Principle and Use of Gas Chromatography (GC)

Principle:

Gas Chromatography (GC) is an analytical technique used to separate and analyze volatile compounds based on their **partitioning between a mobile gas phase and a stationary phase** inside a column.

1. **Separation Mechanism**:
   - The sample is vaporized and carried by an **inert gas (mobile phase, e.g., He, N_2, H_2)** through a **coated capillary column (stationary phase)**.
   - Components separate based on their **boiling points, polarity, and affinity** for the stationary phase.
   - **Higher affinity or lower volatility → longer retention time**.

2. **Detection Principle**:
   - As compounds exit the column, a **detector** (e.g., FID, TCD, MS) measures their concentration, generating a **chromatogram** (peaks vs. time).

Uses of Gas Chromatography:

1. **Qualitative & Quantitative Analysis**:
   - Identifying unknown compounds (e.g., drugs, pollutants, flavors).
   - Measuring concentrations (e.g., blood alcohol, pesticide residues).

2. **Petrochemical Industry**:
   - Analyzing hydrocarbons in fuels and oils.

3. **Environmental Testing**:
   - Detecting volatile organic compounds (VOCs), greenhouse gases.
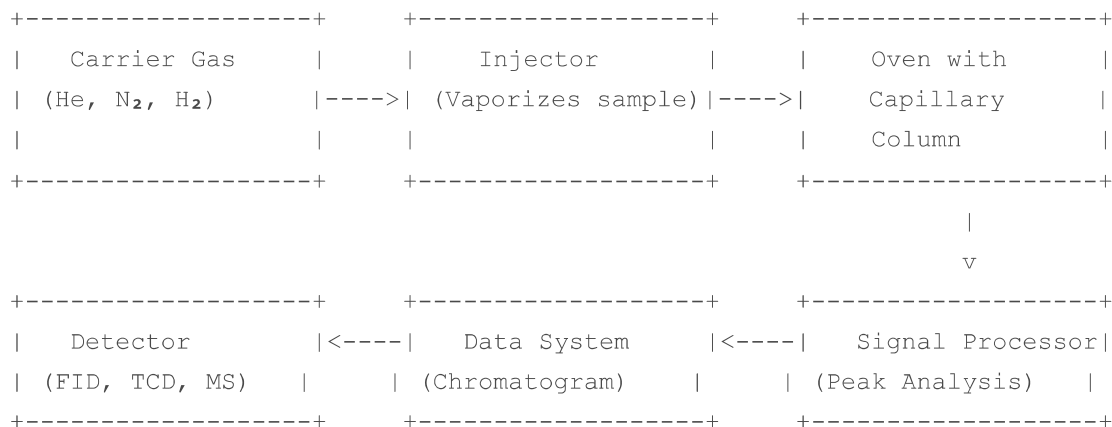
4. **Forensic & Pharmaceutical Applications**:
   - Drug testing, toxicology, purity checks.

5. **Food & Fragrance Industry**:
   - Analyzing food additives, essential oils, spoilage markers.

Schematic Diagram of a Gas Chromatograph

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+-----------------+      +-----------------+      +-----------------+
|   Carrier Gas   |      |    Injector     |      |   Oven with     |
| (He, N₂, H₂)    |----->| (Vaporizes sample)|---->|   Capillary    |
|                 |      |                 |      |   Column        |
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+-----------------+      +-----------------+      +-----------------+
|   Detector      |<----|   Data System   |<----| Signal Processor|
| (FID, TCD, MS)  |     | (Chromatogram)  |     | (Peak Analysis) |
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Key Components:

1. **Carrier Gas**: Inert gas that carries the sample (e.g., Helium, Nitrogen).

2. **Injector**: Introduces and vaporizes the sample (split/splitless mode).

3. **Column**:

    ○ **Packed Column** (for simple mixtures).

    ○ **Capillary Column** (higher resolution, common in modern GC).

4. **Oven**: Controls column temperature (isothermal or gradient).

5. **Detector**:

    ○ **Flame Ionization Detector (FID)** – Hydrocarbon analysis.

    ○ **Thermal Conductivity Detector (TCD)** – Universal detection.

    ○ **Mass Spectrometer (GC-MS)** – Compound identification.

6. **Data System**: Records and analyzes chromatographic peaks.

Advantages of GC:

✔ High resolution & sensitivity.

✔ Fast analysis (minutes to hours).

✔ Compatible with various detectors (FID, MS).

Limitations:

✘ Only works for **volatile & thermally stable** compounds.
✘ Requires sample preparation (derivatization for non-volatile compounds).

GC is widely used in **research, industry, and regulatory testing** due to its precision and reliability in separating complex mixtures.