Skill Development Program at CSIR-CGCRI

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Central Glass and Ceramic Research Institute (India)

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CLASSICAL CHEMISTRY

➢ Introduction

Titration is a classical volumetric analytical technique used to determine the unknown concentration of a solution by reacting it with a solution of known concentration. It is fundamental in analytical chemistry and has applications in pharmaceuticals, food science, environmental science, and education.

➢ Definition of Titration

Titration is a laboratory method of quantitative chemical analysis used to determine the concentration of an identified analyte (a substance to be analyzed). A reagent, called the titrant, of known concentration and volume is added to a solution of the analyte until the reaction reaches the equivalence point.

➢ Principle of Titration

The core principle involves a chemical reaction between the titrant and the analyte. Once stoichiometric equivalence is achieved, an indicator shows a visible change (usually color), known as the endpoint.

➢ Classical Titration Instruments and Apparatus

Instrument	Function
Burette	Dispenses titrant with accuracy
Pipette	Measures a fixed volume of analyte
Conical Flask	Holds the analyte and allows swirling
Beaker	Prepares and transfers solutions
Funnel	Transfers liquids into narrow containers
Indicator	Detects endpoint via color change
Clamp Stand	Holds burette in vertical position
Wash Bottle	Rinses the walls of conical flask

➢ Types of Classical Titration Methods

Acid-Base Titration

Reaction: Neutralization

Example: HCl (acid) vs NaOH (base)
Indicator: Phenolphthalein (colorless → pink in base) Color Changes:
Phenolphthalein: Colorless (acidic) → Pink (basic)
Methyl Orange: Red (acidic) → Yellow (basic)
Redox Titration Reaction: Electron transfer Example: $KMnO_4$ vs Fe^{2+}
Indicator: Self-indicating ($KMnO_4$ is purple → colorless) Color Change: Purple → Colorless (endpoint is faint pink)
Complexometric Titration Reaction: Formation of complex ions Example: EDTA vs Ca^{2+}/Mg^{2+} Indicator: Eriochrome Black T (EBT)
Color Change: Wine-red → Blue
Precipitation Titration
Reaction: Formation of an insoluble precipitate Example: $AgNO_3$ vs Cl^- (Mohr's method) Indicator: Potassium chromate
Color Change: Yellow → Red brick precipitate (Ag_2CrO_4)

➢ General Procedure of Classical Titration

Clean all glassware.
Fill burette with standard solution (titrant).
Pipette a known volume of analyte into conical flask.
Add appropriate indicator.
Add titrant dropwise while swirling until endpoint.
Record burette readings.
Repeat for concordant results.

➢ Calculations in Titration

Basic Formula for Titration:
$N_1 \times V_1 = N_2 \times V_2$ Where:
N_1 = Normality of titrant
V_1 = Volume of titrant used (in mL)
N_2 = Normality of analyte
V_2 = Volume of analyte taken (in mL)

Example:

If 25 mL of 0.1N NaOH neutralizes 20 mL of HCl, then:
$0.1 \times 25 = N_2 \times 20 \Rightarrow N_2 = 2.5 / 20 = 0.125$ N

➢ Disadvantages of Classical Titration Methods

Subjective Color Detection
Manual Reading Errors
Time-Consuming
No Digital Record
Not Suitable for Turbid/Colored Samples
Sensitive to Temperature and Mixing

➢ Evolution: From Classical to Modern Titration Techniques

Feature	Classical Titration	Modern Titration
Endpoint Detection	Visual indicators	pH meters, conductometric, photometric
Data Recording	Manual	Automatic (software- assisted)
Precision	Moderate	High
Speed	Slow	Fast and continuous
Automation	No	Yes (auto-titrators)
Error Margin	High (manual)	Low (digital)

➢ Modern Titration Techniques and Instruments

Potentiometric Titration

Uses pH electrode to detect the endpoint.
Ideal for strong/weak acids or bases and colored solutions.

Conductometric Titration

Measures conductivity change as ions react.
Useful for weak acid/base titrations and precipitations.

Spectrophotometric Titration

Monitors light absorbance using a UV/Vis spectrophotometer. Good for reactions with no visible color change.

Thermometric Titration

Detects temperature changes.

Used in non-aqueous or fast reactions.

Automatic Titrators

Integrates burette, sensor, motor, and software. Provides titration curves and stores digital data. Widely used in pharmaceutical and chemical industries.

➢ Applications of Titration

Pharmaceutical quality control Water hardness and pollution testing Food and beverage industry Educational labs

Soil and mineral analysis

Spectrophotometer

A spectrophotometer is a precision optical instrument used to quantitatively measure the absorption or transmission of light by a substance as a function of wavelength.

➢ Operating Principle

Based on the Beer-Lambert Law, which states:

Figure 1 UV-VIS Spectrophotometer

A=εclA

where: *A* =
Absorbance *ε* =
Molar absorptivity *c* = Concentration *l* =
Path length of light through the sample

The instrument analyses how much light is absorbed by the sample at a specific wavelength to determine concentration.

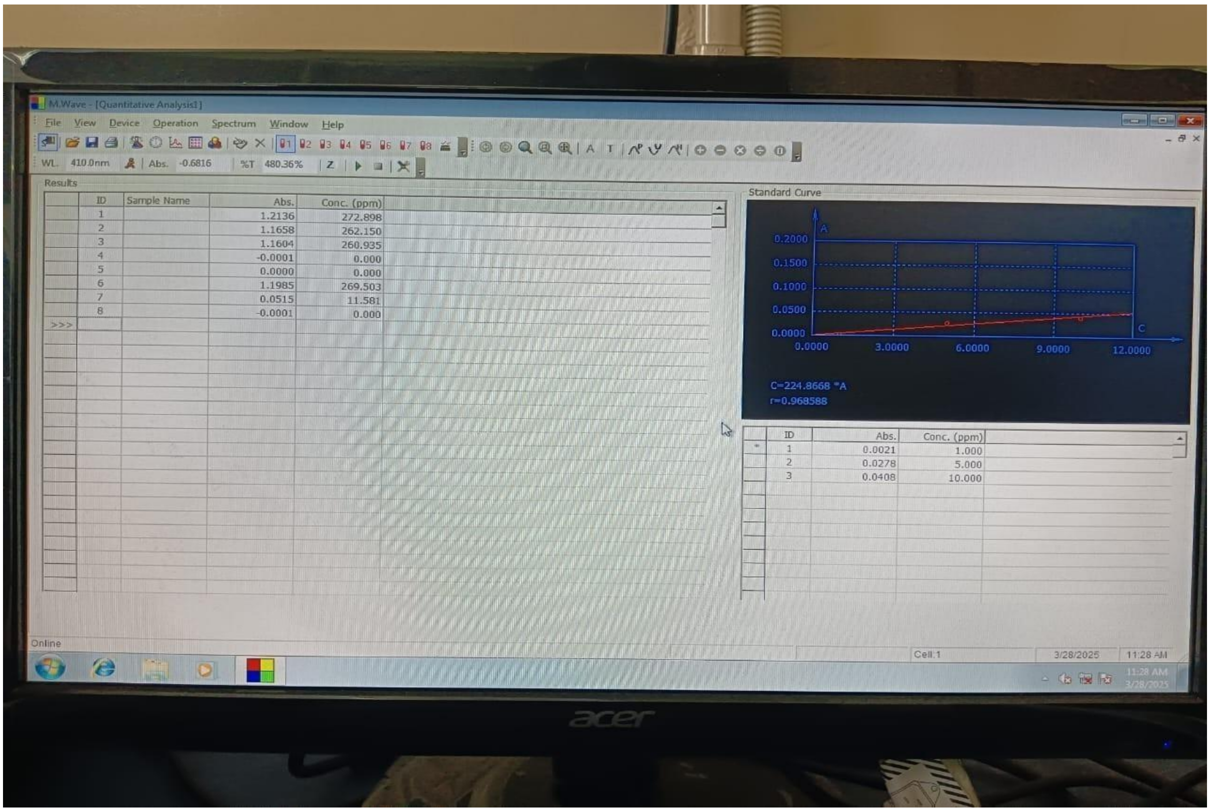
➢ Core Components

- **Light Source**: Provides stable radiation (e.g., tungsten for visible, deuterium for UV)
- **Monochromator**: Isolates specific wavelengths (prism or diffraction grating)

- **Sample Holder**: Cuvettes typically made of quartz or glass
- **Detector**: Converts transmitted light into electrical signals (photodiode or photomultiplier tube)
- **Display System**: Outputs absorbance or transmittance data

➢ How does it work?

A spectrophotometer works by passing a beam of light through a sample and measuring how much of that light is absorbed at a specific wavelength. The light first passes through a monochromator, which selects the desired wavelength, and then through the sample contained in a cuvette. As the sample absorbs some of the light, the remaining light reaches a detector. The instrument then compares the intensity of the incident and transmitted light to calculate **absorbance**. The **output** is usually displayed digitally as absorbance or transmittance values, which can be further used to determine the **concentration** of the analyte in the sample using calibration curves or standard reference data.



➢ Types of Spectrophotometers

- **UV-Visible Spectrophotometer** (190–800 nm): Common in chemical and biological labs
- **Infrared (IR) Spectrophotometer**: Used for structural analysis of organic compounds
- **Atomic Absorption Spectrophotometer (AAS)**: Detects trace metal ions in samples

➢ Applications

- **Pharmaceutical Analysis**: Drug purity and concentration assessment
- **Environmental Monitoring**: Water and air quality testing
- **Clinical Diagnostics**: Blood and urine analysis
- **Molecular Biology**: DNA/RNA/protein quantification
- **Food & Beverage Industry**: Additive and contaminant detection

➢ Advantages

- **High precision and reproducibility**
- **Rapid and non-destructive** analysis
- Suitable for **both qualitative and quantitative** studies • Applicable across **diverse scientific disciplines**

PID CONTROLLER

1. Introduction

A PID Controller (Proportional-Integral-Derivative Controller) is a type of control system widely used in industrial automation and control processes. It continuously calculates an error value as the difference between a desired setpoint and a measured process variable, and applies a correction based on proportional, integral, and derivative terms.

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2. Components of a PID Controller

A PID controller consists of three main components:

2.1 Proportional (P)

- The proportional component produces an output that is proportional to the current error value.
- **Formula**: $P_{out}=K_p e(t)$
- **Effect**: Reduces the overall error. A higher Kp reduces error faster, but may lead to instability.

2.2 Integral (I)

- The integral component accounts for past values of the error and integrates them over time to eliminate residual steady-state errors.
- **Formula**: $I_{out}=K_i\int e(t)dt$;integrate(0-t)

- **Effect**: Eliminates steady-state error. Too much can cause slow response or oscillations.

2.3 Derivative (D)

- The derivative component predicts future error based on its rate of change.
- **Formula**: Dout=Kdde(t)/dt
- **Effect**: Improves stability and dampens the system response.

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3. PID Controller Equation

The overall output of a PID controller is the sum of the three terms:

u(t)=Kpe(t)+Ki∫e(t)dt+Kdde(t)/dt ; integrate(0-t) Where:

- u(t) = controller output • e(t) = error at time ttt
- Kp = proportional gain
- Ki = integral gain
- Kd = derivative gain

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4. Working Principle

The PID controller continuously reads the error between the desired setpoint and the process variable. It then:

1. Applies a correction based on current error (P),
2. Accumulates past errors to eliminate steady-state error (I),
3. Predicts future trends to stabilize response (D).

By tuning the gains Kp , Ki , and Kd , the controller can be adjusted for optimal performance.

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5. Tuning Methods

- **Manual Tuning**: Adjust Kp , Ki , and Kd manually based on system response.
- **Ziegler-Nichols Method**: Increase Kp until oscillation, then calculate Ki, Kd using predefined formulas.
- **Software Tools**: Use simulation software (like MATLAB) for auto-tuning.

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6. Applications

- **Temperature control systems** (e.g., ovens, HVAC)
- **Speed control of motors**
- **Process control in chemical industries**
- **Autopilot in aircraft**
- **Robotics and automation system.**

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7. Advantages

- Simple and effective for a wide range of systems
- Improves system stability and accuracy
- Can eliminate steady-state error
- Flexible and tunable for different processes

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8. Limitations

- Not suitable for highly non-linear or time-varying systems without adaptation
- Derivative term is sensitive to noise
- Tuning can be complex for systems with delay or rapid dynamics

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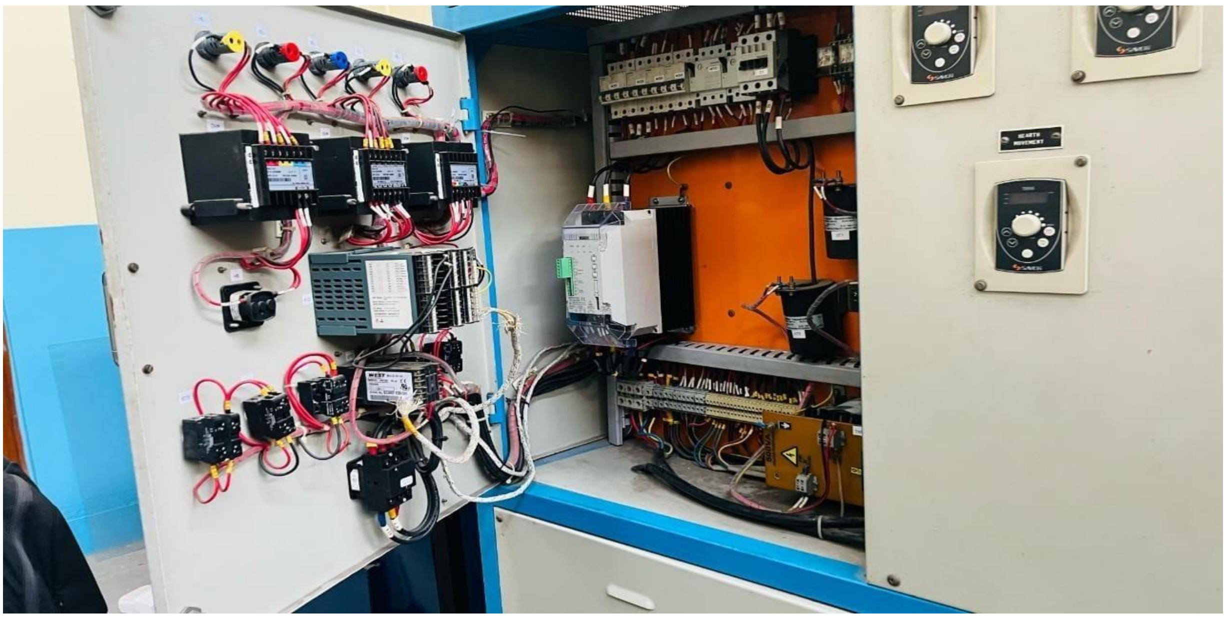


Figure 1Furnace temperature control loop

PID Controller Architecture

1. Key Components in the PID Control Loop

☑ **Setpoint (SP)**

- The desired value that you want the system to maintain.
- For example: In a room heating system, the setpoint could be **25°C** (your desired temperature).

☑ **Process Variable (PV)**

- The current value of the variable being measured and controlled.
- In the heating example, PV would be the **current room temperature** measured by a sensor.

☑ **Error (e)**

- The difference between the setpoint and the process variable.
- **Formula**: $e(t) = SP - PV$
- This error is what the PID controller tries to minimize.

☑ **Controller Output (CO)**

- The signal sent by the PID controller to the **final control element** (e.g., heater, motor, valve) to influence the system.
- It is the combined result of the **P**, **I**, and **D** terms.

☑ **Actuator / Final Control Element**

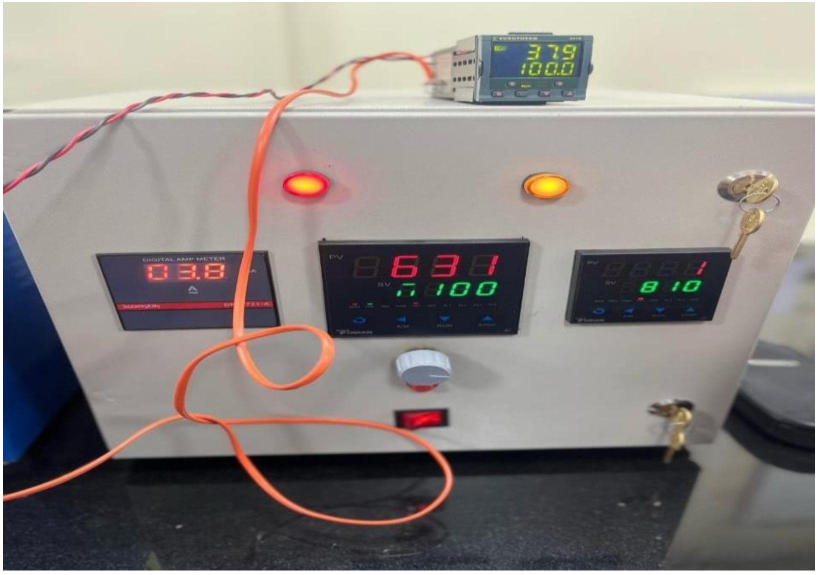
- The device that physically influences the system based on the controller's output.
- Examples: A heater (for temperature), a valve (for fluid flow), or a motor (for speed control).

☑ **Process**

- The actual system or environment you're controlling.
- This is what changes in response to the actuator and gives feedback through sensors.

☑ **Sensor**

- Measures the current value of the process variable (PV) and feeds it back to the controller.



Pyrometer

Introduction

A pyrometer is a temperature measurement device designed to measure the temperature of an object without making physical contact. Unlike traditional thermometers that rely on direct contact with the object, pyrometers measure the radiation emitted by the object, often in the infrared spectrum, to determine its temperature. These instruments are crucial in various industries, especially those dealing with high-temperature processes or hazardous environments, where conventional temperature measurement tools might not be feasible or safe to use. This report explores the principles of operation, types, and applications of pyrometers.

Principle of Operation

The fundamental operating principle of a pyrometer is based on the StefanBoltzmann law, which states that all objects emit electromagnetic radiation proportional to their temperature. In essence, the higher the temperature of an object, the more radiation it emits, particularly in the infrared region. Pyrometers detect this emitted radiation and, using sophisticated sensors, calculate the temperature of the object.

There are two key components involved in pyrometer operation: the sensor and the optical system. The sensor is responsible for detecting the radiation emitted by the target object, while the optical system focuses this radiation ontothe sensor. The sensor converts the detected radiation into an electrical signal, which is then processed and calibrated to provide a temperature reading. This non-contact method makes pyrometers particularly useful for measuring the temperature of objects that are too hot, dangerous, or difficult to reach.

Figure 2 OPTICAL PYROMETER

Types of Pyrometers

1. Optical Pyrometers

Optical pyrometers are one of the oldest types of pyrometers. They rely on the visible spectrum of light to measure temperature. In an optical pyrometer, the user adjusts the brightness of a comparison light source until it matches the brightness of the target object. The temperature is then calculated based on the brightness ratio. These pyrometers are typically used for very high temperatures, such as in metal and glass industries, and are effective for objects emitting visible light at high temperatures.

2. Infrared Pyrometers

Infrared pyrometers are more modern and widely used than optical pyrometers. These instruments detect infrared radiation emitted by an object, which is not visible to the naked eye. The infrared radiation is converted into an electrical signal, which is then used to determine the temperature of the object. Infrared pyrometers are highly versatile and can measure the temperature of a wide range of surfaces, from cold to extremely high temperatures, without being affected by the object's emissivity (the ability to emit infrared radiation). Infrared pyrometers are used in a variety of industrial and laboratory settings.

3. **Color-Change Pyrometers**

Color-change pyrometers, a subtype of optical pyrometers, use the color of an object as an indicator of temperature. As an object heats up, its color changes from red to orange, yellow, and eventually white. By observing these color changes, the pyrometer can estimate the temperature. While this type is less precise than infrared pyrometers, it can still provide useful temperature data in certain applications, especially for metals and materials that exhibit clear color changes at different temperatures.

Applications

Pyrometers have numerous applications in industries where temperature control is crucial. Key areas include: 1. **Metal and Steel Manufacturing**

In metal processing industries, pyrometers are essential for measuring the temperature of molten metal, furnace interiors, and heated metal products. Precise temperature control is necessary for processes such as casting, forging, and welding.

2. **Automotive Industry**

Pyrometers are used in automotive manufacturing to measure the temperature of components like engines, exhaust systems, and brake components. They also help in monitoring the temperature during the testing of car engines and other machinery.

3. **Glass and Ceramics**

The production of glass and ceramics involves heating materials to high temperatures. Pyrometers are used to monitor the temperature of kilns, furnaces, and molds during these processes, ensuring product quality and preventing overheating.

4. **Research and Laboratory Settings**

In scientific research, pyrometers are used in experiments requiring precise temperature measurements, such as those in material science or thermodynamics. Their non-contact nature ensures that the measurement process does not interfere with the object under study.

Thyristor Analyzer

1. Introduction

A thyristor analyzer is an essential instrument used to test, analyze, and characterize the static and dynamic behavior of thyristors (SCRs), triacs, and other thyristor-family devices. Thyristors are widely used in power electronics for switching and controlling high voltages and currents.

Proper analysis ensures reliable operation in applications like AC/DC motor drives, phase control, and rectifiers.

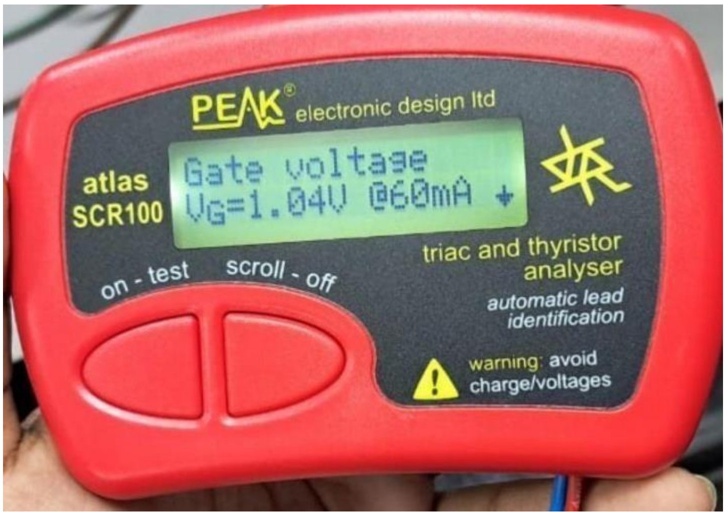


Figure 2 SCR tester(At CSIR-CGCRI)

2. Objective

The primary objective of a thyristor analyzer is:
To determine the VI characteristics of SCRs and triacs.
To measure key parameters like latching current, holding current, breakover voltage, and gate triggering voltage.
To check thyristor functionality before circuit integration.

3. Construction and Components

A typical thyristor analyzer consists of the following major parts:
Power Supply Unit: Provides the DC and AC voltages required for device testing.
Test Fixture: Holds the thyristor under test (DUT) securely and connects it to the circuit.
Control Unit: Allows variation of parameters like gate current, anode voltage, and load current.
Display System: Shows current, voltage, and other readings either on analog/digital meters or on an oscilloscope.
Protection Circuit: Prevents damage to the analyzer and the DUT during overcurrent or incorrect connections.

4.Working Principle

The analyzer applies a controlled anode-to-cathode voltage across the thyristor and a gate signal to trigger conduction. The output voltage and current are then monitored to plot the VI characteristics or to determine the switching parameters. **Basic Operating Steps:**
Apply forward voltage across the anode and cathode.
Increase gate current until the thyristor turns ON.
Record the anode current at which conduction begins (latching current).
Gradually reduce current and record the value at which the device turns OFF (holding current).
Increase anode voltage without gate signal to determine breakover voltage.

5.VI Characteristics of SCR

The VI characteristics curve typically has three regions:
Forward Blocking Region: SCR is off; small leakage current flows.
Forward Conducting Region: SCR turns ON when gate current is applied.
Reverse Blocking Region: Similar to reverse-biased diode; small leakage current until breakdown.
A thyristor analyzer plots this curve to help in understanding and verifying the behavior of the device under different conditions.

1. Measurement Parameters

Some of the parameters that a thyristor analyzer can measure include:
Breakover Voltage (V_BO): Minimum forward voltage at which the device conducts without gate signal.
Gate Trigger Current (I_GT): Minimum gate current needed to turn the SCR ON.
Latching Current (I_L): Minimum anode current required to maintain conduction after triggering.
Holding Current (I_H): Minimum current below which the SCR turns OFF. Leakage Current (I_R): Reverse current when SCR is reverse-biased.

2. Types of Thyristor Analyzers

Manual Thyristor Analyzer: Uses manual knobs and analog meters for basic testing and educational labs.
Digital/Automated Analyzer: Provides high precision, automated test sequences, and data logging.
Oscilloscope-Based Analyzer: Allows dynamic testing with waveform monitoring for turn- on and turn-off transients.

3. Applications

Testing SCRs and triacs in manufacturing and quality control.
Educational labs for learning power electronics.
Maintenance in power control systems like AC drives and controlled rectifiers. Characterizing devices before using in high-power applications.

4. Safety Precautions

Always verify connections before powering ON the analyzer.
Use appropriate voltage and current ranges to prevent damage.
Allow sufficient cooling time after testing high-power devices. Never exceed rated values of the device under test.

Temperature Calibrator System

This image shows a laboratory temperature calibration setup using a dry block calibrator (Pegasus) and a precision temperature scanner (Fluke 1586A Super-DAQ).

1. **Pegasus Dry Block Calibrator**:
- Provides a stable and uniform temperature environment.
- Used for calibration of RTDs, thermocouples, and temperature transmitters. - Highly portable and suitable for both field and laboratory use.

2. **Fluke 1586A Super-DAQ**:
- A precision temperature scanner that supports multiple sensor types.
- Capable of high-accuracy measurement and data logging.
- Ideal for validation, testing, and calibration of thermal sensors.

Applications:
- Industrial process instrumentation.
- Research and development labs.
- Quality assurance and equipment certification.

Calibration Process:
- Insert the DUC (Device Under Calibration) and a reference thermometer into the dry block.
- Use the Fluke 1586A to record and compare temperatures.
- Determine and document deviation, then calibrate accordingly.

Figure 3 Temperature calibration setup

CALIBRATION DATA TABLE

Channel	Reading (°C)	Time
101	595.96°C	15:15:08
103	600.53°C	15:15:08
101	595.99°C	15:18:08
103	600.52°C	15:18:08
101	595.95°C	15:21:08

103	600.47°C	15:21:08
101	595.97°C	15:24:08
103	600.49°C	15:24:08
101	595.94°C	15:27:08
103	600.43°C	15:27:08

ON-OFF CONTROL USING CONTACTOR

This experiment demonstrates the basic ON-OFF control using a contactor system. It involves a push button switch (ON), a contactor, a thermostat, and an indication lamp. The push button energizes the contactor coil, which then activates the load circuit. The thermostat can cut off the circuit based on temperature, simulating an automatic control. The indication lamp shows the status of the circuit.

Components used:

1. Contactor (MNX-12)
2. Push button switch
3. Thermostat
4. Indication lamp
5. Experimental setup board

Working Principle:

When the ON push button is pressed, the contactor coil is energized. This closes the main contacts, allowing current to flow to the lamp. The thermostat provides a control point for switching OFF the lamp based on the set temperature. This is a typical control system used in industrial automation for load management.

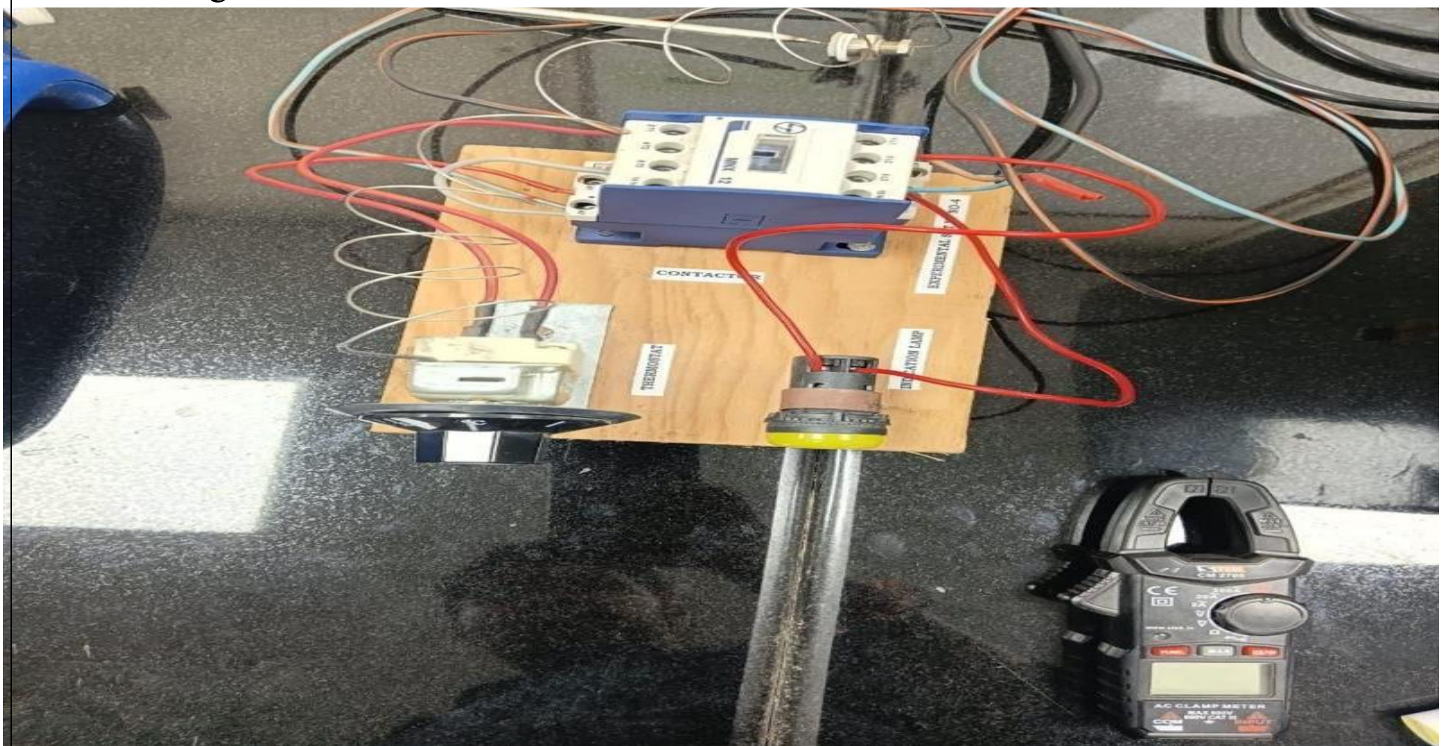


Figure 4 ON OFF control using contactor

INSTRUMENTATION IN ANALYTICAL CHEMISTRY

What is Analytical chemistry?

Analytical chemistry involves the *separation, identification, and the quantification of matter*. It involves the use of classical methods along with modern methods involving the use of scientific instruments.

Analytical chemistry involves the following methods:

- The *process of separation* isolates the required chemical species which is to be analysed from a mixture.
- The *identification of the analyte substance* is achieved via the method of qualitative analysis.
- The *concentration of the analyte* in a given mixture can be determined with the method of quantitative analysis.

Today, the field of analytical chemistry generally involves the use of modern, sophisticated instruments. However, the principles upon which these instruments are built can be traced to more traditional techniques.

Branches of Analytical chemistry

Quantitative Analysis

Quantitative analysis is a method of determining the absolute or relative quantity regarding the concentration of one or more substances present in a sample or compound. For example, take a sample of an unknown solid substance.

Qualitative Analysis

Quality means the standard or the feature of one substance. Hence, Qualitative analysis method deals with the determination of the quality of a particular compound, irrespective of its quantity or concentration. In simpler words, the qualitative analysis does not measure the amount of the substance but measures the quality of that material. One of the best examples of this type of method is the observation of a chemical reaction, whether there will be a change in colour or not.

Need of instrumentation in Analytical Chemistry

Instrumentation is crucial in analytical chemistry because it allows for accurate, precise, and rapid analysis of samples, providing qualitative and quantitative information about their composition, structure, and properties. It enables the identification of chemical species, determination of their concentrations, and investigation of their molecular and atomic structures. This is essential for various applications, including fundamental research, product development, quality control, environmental monitoring, and medical diagnostics.

1. **Enhanced Speed and Precision:**

- Instrumental methods are generally faster and more precise than traditional manual techniques.
- Automated instruments can perform repetitive tasks and handle large sample sets efficiently.
- This speed and precision are crucial for timely analysis, especially in areas like environmental monitoring and forensic science.

2. **Increased Sensitivity and Specificity:**

- Instrumental methods can detect very small amounts of substances in a sample, enhancing sensitivity.
- Many instruments are highly specific, allowing for the accurate identification of individual components even in complex mixtures.
- This sensitivity and specificity are vital for analyzing trace elements, pollutants, and biological molecules.

3. **Qualitative and Quantitative Analysis:**

- Instruments can provide both qualitative and quantitative information about a sample's composition.
- Qualitative analysis identifies the presence of specific chemical species, while quantitative analysis determines their amounts.
- This information is crucial for understanding the properties of materials, identifying contaminants, and monitoring chemical processes.

4. **Diverse Applications:**

- Analytical instrumentation is used in a wide range of fields, including chemistry, biology, medicine, environmental science, and materials science.
- Examples include analyzing the composition of drugs, monitoring pollutants in water and air, and identifying genetic markers in biological samples.

Instruments observed

➢ Ions Elective Electrode

The Ion-Selective Electrode (ISE) is an analytical instrument used to measure the concentration of specific ions in a solution, such as sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), chloride (Cl^-), and others. It works based on the potential difference developed across a membrane that is selective to a particular ion.

Figure 3:Ions Elective Electrode (At CSIR-CGCRI)

- **Working Principle:**

The ISE uses a membrane that allows only a specific ion to interact with it. This interaction creates a voltage that is directly related to the ion's activity (concentration) in the solution.

- **Purpose in Industry:**

ISEs are widely used in quality control labs to rapidly determine ion concentrations in water, beverages, pharmaceuticals, and chemical product.

- **Classical Method Replaced:**

ISEs replace traditional methods like:

- **Complexometric titration** (e.g., using EDTA for Ca^{2+} and Mg^{2+}),
- **Precipitation reactions or manual spot tests** for ions like chloride.

➢ ICP-OES (Inductively coupled plasma optical emission spectroscopy)

ICP-OES is a powerful analytical technique used to detect and quantify multiple metal elements in a sample with very high sensitivity. It is especially useful when several metals need to be analyzed simultaneously in industrial samples like water, alloys, chemicals, and pharmaceuticals.

Figure 4 ICP-OES (At CSIR-CGCRI)

✞ Working Principle:

The sample is introduced into a high-temperature plasma (around 10,000 K), which excites the atoms. These excited atoms emit light at specific wavelengths unique to each element. The emitted light is analyzed to determine the type and concentration of metals present.

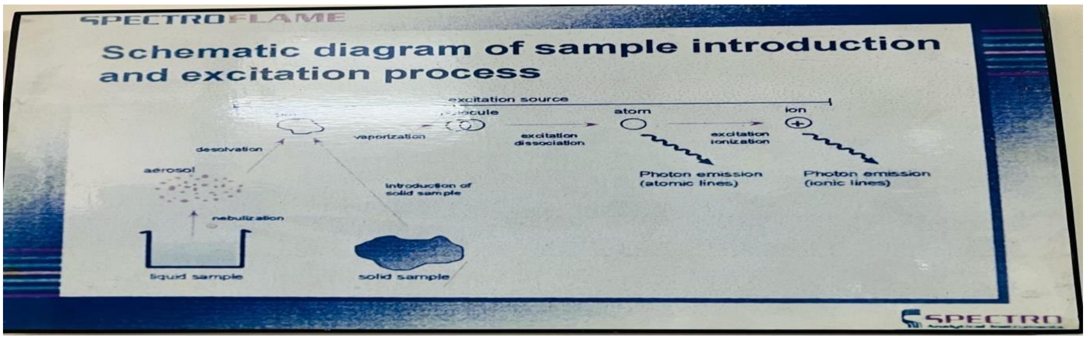


Figure 5 Working principle of ICE-OES.

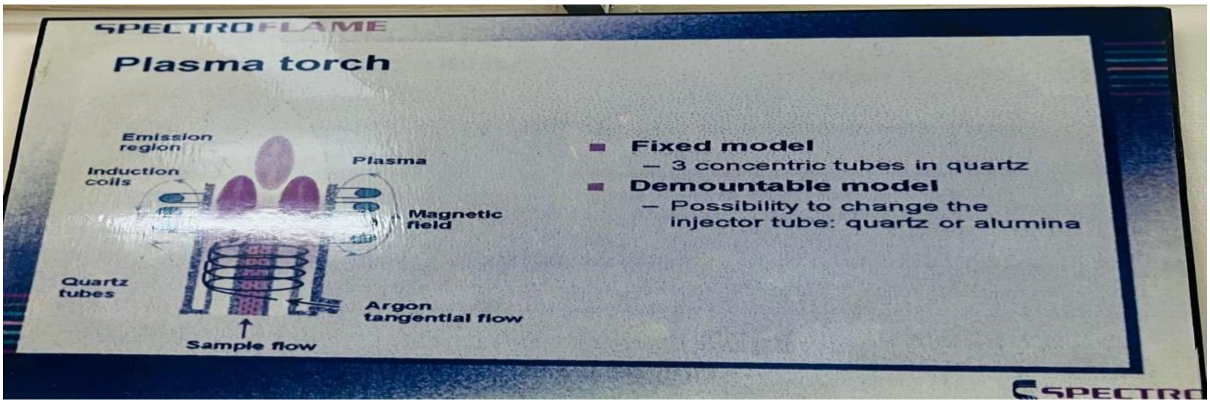


Figure 6 Plasma Torch Concept

✞ Purpose in Industry:

ICP-OES is used for:

- Multi-metal analysis in water, environmental samples, and raw materials

- Trace-level detection (ppm or ppb)
- Monitoring impurities in production processes **Classical Method Replaced:**

ICP-OES replaces:

- Redox titrations for oxidizing/reducing metal ions (e.g., Fe^{2+}/Fe^{3+})
- EDTA complexometric titrations for Ca^{2+}, Mg^{2+}, Zn^{2+}, etc.
- Multiple separate titrations that were time-consuming and less sensitive

➢ Atomic Absorption Spectroscopy (AAS)

AAS is an analytical instrument used for the quantitative detection of specific metal ions in a sample. It is highly accurate for measuring metals like iron (Fe), copper (Cu), zinc (Zn), lead (Pb), calcium (Ca), and magnesium (Mg) even at trace levels.

Figure 7 AAS (At CSIR-CGCRI)

✞ Working Principle:

In AAS, the sample is atomized in a flame or graphite furnace. A light beam from a hollow cathode lamp (specific to the metal being measured) passes through the atomized sample. The atoms absorb part of the light, and the amount of light absorbed is proportional to the metal's concentration in the sample.

✞ Purpose in Industry:

AAS is used in:

- **Water and wastewater testing** (e.g., for lead, arsenic, or iron)
- **Food and beverage industry** to monitor trace minerals
- **Pharmaceutical and chemical industries** to check raw material purity
- **Metal analysis** in quality control

Classical Method Replaced:

AAS replaces:

- Redox titrations (e.g., permanganate titration for Fe^{2+})
- Gravimetric analysis for metal content
- EDTA titrations for divalent/trivalent metals

Conclusion

The skill development program at CSIR-CGCRI provided a valuable hands-on learning experience in key areas of materials science and process engineering. We gained practical insights into the functioning and design of heating elements in furnaces, essential for high-temperature applications. Additionally, we explored the chemical characterization techniques used to analyze glass and ceramic materials, deepening our understanding of their composition and properties. The program also introduced us to essential concepts in process control, including feedback loops and the calibration of temperature sensors such as thermocouples. Overall, this training has enhanced our technical knowledge and prepared us for further work in research and industrial environments.