Conduction and Breakdown in Pure Liquid Dielectrics:
Pure liquids are those which are chemically pure and don’t contain any other impurity even in the trace of 1 in $10^9$, and are structurally simple. Examples:
- n-Hexane ($C_6H_{14}$)
- n-Heptane ($C_7H_{16}$)
- Paraffin Hydrocarbons

- Figure 1 shows the characteristic of conduction current-electric field in a hydrocarbon liquid. The curve has three distinct regions.

Conduction and Breakdown in Commercial Liquids:
- Commercial insulating liquids are not chemically pure and have impurities like gas bubbles, suspended particles etc. These impurities reduce the breakdown strength.
- When breakdown occurs in these liquids, additional gases and gas bubbles are evolved and solid decomposition products are formed.
- The breakdown mechanism depends on,
  - Nature and condition of the electrodes
  - Physical properties of the liquid and
  - Impurities and gases present in the liquid.
- In general the breakdown mechanisms are classified as follows:
  - a. Suspended Particle Mechanism
  - b. Cavitation and Bubble Mechanism
  - c. Thermal Mechanism
  - d. Stressed oil volume theory

a. Suspended Particle Mechanism:
- The impurities will be present as fibers or as dispersed solid particles. The permittivity of this particle ($\varepsilon_2$) will be different from the permittivity of the liquid ($\varepsilon_1$).
- If we considered the impurities to be spherical particles of radius $r$, the particles experience a force $F$,
  \[ F = \frac{1}{2r^3} \frac{(\varepsilon_2 - \varepsilon_1)}{2\varepsilon_1 + \varepsilon_2} \text{grad} E^2 \]
  This force is directed towards areas of maximum stress.
- If the voltage is continuously applied (d.c.) or the duration of the voltage is long (a.c.), then this force drives the particles towards the areas of maximum stress. If the number of particles present are large, they becomes aligned due to these forces, and thus form a stable chain bridging the electrode gap causing a breakdown between the electrodes.
- If there is only a single conducting particle between the electrodes, it will give rise to local field enhancement depending on its shape. If
this field exceeds the breakdown strength of the liquid, local breakdown will occur near the particle, and this will result in the formation of gas bubbles, which may lead to the breakdown.

- The larger the size of the particles, the lower is the breakdown strengths.

b. Cavitation and Bubble Mechanism:
- The following processes have been responsible for the formation of the vapour bubbles.
  i. Gas pockets at the surface of the electrodes.
  ii. Electrostatic repulsive forces between space charges which may be sufficient to overcome the surface tension.
  iii. Gaseous products due to the dissociation of liquid molecules by electron collisions.
  iv. Vapourization of the liquid by corona type discharge.
- The bubble will elongate in the direction of the electric field under the influence of electrostatic forces. Breakdown occurs when the voltage drop along the length of the bubble becomes equal to the minimum value on the Paschen’s curve, and the breakdown field is given as:

\[
E_0 = \frac{1}{(\varepsilon_1 - \varepsilon_2)} \left( \frac{2\pi r \sigma (2\varepsilon_1 + \varepsilon_2)}{\varepsilon_1} \right) \left( \frac{\pi}{4} \left( \frac{V_b}{2 r E_0} \right)^{1/2} - 1 \right) \]

where,
\( \sigma \): Surface tension of the liquid
\( \varepsilon_1 \): Liquid permittivity
\( \varepsilon_2 \): Gas bubble permittivity
\( r \): Initial radius of the bubble (sphere shape)
\( V_b \): voltage drop in the bubble
- This theory does not take into account the production of the initial bubble and hence the results given by this theory do not agree well with the experimental result.

c. Thermal Breakdown:
- Based on the experimental observations of extremely large currents just before breakdown. The high current pulses originate from the tips of the microscopic projections on the cathode surface with densities of the order of 1 A/cm³. This high density current pulses give rise to localized heating of the oil which may lead to the formation of vapour bubbles.
- When a bubble is formed, breakdown follows, either because of its elongation to a critical size or when it completely bridges the gap between the electrodes.
- The breakdown strength depends on the pressure and the molecular structure of the liquid.

d. Stressed Oil Volume Theory:
- Breakdown strength is determined by the “largest possible impurity” or “weak link” in commercial liquids where minute traces of impurities are present.
- The breakdown strength of the oil is defined by the region which is stressed to the maximum (Weak region).
- In non-uniform fields, the stressed oil volume contains maximum stress between \( E_{\text{max}} \) Contour and 0.9\( E_{\text{max}} \) Contour.
- This theory defines the breakdown strength is inversely proportional to the stressed oil volume.
- The breakdown voltage determined by,
  - Gas content in the oil
  - Viscosity of the oil
  - Impurities present in the oil

Fig.2. Power frequency (50 Hz) a.c. breakdown stress as a function of the stressed oil volume