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FRICTION IN FLUIDS - VISCOSITY

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Contents

- Friction in fluids
- Drag on objects falling through a viscous fluid
- Terminal velocity for solids falling through a fluid
- Experimental determination of terminal velocity
- Effects of viscosity
- Applications of viscosity
- Lubrication

Learning objectives

At the end of the lesson you should be able to:

- Define viscosity
- Describe experiment to determine terminal velocity
- Compare viscosities of various liquids
- List applications of viscosity
- Explain effect of temperature & pressure on lubrication

Previous knowledge

- Contact & force fields
- Newton's laws of motion
- Friction between solid surfaces
- Resultant & components of forces
- Fluid mechanics
- Effect of friction on efficiency of machines

Definition

Friction is a force that opposes the relative sliding motion of two surfaces in contact with one another.

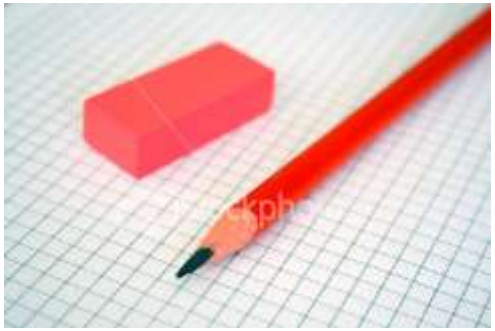
Friction slows down or prevents motion.

Advantages of Friction - all friction is not 'evil'

- It enables us to walk and run, without it we would slip particularly when we try to move on slippery surface such as wet floor.
- Pattern of tyre thread are designed to prevent accident particularly on wet roads by providing a firm grip. The grooves clear away water on wet road which could reduce traction between the tyre and road.
- The frictional force between the wheel and brake blocks in the brake linings of automobiles slows down on the wheels.

Advantages of friction

Brakes on a bike



Pencil & eraser

Pattern on tyre thread

Ski’s on the snow

Advantages of friction

- Friction is used in friction belt or belt drive used in machines e.g. fan belt of car engine, conveyor in bottling companies or pharmaceuticals for packaging, airport baggage transportation etc.

Conveyor in bottling companies

Airport baggage carousel

Advantages of friction

- A household application of friction is the production of heat between the match stick and the box when struck, this heat generated ignites the inflammable substance on the match stick and subsequently the match stick itself. Same thing in cigarette lighter.

Advantages of friction

- Friction (air drag) acts as life saver in parachute and skydiving.
- Friction helps nuts and bolts to stay tight.
- Friction prevents ladder from slipping.
- Without air drag, raindrops and snowballs will not attain terminal velocity hence will hit us at a dangerously high speed and momentum.
- Sharpening of blunt cutlasses and knife with stones depends on friction.
- Grinding of pepper with grinding stones for an African housewife.

Disadvantages of friction

- Friction causes wear and tear of parts of a machine rubbing against each other.
- Friction generates unwanted heat in machines.
- Friction reduces the efficiency of machines because part of the energy supplied into it is used in overcoming friction. (Dissipation of energy as heat) Some parts of a machine may also seize or weld together as a result of friction. In extreme cases, it could lead to fire outbreak.
- Friction reduces speed of moving objects.

Disadvantages of friction

- Friction damps oscillation i.e. Progressively reduces amplitude of oscillation e.g. Simple pendulum due to air resistance.

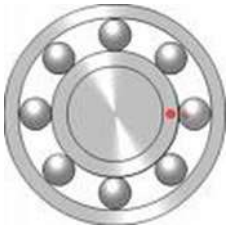
- Friction causes unwanted noise in machines.

Methods of reducing friction

- Lubrication – Applying lubricating oil or grease between metal surfaces rubbing against each other e.g. engine oil of different grades to keep engine running smoothly.
- Use of ball or roller bearings where a wheel is turning on an axle.
- Fluid friction is reduced by streamlining of ships travelling in water and airplane in air. Cars are also streamlined to reduce the drag or air resistance.
- Smoothening of surfaces.
- Create a cushion of air

  Eg. Like a hovercraft or dynamic cart.

Ball bearings in cars



Create a cushion of air on a dynamic cart

Dynamic cart - A frictionless air track shows the inertia of motion.
Description - A glider is placed on an air track and is given a push. It maintains a visibly near constant velocity for a very long time.

Magnetic Levitation Train (Maglev)

- Magnetic levitation (magnetic suspension system without friction) and superconductivity gave birth to Maglev trains.
- Magnetic levitation trains levitate above the track by means of a magnetic suspension system, thus reducing or eliminating vibration, friction, and noise.
- Magnetic levitation trains can reach extremely high speeds. This experimental train in Germany reaches **435 km/hr** (270 mph).

Africa's first high speed train at OR Tambo International Airport, Jo'burg

Just in time for the 2010 world cup.

Viscosity – Friction in fluids

Viscosity is a measure of fluid friction and it is the property of a fluid which tends to oppose/prevent motion of one layer of fluid over another layer.

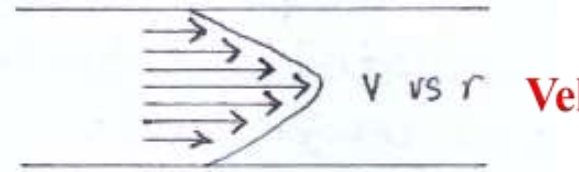
Highly viscous materials are those that possess a great deal of internal friction when layers are in relative motion. They cannot be spread or poured as easily as less viscous materials.

Higher pressure difference is needed between the two ends of a pipe to maintain a steady flow of a viscous fluid.

Viscosity – Internal friction of a fluid

Real fluids have a certain amount of internal friction which tends to oppose motion of one layer of fluid over another layer as they move past one another.

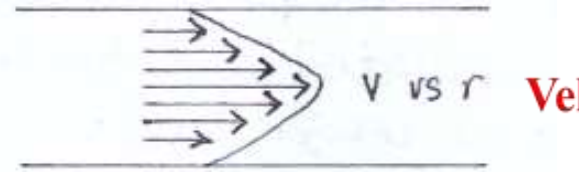
When a viscous fluid flows in a stationary tube or pipe, the flow velocity is different at different points of a cross section. The velocity is greatest at the centre and decreases to zero at the walls.



Velocity distribution for viscous flow

Viscosity – Internal Friction of a fluid

- When a fluid, either a liquid or a gas, is set in motion, different parts of the fluid move with different velocities. Just as there is friction when one surface of a solid slides over another, so there is friction when one layer of a fluid slides over another. This friction in fluids is called *viscosity.*
- When a fluid flows through a cylindrical pipe, the part of the fluid in contact with the pipe adheres to it and remains at rest. We may think of the rest of the fluid as divided into concentric cylindrical layers, the velocity of each succeeding inner layer increasing as we go to the center.
- A difference in pressure between the two ends of the pipe is needed to maintain a steady flow through it and oppose the force due to the viscosity of the fluid.



Velocity distribution for viscous flow

Factors affecting viscosity

The coefficient of viscosity of liquids decreases with an increase in temperature while in the case of gases, the coefficient of viscosity increases with increasing temperature.

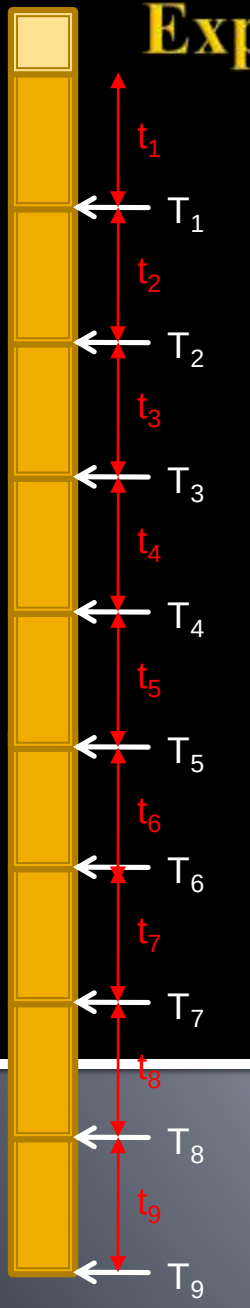
The most important thing in lubrication theory is that viscosity changes very strongly with temperature and pressure.

Viscosity is measured in stokes using viscometer.

Fluid Friction and Motion

- Description qualitatively of the motion of bodies falling in a uniform gravitational field with fluid resistance.
- Refer back to non-uniformly accelerated motion.
- Discussion of ideas of unbalanced forces followed by balanced forces
- Terminal velocity.

Experiment to determine terminal velocity of a steel ball falling through a jar of glycerine.



Mark out 10cm distances along the tube of glycerine using small elastic bands, time the fall of the steel ball each through 10cm; 20cm; 30cm etc

Plot a graph of v against T for 1 to 9.

9 people are equipped with timers, a 10th person carefully drops a steel ball bearing into the glycerine oil, as the ball passes each line that timer is stopped in turn. Hence you record T_1 through T_9. All the timers are started simultaneously as the ball enters the glycerine. Subtraction will give the time for each section t_1 through t_9. The velocity v_1 to v_9 for each section can then be found.

Analysis of motion of a solid body falling through a viscous fluid

Identify all forces acting on the body and determine the resultant

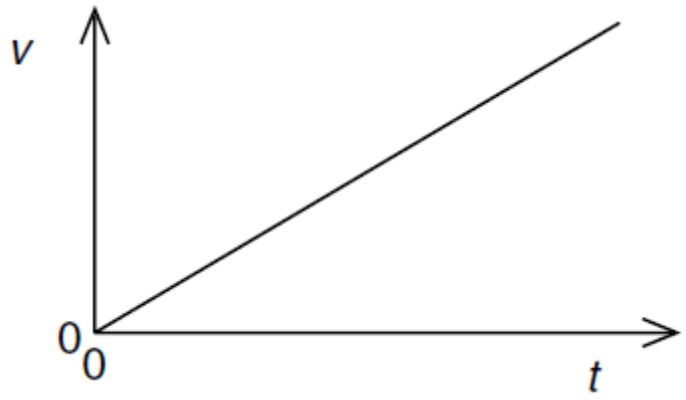
Sketch graphs: s-t and v-t [slopes of s-t graphs] and analyse the motion

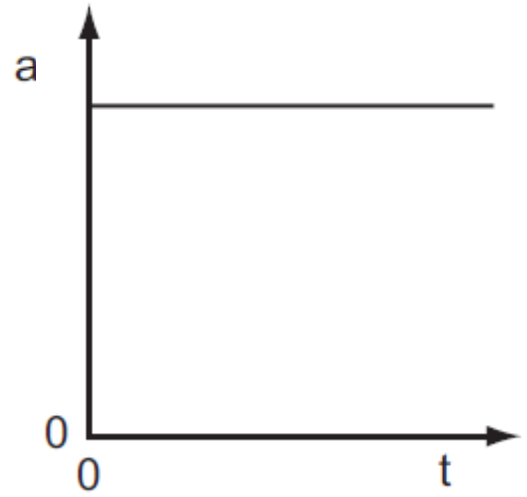
Graphical representation of terminal velocity

Quick Class Exercise

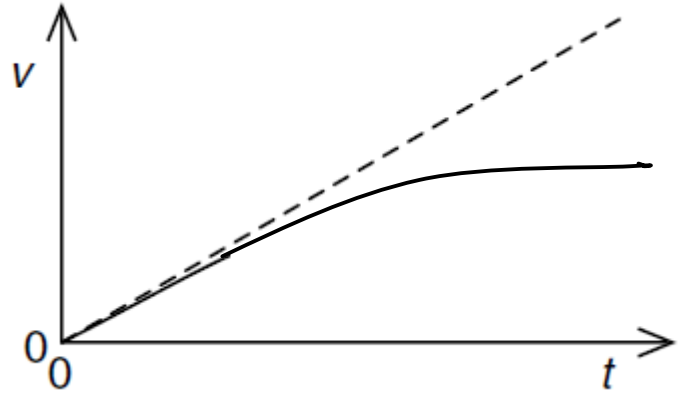
Sketch vel-time and acc-time graphs for a body falling from rest
(i) in a vacuum
(ii) through the air
at the same place near the Earth's surface.

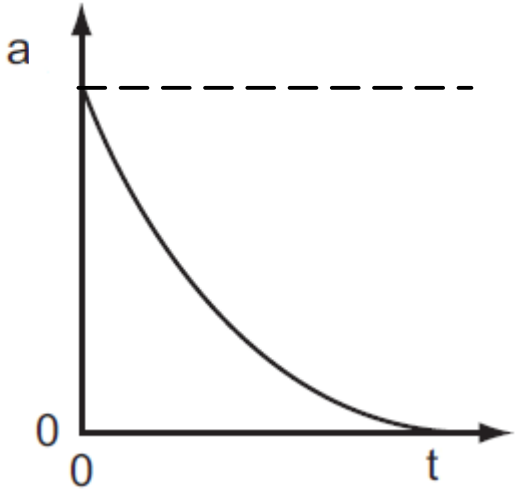
Result of Quick Class Exercise





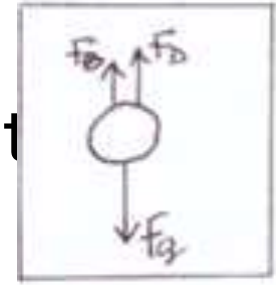
In a vacuum





Through the air

Solid body falling through a viscous fluid and terminal velocity



An object of mass m falling through a fluid will experience force of gravity $\mathbf{F_g}$, negligible buoyant force $\mathbf{F_B}$ and the drag force $\mathbf{F_D}$.

By Newton's second law, the net force is given by

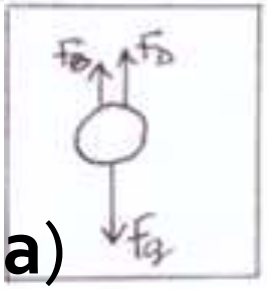
$\mathbf{F_g - (F_B + F_D) = ma}$

or $\mathbf{F_g - F_D = ma}$ since the buoyant force F_B is negligible.

The size of this viscous (drag) force F_D is directly proportional to the speed v of the object. So $\mathbf{F_D = kv}$

Therefore the equation could be written as $\mathbf{F_g - kv = ma}$

Solid body falling through a viscous fluid and terminal velocity

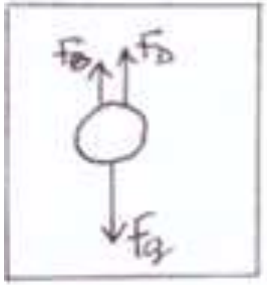


Initially the object will be accelerated by gravity since there is initially no drag when the initial velocity v is zero. (Then $\mathbf{F_g \approx ma}$, from $\mathbf{F_g - kv = ma}$)

But as the object falls, the vertical downwards velocity v increases, the drag force **kv** also increases until eventually the magnitude (size) of the drag force equals the size of the force of gravity, then the forces are balanced and the object will no longer accelerate, a constant velocity will have been reached. **We call this the "terminal velocity"**

That is when ($\mathbf{F_g = kv}$), then $\mathbf{F_g - kv = o}$, so **ma = o**, implying **a = o**, and vel v = constant.

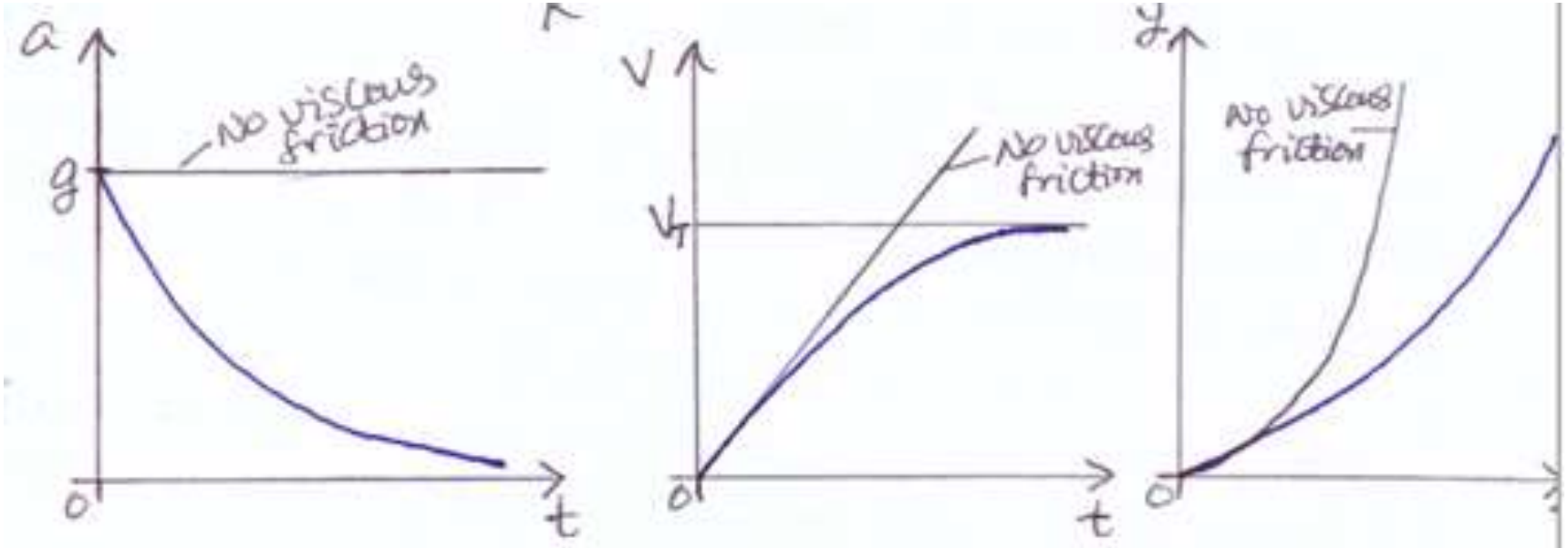
Solid body falling through a viscous fluid and terminal velocity



At this point, the acceleration is zero and the speed increases no further.

This maximum speed V_T attained is called the terminal velocity.

Acceleration-time, velocity-time & displacement-time graphs for a body falling through a viscous fluid



Graphs of acceleration, velocity and position versus time for a body falling in a viscous fluid.

Quick Concept Question

What is responsible for the resistance experienced by solid body moving through viscous fluid?

Relate this to the experience of wading through water.

Answer to Quick Concept Question

The resistance experienced by a solid moving through a fluid is due essentially to the fact that some of the momentum of the solid has been given up to setting the fluid in motion.

An additional cause of the resistance experienced by objects moving through fluids is the turbulence set up in the fluid behind the object at high speeds.

Class Activity 2

Comparison of viscosities of glycerine (glycerol) and water by allowing a small steel ball to fall vertically down the centre of 1m length tube containing the liquids and then measuring the time taken from which the average velocities are determined.

Note: Honey could be used in place of glycerine.

Effects of viscosity

- Viscosity is what is responsible for the different rates of flow of fluids.
- Viscosity affects motion of bodies in fluids. (e.g. ships and aircrafts)

Applications of viscosity

- The knowledge of viscous drag is applied in the design of ships and aircrafts.
  (Man's attempt at imitating special adaptation of fish and birds respectively)
- Used in the design of parachute.
- Viscous liquids are used as lubricants.

Note: Synovial fluid serves as a lubricant during movement, it allows free movement of the bones meeting at the joint in human body.

Factors affecting terminal velocity

- **The shape:**
  - The more streamlined and the smaller the surface area of the body the higher the terminal velocity

- **The Viscosity of the fluid:**
  - The thicker, (more viscous) the fluid is the lower the terminal velocity

Parachute

Terminal velocity problems are often applied to falling objects (Freefall Parachutists for example)

Skydiving with parachute (Playing dangerously!)

An Australian woman died in a base jumping accident in Malaysia, after her parachute failed to open!

Tantiky Lie Marion, 42, was conducting a practise jump from a 165-metre tall communications tower in the Malaysian city of Alor Setar in 2011.

Advantages of viscosity

- Viscosity (air drag) acts as life saver in parachute and skydiving.
- Without air drag, raindrops and snowballs will not attain terminal velocity hence will hit us at a dangerously high speed and momentum.

Disadvantages of viscosity

- Viscosity reduces speed of moving objects in viscous fluids.
- Viscosity damps oscillation i.e. Progressively reduces amplitude of oscillation e.g. Simple pendulum due to air resistance.
- Viscosity generates unwanted heat for fluids in motion.
- Viscosity reduces the efficiency of machines because part of the energy supplied into it is used in overcoming friction.

Recap

- What is drag force?

- A force opposing the motion of an object due to fluid (e.g. air) flowing past the object as it moves.

Recap

- What is terminal velocity?
- The constant (maximum) velocity reached by an object moving through a viscous fluid.

Recap

- What does it mean to streamline?

- To design or build something with a smooth shape (and minimum surface area) so that it moves with minimum resistance through fluid (e.g. air or water).

Recap

- List examples of streamlined bodies?

- Cars, boats & airplanes.

Assignment

Study the functions of

- Synovial fluid,
- ligaments,
- cartilage and
- muscles in the human body.

Problem-solving