**Fluid Mechanics & its Application**
**Professor Vijay Gupta**
**Sharda University**
**Indian Institute of Technology Delhi**
**Lecture 22A**
**Kinematic Reversibility**

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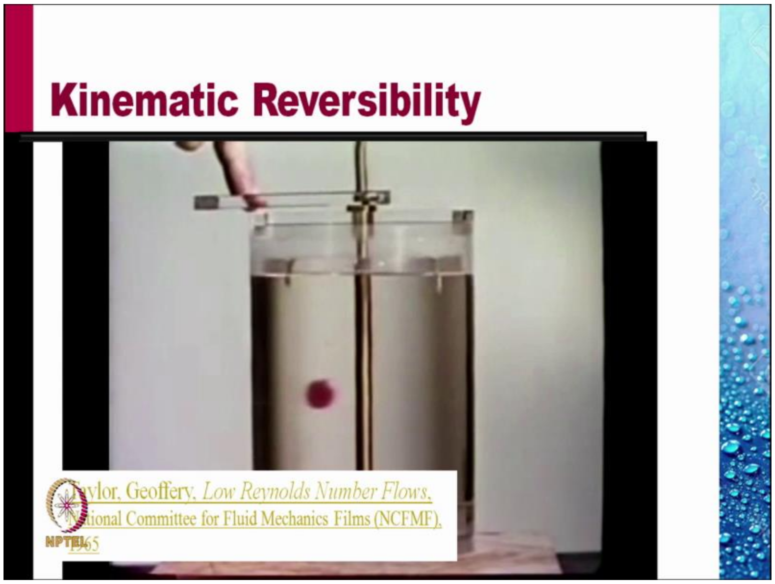


Geoffrey Taylor of Oxford University conducted some experiments to show kinematic reversibility of low Reynolds number flows. The following film illustrates this effect.

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Low Reynolds number flows are reversible, when the direction of motion of the boundaries which gave rise to the flow is reversed. This may lead to some surprising situations, which might almost make one believe that the fluid has a memory of its own.

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Here are two concentric cylinders, the fluid can be moved by turning the inner cylinder with this handle. The annular space between them is filled with a fluid that is serene.

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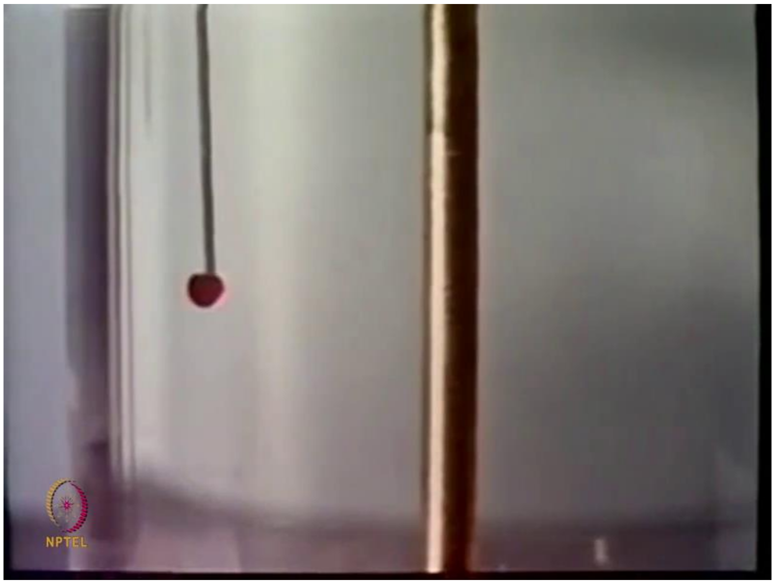

Into this space I introduce some dye which stays put due to the high viscosity of the glycerine. Note its position before I start turning it.

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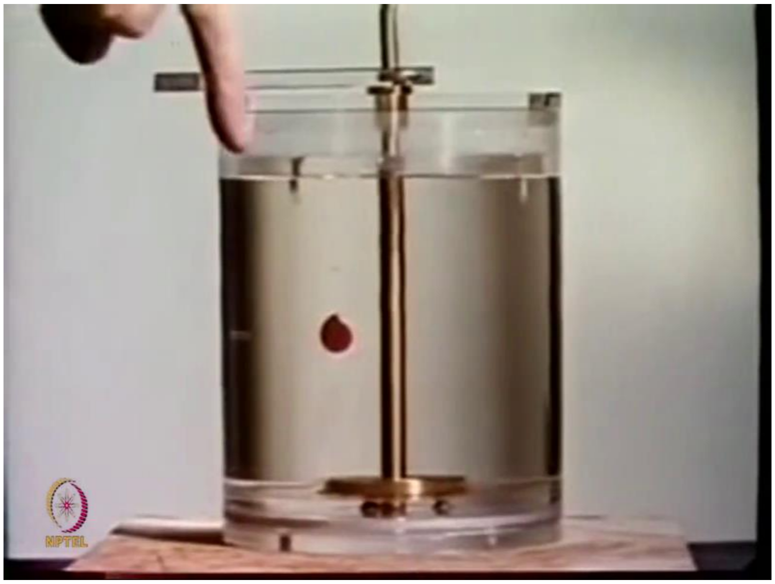

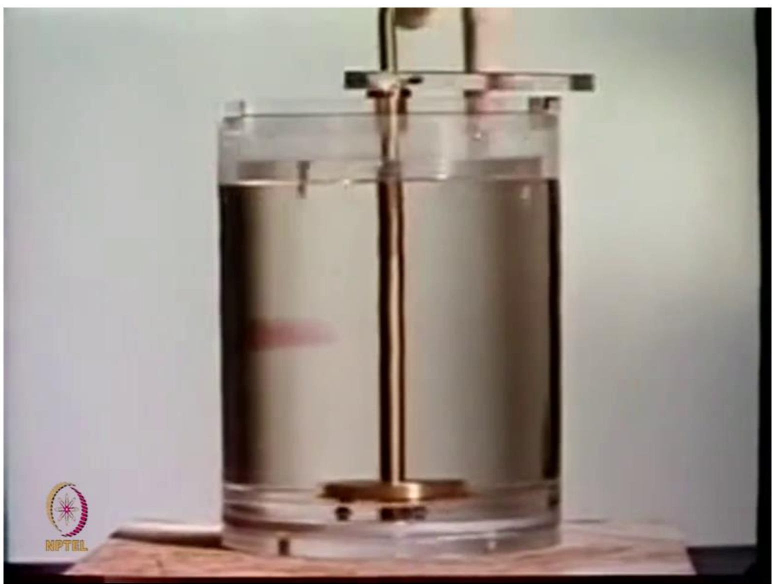

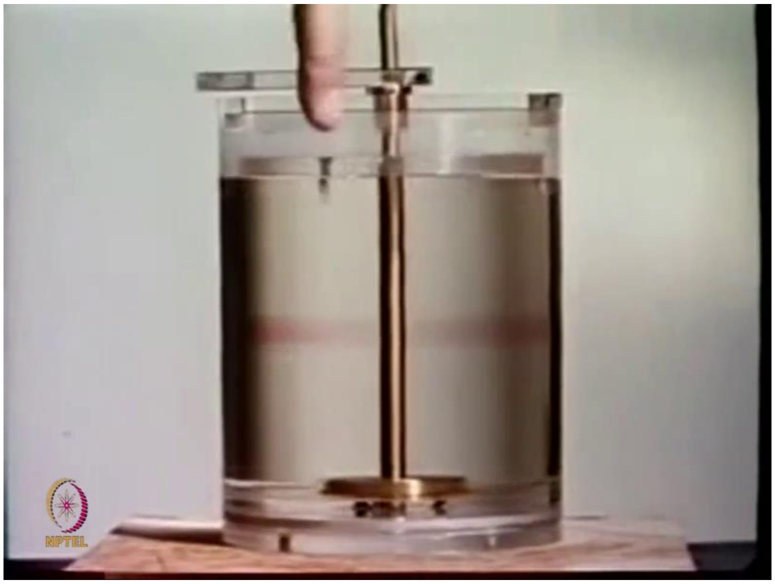

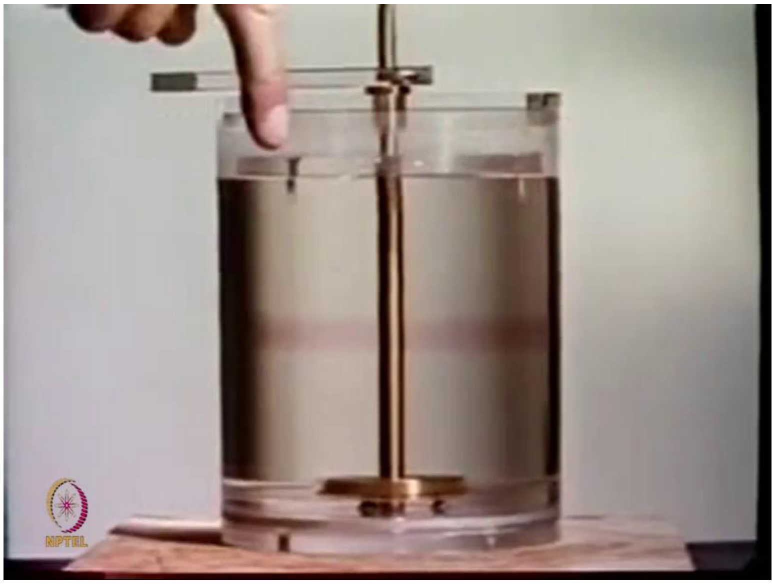

I now turn it four times pushing the handle clockwise. The dye seems to mix as a drop of milk mixes when it is stirred into a cup of tea.

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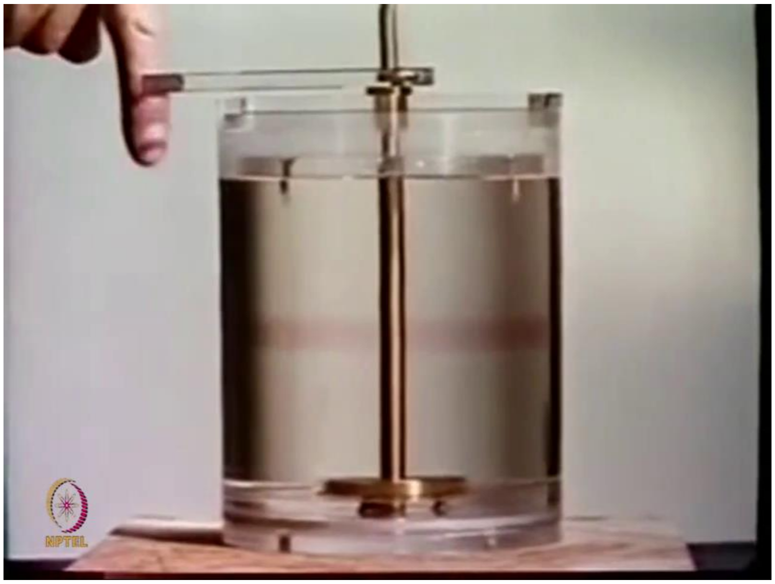

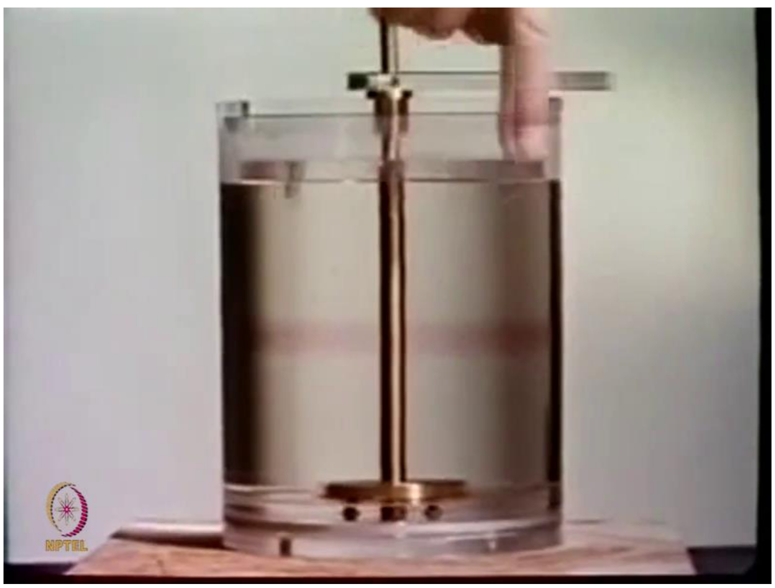

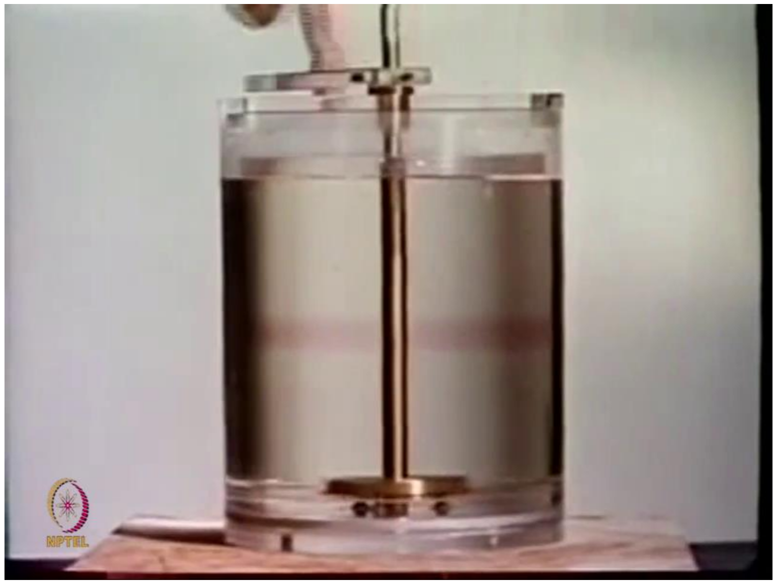

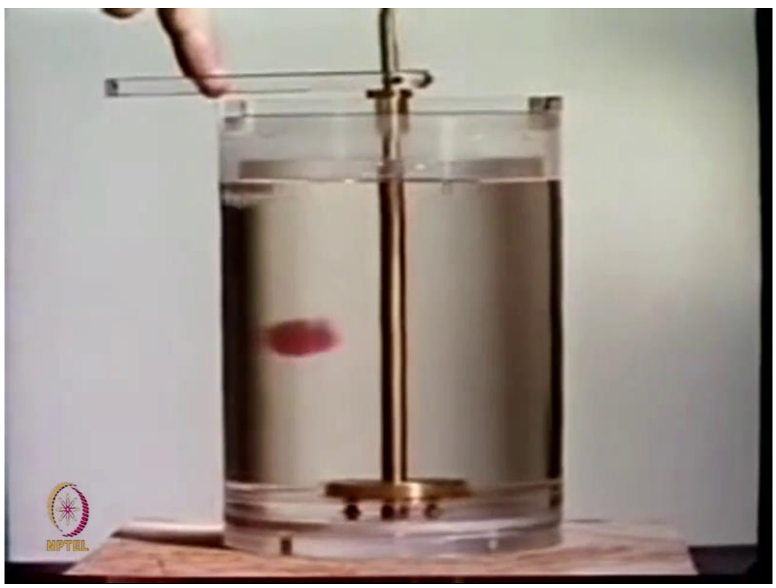

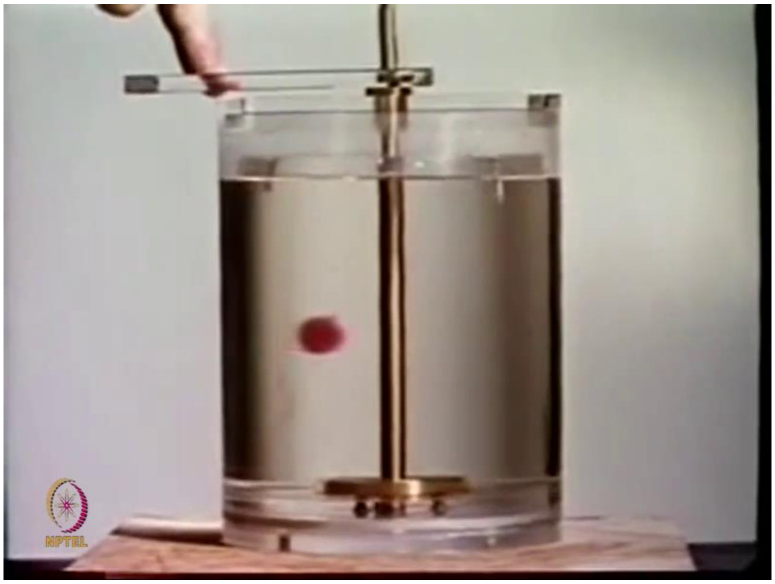

Now, I reverse the direction, and after turning exactly four turns, the dye there reappears in its original position with the little fuzziness due to molecular diffusion.

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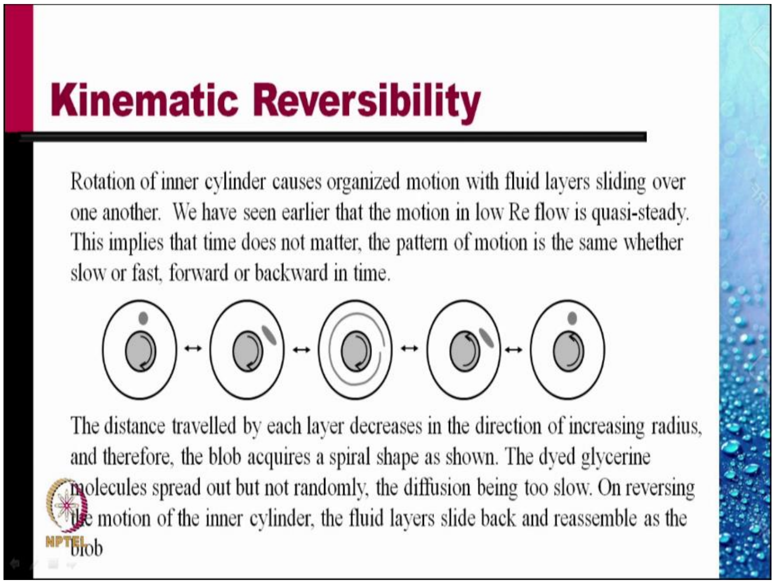


In this picture, we saw that the rotation of the inner cylinder causes organized motion with the fluid layers sliding over one another. We have seen earlier that the motion in low Reynolds number flows is quasi steady. This implies that time does not matter. The pattern of motion is the same, whether slow or fast, forward or backward in time.

Thus, the blob in the first figure becomes oblong in the second figure. It becomes part of a spiral in the third figure. And then we reverse the flow and we go through the stages and finally, we acquire the same blob shape, except for a little diffusion that might have taken place during this time.

The distance travelled by each layer decreases in the direction of increasing radius, and therefore, the blob acquires a spiral shape as shown. The dyed glycerine molecules spread out, but not randomly. The diffusion being too slow on reversing the motion of the inner cylinder, the fluid layers slide back and reassemble as the blob.

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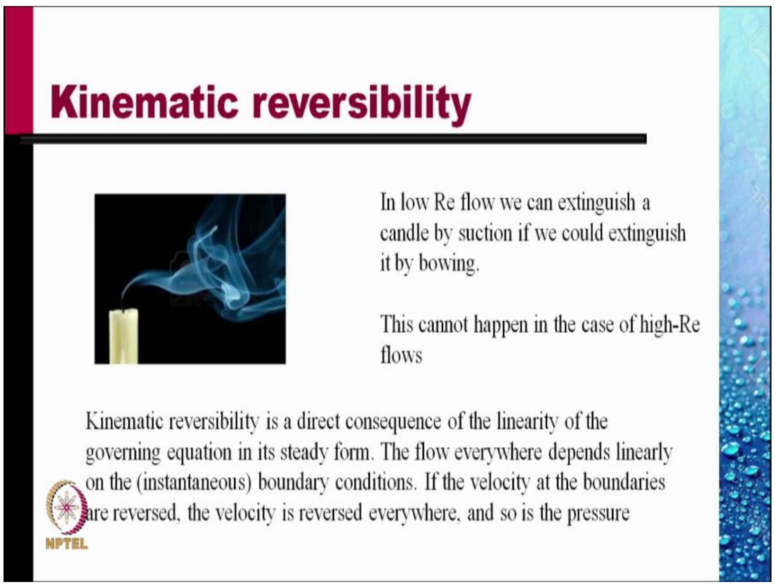


In low Reynolds number flows, we can extinguish a candle by suction if we could extinguish it by blowing. It is another matter that we cannot blow out such a candle. But if we could, we could also suck it out, because the motion is reversible. This cannot happen in the case of high Reynolds number flows where it is easy to blow out a candle, but you cannot suck it out.

Kinematic reversibility is a direct consequence of the linearity of the governing equation in its steady form. The flow everywhere depends linearly on the instantaneous boundary conditions. If the velocity at the boundaries are reversed, the velocities are reversed everywhere, and so is the pressure.

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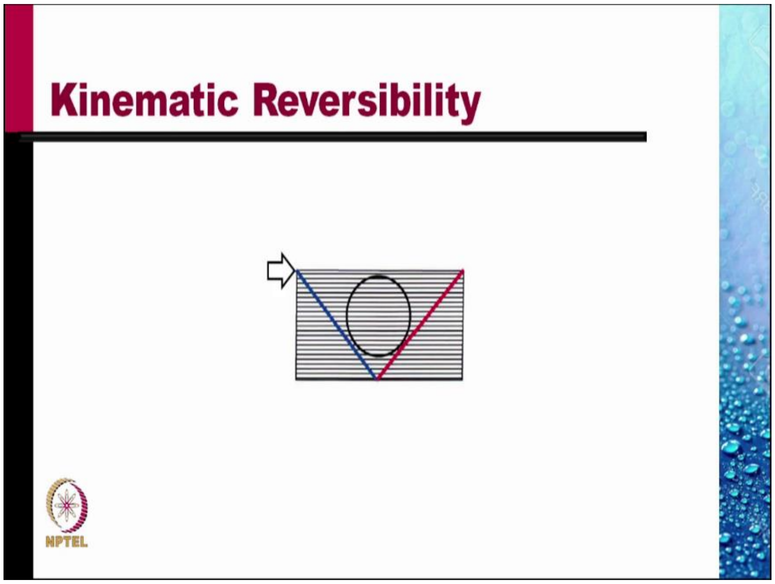


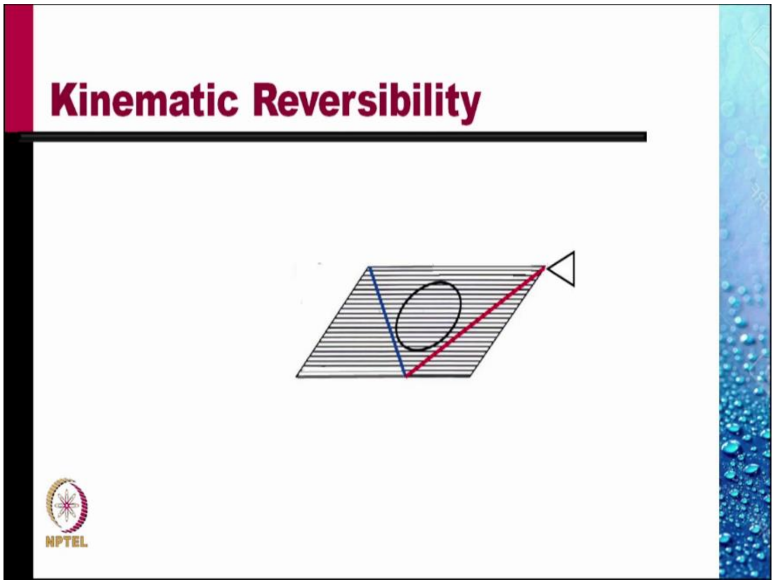


It is easy to demonstrate the kinematic reversibility by a deck of cards on the side of which we painted this picture, and when we slide this deck, it acquires this shape. If we apply a force in the reverse direction to slide, we can get back the same. This very roughly gives you an idea of kinematic reversibility.

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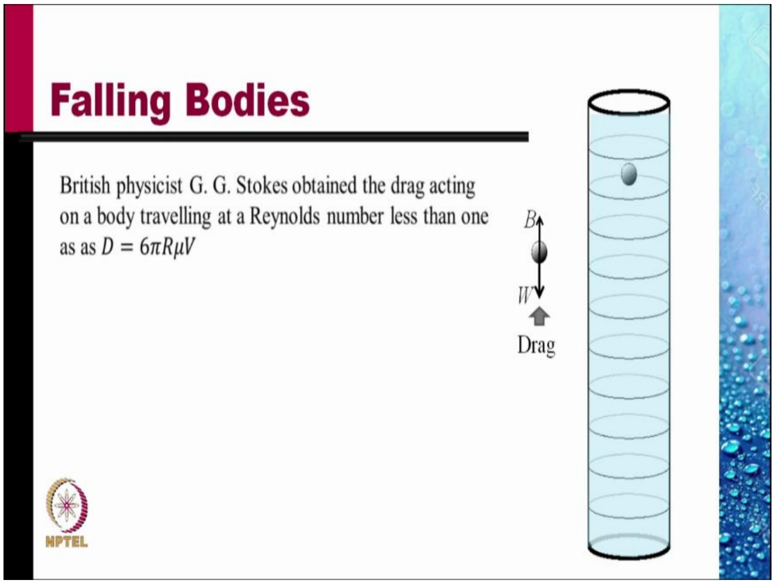


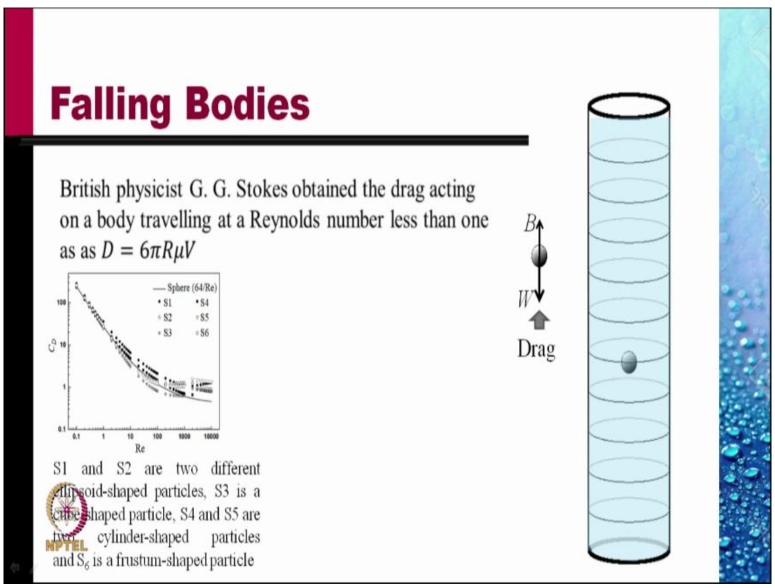

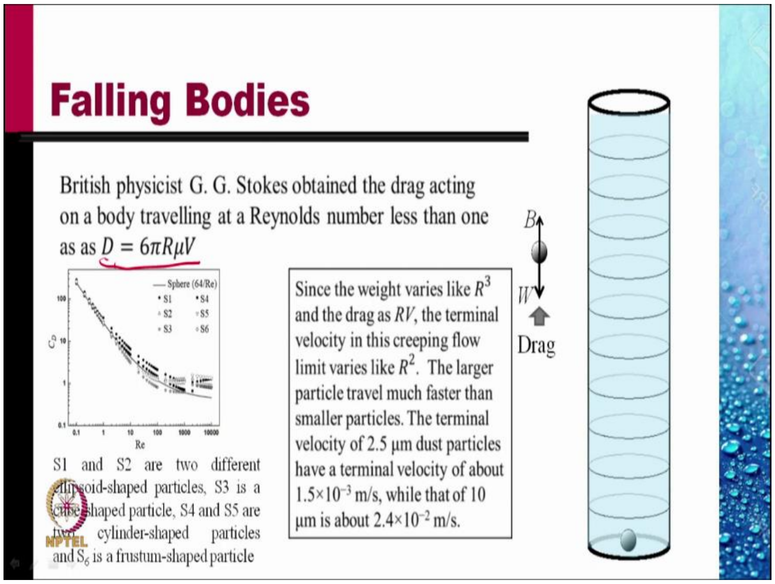


Let us, now talk of the falling bodies. We have talked of the terminal velocity, which is the velocity that a body acquires under the action of its own wet weight and the drag in the fluid it is moving in. The Stokes equation gave the drag as $D = 6\pi R\mu V$ for a sphere. But the interesting thing is that this drag does not depend upon the shape of the body. This graph here shows that at low Reynolds numbers, Reynolds numbers less than 1. All points for six different types of bodies, sphere, ellipsoid shaped particles, cube shaped particles, cylinder shaped particles, and frustum shaped particles, all have the the same drag coefficient.

So, it is quite independent of the shape of the body at very lower Reynolds numbers. Of course, as Reynolds number increases, this particle deviate from the line for the spherical particles. Since the weight of the particle varies like $R^3$, and the drag on it varies like $R \times V$ from the equation $D = 6\pi R\mu V$. The terminal velocity in this creeping flow limit varies like $R^2$. The larger particle travels much faster than smaller particles. If the diameter of the particle is twice that of a smaller particle, then its terminal speed would be 4 times. This is seen, in the fact that a terminal velocity of 2.5 µm dust particles which cause lot of air pollution, is about $1.5\times10^{-3}$ m/s, 1.5 mm/s, while that of 10 µm particles, 4 times the diameter, the terminal speed is 2.4 cm/s compared to 1.5 mm/s

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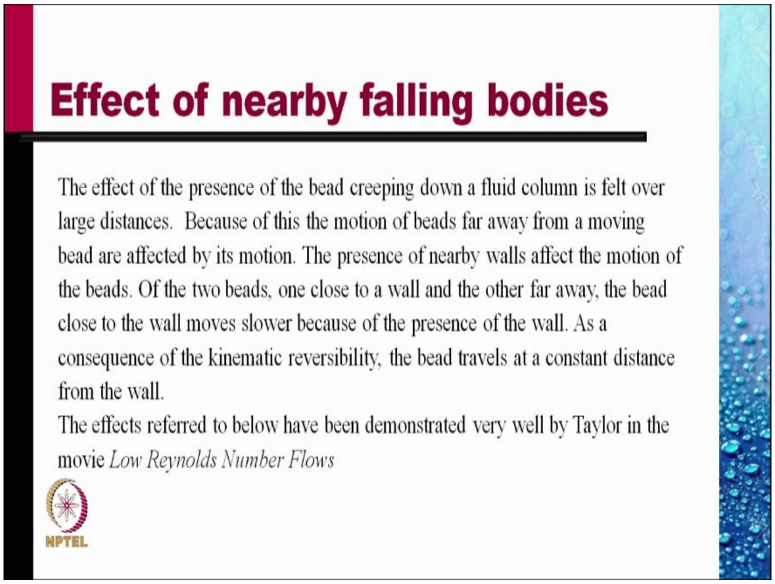


The effect of the presence of beads creeping down a fluid column is felt over a large distance. Because of this, the motion of beads far away from a moving bead are affected by its motion. The presence of nearby wall affects the motion of the beads. This happens only in low Reynolds number flows; it will not happen in high Reynolds number flows. Of the two beads, one close to a wall and the other far away, the bead close to the wall moves slower, because of the presence of the wall. As a consequence of the kinematic reversibility, the bead travels at a constant distance from the wall. The effects referred to above have been demonstrated very well by Geoffrey Taylor in the same movie that was referred to above.

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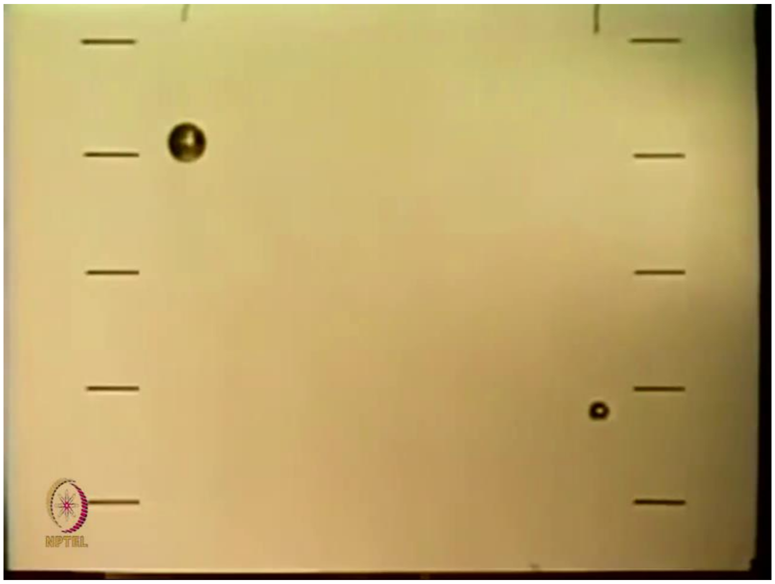

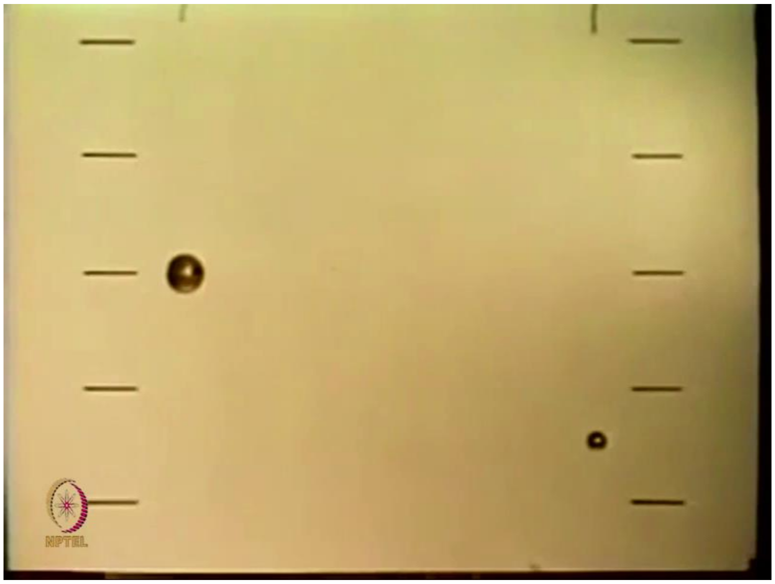

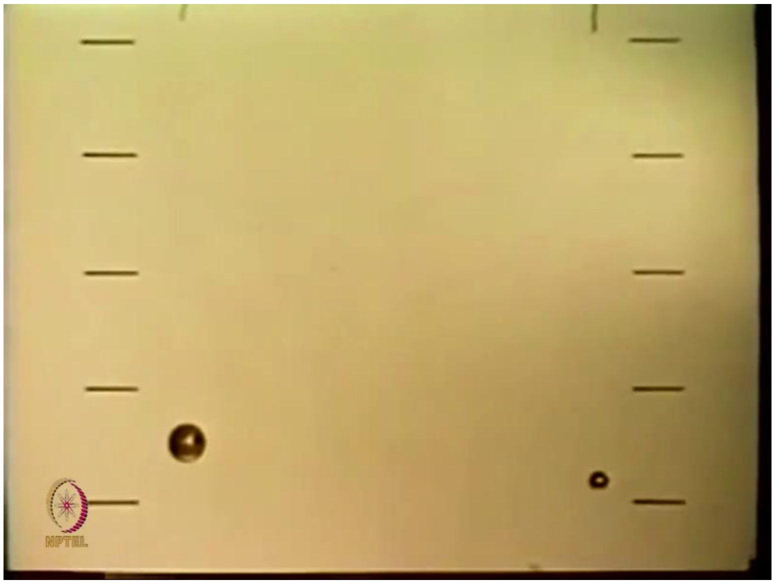

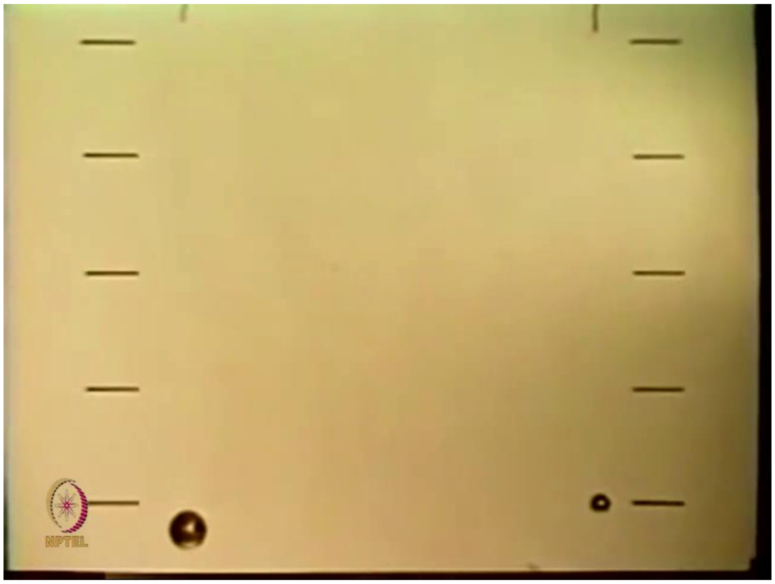

The drag of a falling sphere is proportional to its diameter and to its speed.

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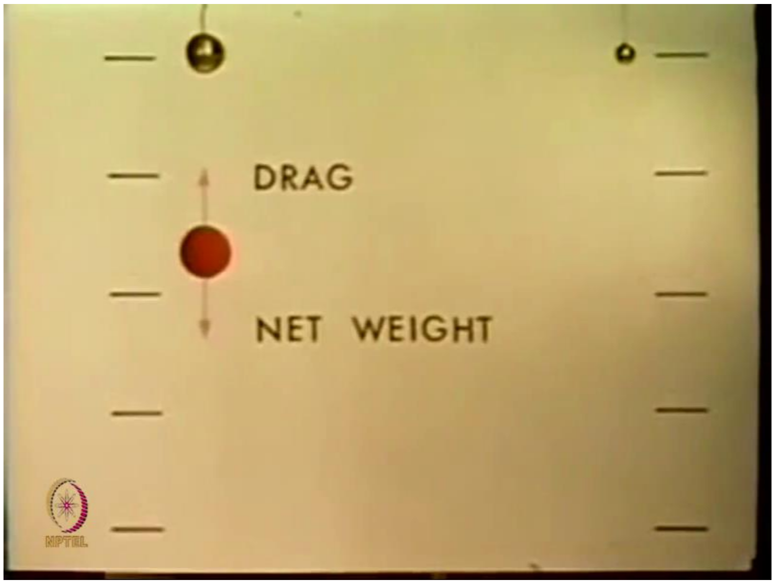


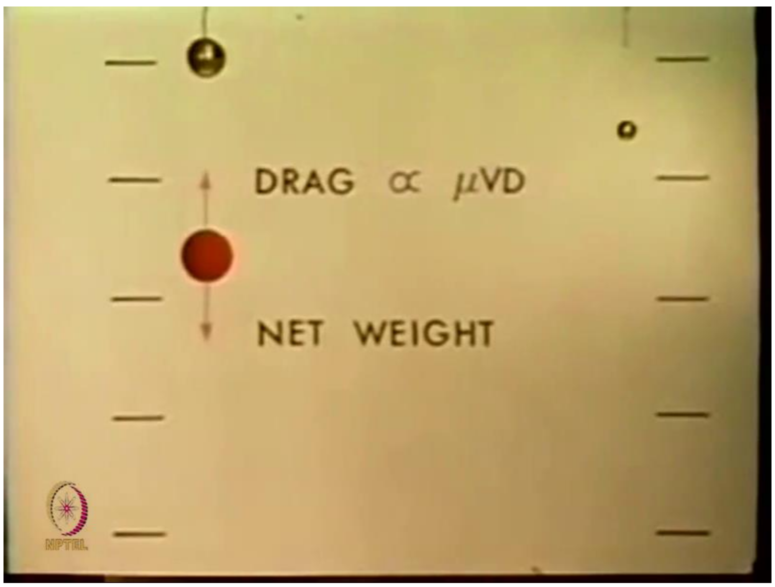

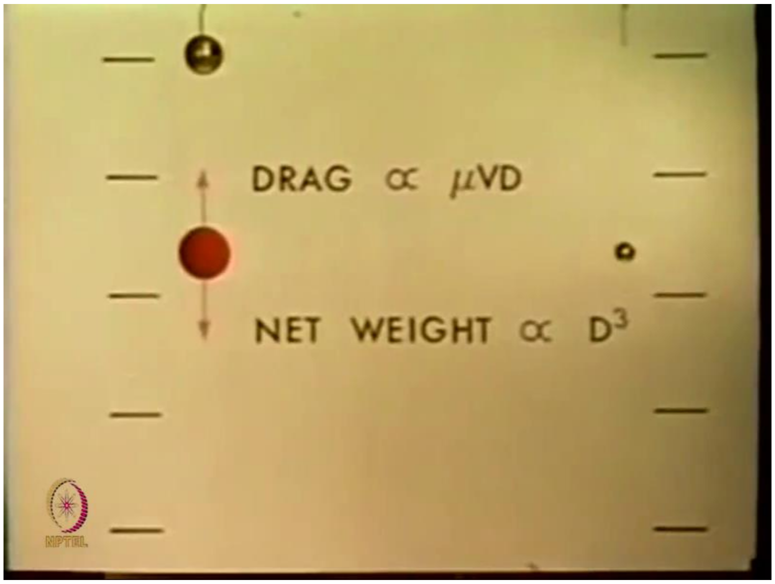


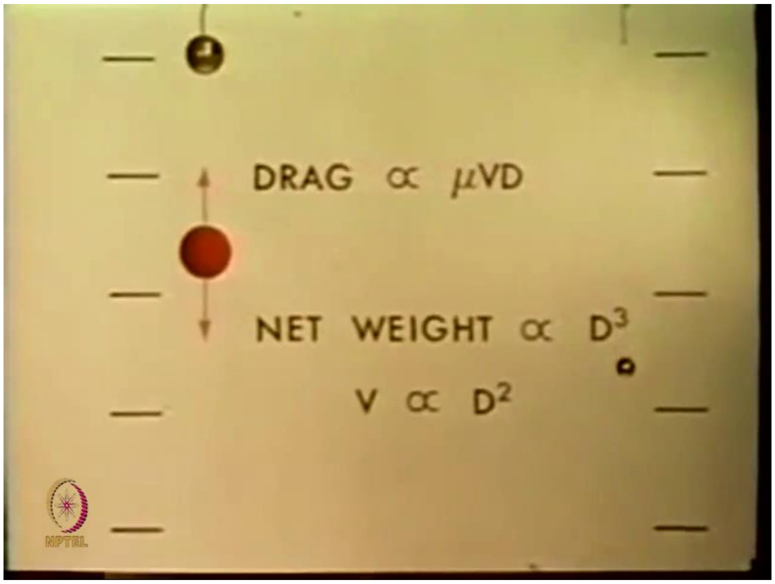


The net weight of the sphere is proportional to the cube of its diameter. The velocity is therefore proportional to D squared. They have diameters in the ratio of 2 to 1.

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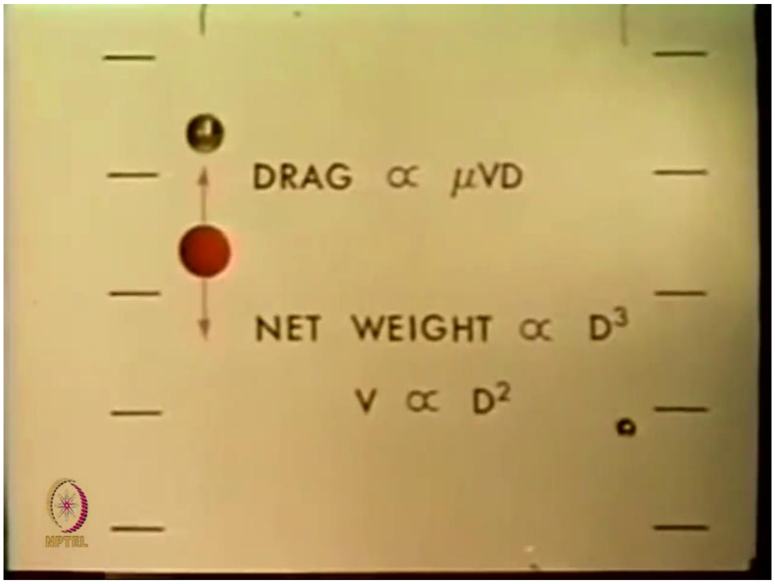


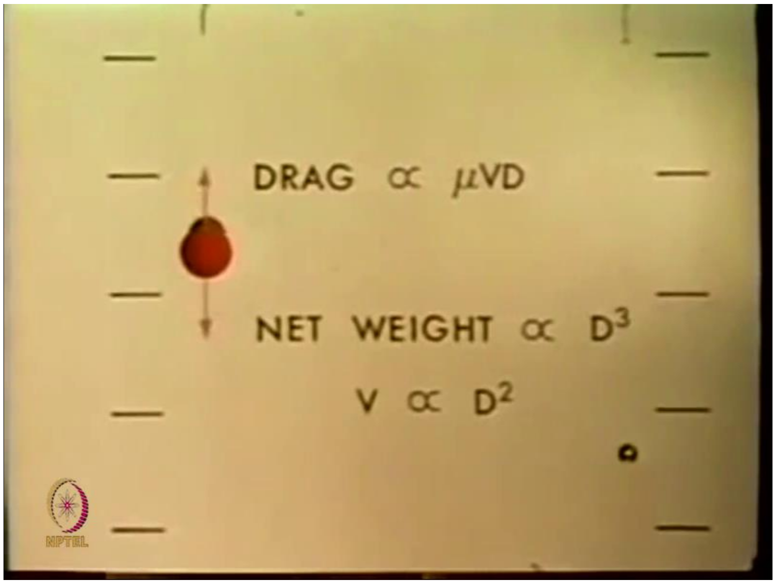

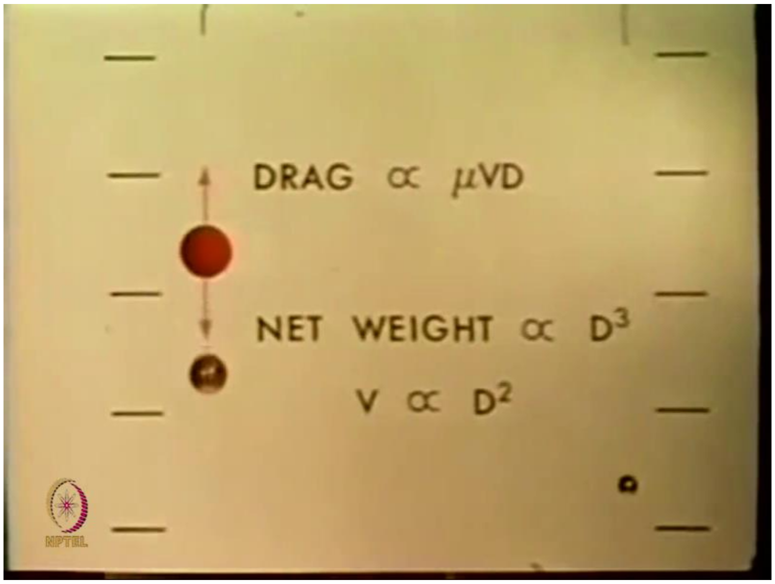

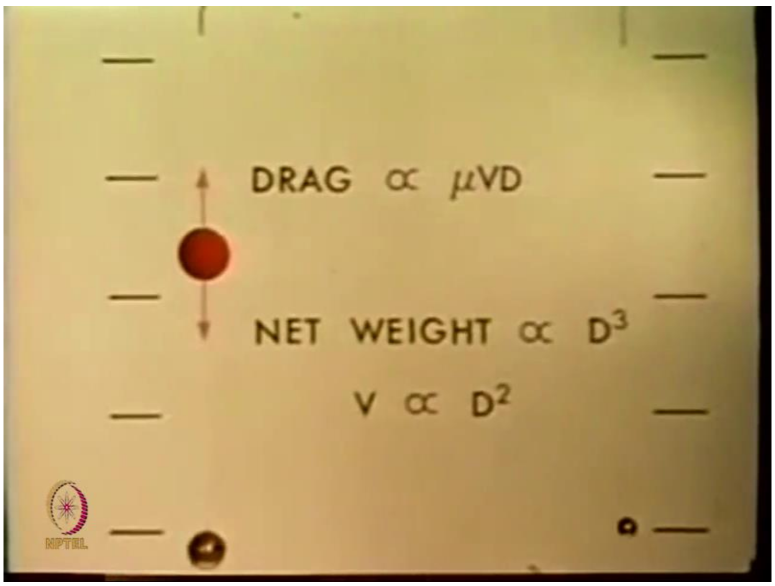


So, the larger one falls in syrup 4 times as fast as the smaller one. At low Reynolds numbers, the disturbance produced by moving ball extends many diameters.

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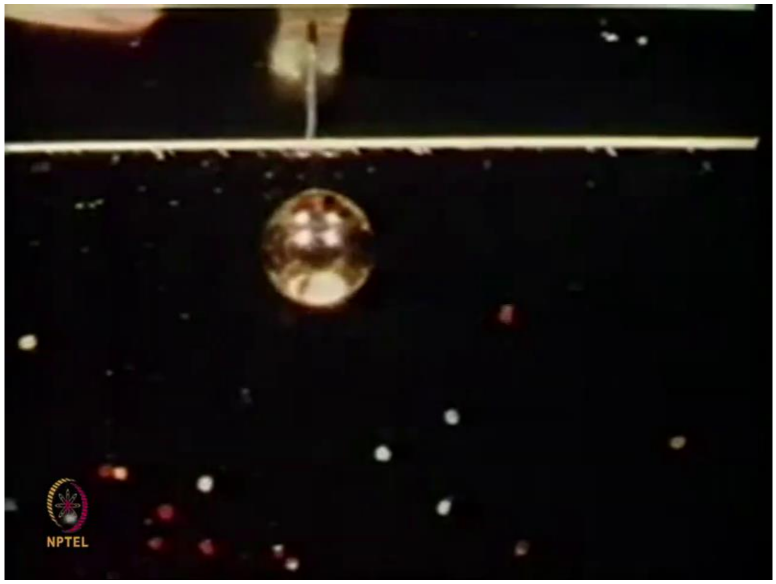


So, the beads far from the wall are moved by its passing. Thus, the presence of a nearby wall can be important.

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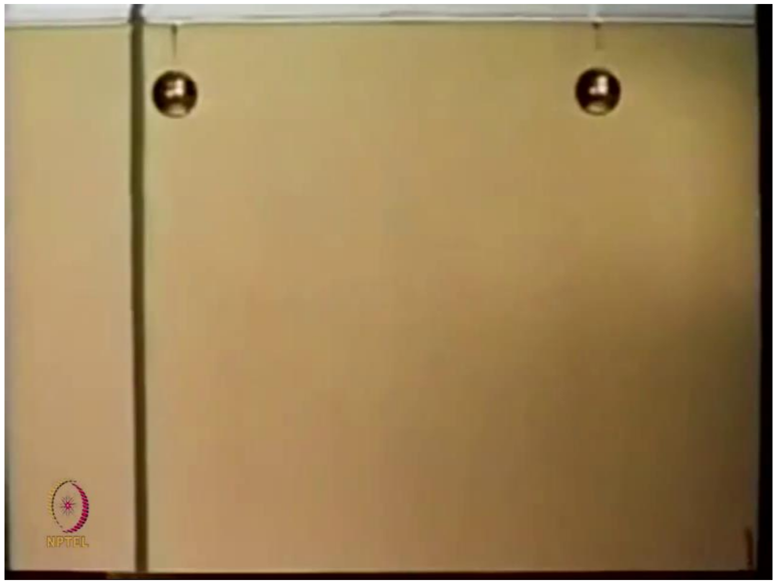


Here are two identical balls, one near a wall and one far from it. The ball near the wall falls more slowly. Incidentally, it remains at a constant distance from the wall, a consequence of reversibility. This retarding effect also slows the follow up particles surrounded by many similar ones.

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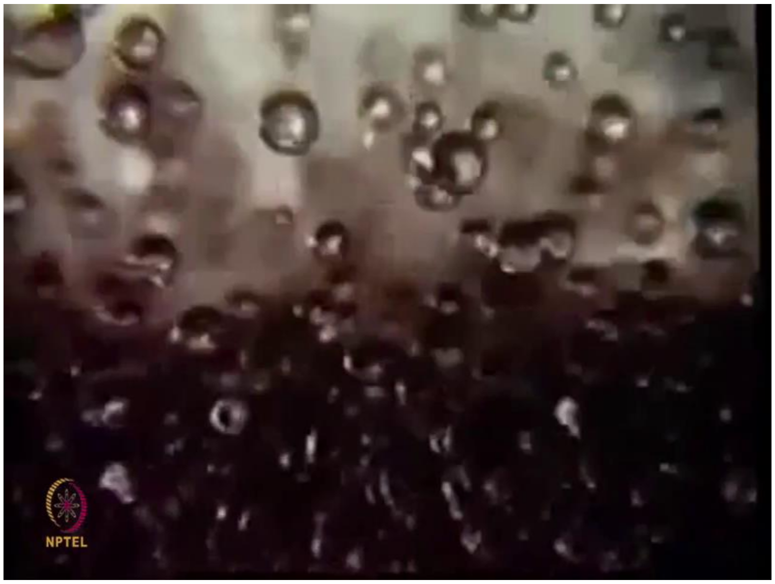


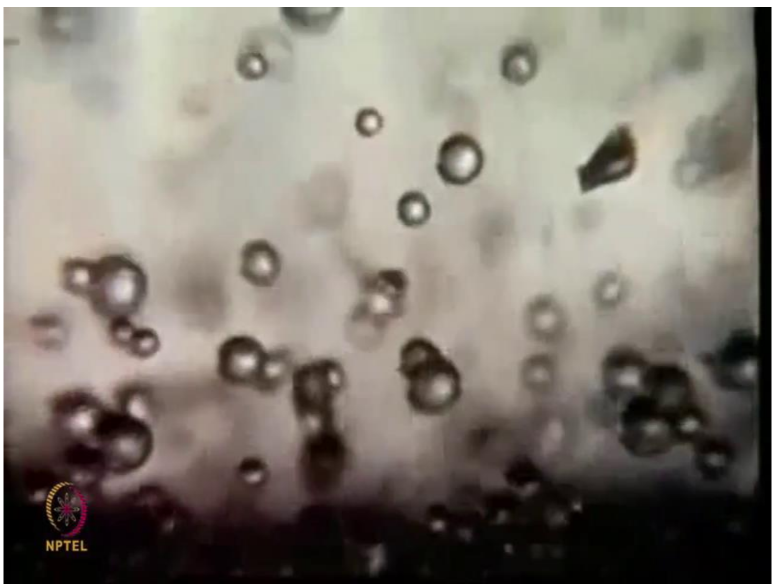


So, a cloud of them falls more slowly than a single one. When a cloud of assorted particles falls in fluid, it develops a sharply defined top.

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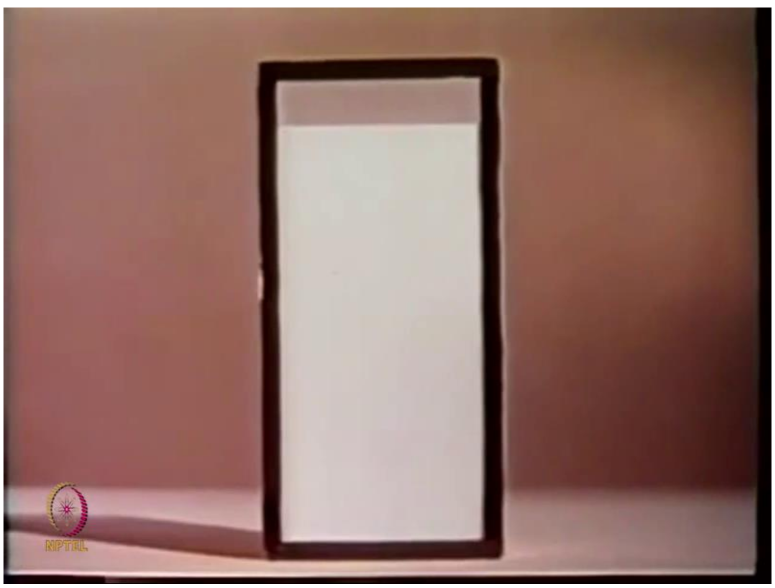

A particle which has a terminal velocity rather lower than its neighbours does not always get left behind. If it did, it would find itself isolated and would fall faster and therefore catch-up the rest.

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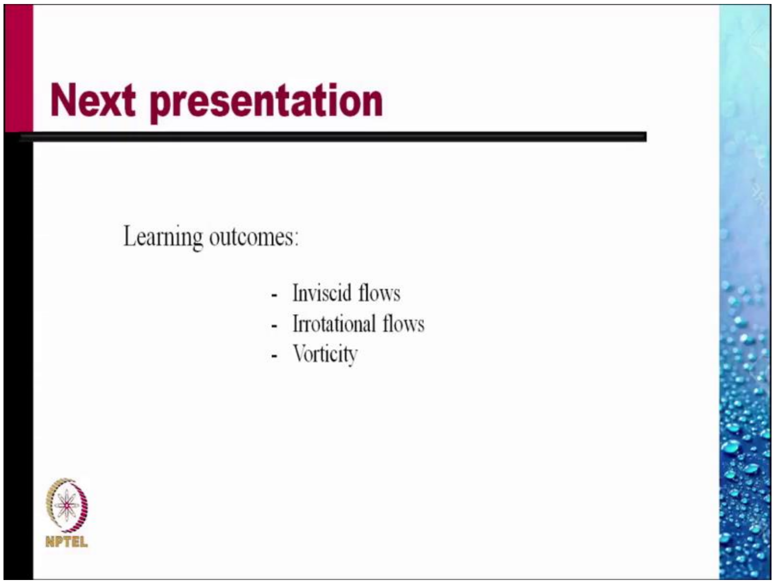


Thank you very much.