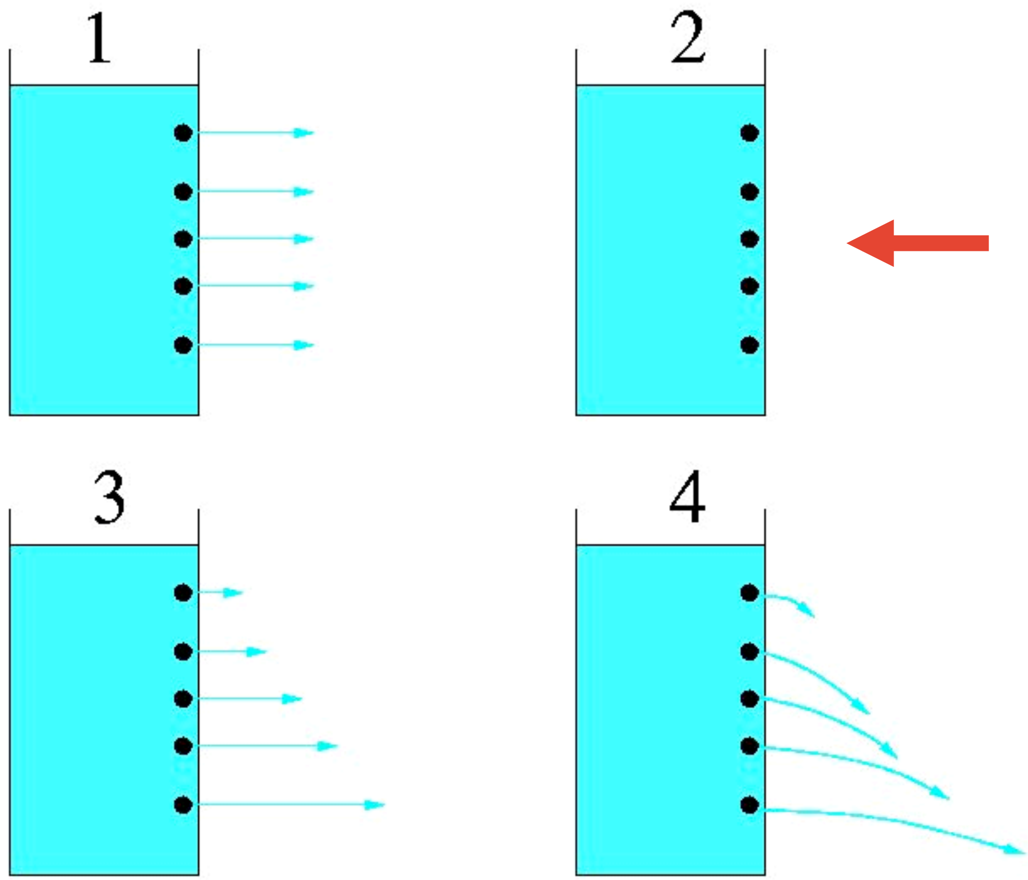
An ideal fluid flows in the above arrangement of tubes. Rank the locations according to the flow velocity, greatest to least.

1) 3, 2, 1
2) 3, 1, 2
3) 1, 2, 3
4) 1, 2=3
5) 1=3, 2

A water tank with an open top sits on a table at rest. If it is rapidly punctured with five, vertically aligned holes, what would resulting flow look like?



A small water tank with an open top is dropped, preserving its vertical orientation, down an elevator shaft. Just after release, it is rapidly punctured with five, vertically aligned holes. What will resulting flow look like?



You sit in a boat on a man-made lake filled with a fixed volume of water. Accompanying you is the pair of large rocks from back in Chapter 10. This time, instead of throwing the rocks sideways, you drop them gently into the water. What happens to the water level in the lake after the rocks have sunk below the surface?

1) It goes up.
2) It goes down.
3) It stays the same.