ASTRO IIT KANPUR

Summer Project

COSMIC QUARRY

Midterm Report

Mentors

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Abstract

This documentation of the mid-evaluation provides the details of concepts taught in this project.

Contents

1 What is Astronomy

Astronomy is the science of studying everything beyond Earth, like stars, planets, moons, and galaxies. It helps us understand how the universe began, how it works, and what it's made of. Using physics, math, and chemistry, astronomy explains the behavior and nature of space objects. From ancient times to today, it has amazed people and continues to reveal new things about the cosmos.

1.1 History Of Astronomy

History of Astronomy dates back to ancient Greeks who linked it to mathematics and created geometrical models to understand the celestial motions.

The astronomers of Ancient Greek gave the various theories and geometrical model of earth and solar system as per their observation and believes.

- **Pythagoras**
  Pythagoras was the earliest known astromer. He placed astronomy as the one of the four major fields of mathematics. He was the first person to proposed that earth was spherical.

- **Aristotle**
  He was the first person to propose that the earth is spherical in shape.He believed that the earth is at the centre of the universe and gave the geocentric model of the earth.

- **Ptolemy**
  He gave the geometrcical reasoning for the geocentric model of the earth and put the earth at slight eccentric position in the solar system.

- **Copernicus**
  He gave the heliocentric model of the universe in which the sun was placed at the centre of the solar system.

- **Tycho Brahe**
  He collected the extensive data about the motion of the stars, moons and planets. He observed the celestial objects without using telescope but gave the pretty correct obsecrvations.

- **Kepler**
  He used the extensive data of the Tycho Brahe to give the laws regarding planetary motion. He determined that the orbits were elliptical and not circular.

- **Galileo**
  He was the first person to observe the night sky with the telescope. He supported the heliocentric model of the solar system and observed various phenomenons with his telescope.

- **Sir Isaac Newton**
  Newton gave the theories of the motion of objects and explained the reason as to why objects follow the particular trajectory. He gave the three laws of motion and the law of universal gravitation.

- **Edwin Hubble**
  He was able to measure the distance to observe celestial objects. He discovered milky way galaxy and provided evidence to suggest that the galaxies are moving away from us.

- **Georges Lemaitre**
  He suggest that the universe must be continuously expanding and gave the evidence for the hubble's work. He proposed the theory of Big Bang.

1.2 Origin of Universe

So it all begins with the big bang. Big bang theory explains the origin of universe as to how it came into existence. he Big Bang is the main scientific theory for how the universe began. It says the universe started about 13.8 billion years ago from a very hot, dense point called a "singularity" and has been expanding ever since.

- **Initial State:** The universe began as a tiny, infinitely dense and hot point—smaller than a subatomic particle.
- **Expansion:** In a fraction of a second, this point began to expand rapidly, a process known as *cosmic inflation*. This expansion was not an explosion in space, but rather an expansion of space itself.
- **Cooling and Formation:** As the universe expanded, it cooled down, allowing particles to form. These particles eventually combined to form atoms, primarily hydrogen, helium, and small amounts of lithium.
- **Formation of Structures:** Gravity pulled these atoms together to form stars and galaxies. Over billions of years, these structures evolved into the universe we see today.
- **Cosmic Microwave Background:** About 380,000 years after the Big Bang, the universe had cooled enough for atoms to form, allowing light to travel freely. This leftover radiation, called the *cosmic microwave background (CMB)*, is still detectable and serves as strong evidence for the Big Bang.
- **Ongoing Expansion:** The universe continues to expand, with galaxies moving away from each other. This expansion is observed through the redshift of light from distant galaxies.

Discovery of Big Bang

The idea of the Big Bang began in the 1920s with Aleksandr Friedmann and Georges Lemaître, who proposed that the universe is expanding. In the 1940s, George Gamow and his team helped develop the theory further and predicted the cosmic microwave background. The name "Big Bang" was coined by astronomer Fred Hoyle, who actually didn't believe in the theory and used the term sarcastically.

Observations support the Big Bang theory in several ways. In the 1920s, Edwin Hubble found that galaxies are moving away from us, showing the universe is expanding. In 1965, scientists discovered the cosmic microwave background—faint radiation left over from the early universe. Also, the amounts of hydrogen, helium, and lithium we see today match what the Big Bang theory predicted.

1.3 Death Of Universe

The "death of the universe" is a way scientists describe how everything in the universe might end, far in the future. Right now, the universe is expanding, and galaxies are moving away from each other. But what will happen in the very, very distant future? There are a few main ideas, or possibilities, that scientists think could happen. Here are the three most popular ones: the Heat Death, the Big Rip, and the Big Crunch.

The Heat Death

This is the most widely accepted idea. In the Heat Death scenario, the universe keeps expanding forever. Stars will eventually burn out, and everything will get colder and colder. After trillions of years, there will be no more energy left for anything to happen. The universe will become dark, empty, and very cold—a place where nothing can live or change. This is also called the "Big Freeze."

The Big Rip

The Big Rip is a more dramatic ending. In this idea, the universe's expansion doesn't just continue—it speeds up more and more. Eventually, the force pulling everything apart becomes so strong that galaxies, stars, planets, and even atoms themselves are ripped apart. Everything is torn to pieces, and the universe ends in chaos.

The Big Crunch

The Big Crunch is almost the opposite of the Big Rip. Here, instead of expanding forever, the universe's expansion slows down and then reverses. Everything starts to come back together, and the universe shrinks. Eventually, all matter and energy collapse into a single, incredibly hot and dense point—like how the universe began with the Big Bang. This would be the end of the universe as we know it.

2 Telescope

A telescope is an instrument designed to form magnified images of distant objects, making them appear closer and brighter.

2.1 Types of Telescopes

There are three main types of telescopes, each distinguished by how they collect and focus light:

1. **Refracting Telescopes (Refractors)**: Use lenses to bend (refract) light into focus.
2. **Reflecting Telescopes (Reflectors)**: Use mirrors to reflect and focus light.
3. **Catadioptric or Compound Telescopes**: Combine lenses and mirrors to focus light, offering benefits of both refractors and reflectors.

Other specialized types include:

- **Radio Telescopes**: Detect radio waves instead of visible light.
- **X-ray and Gamma-ray Telescopes**: Observe high-energy electromagnetic radiation from space.

2.2 Principle of Working

The principle behind a telescope is straightforward: it gathers light from a distant source using a large lens or mirror (the objective), forming a bright, magnified, and often inverted image at the focal point. This image is then further magnified by the eyepiece lens for viewing by the observer.

- In **refractors**, light passes through a convex lens, which bends and focuses the light to a point.
- In **reflectors**, light is collected by a concave mirror, reflected to a focal point, and then directed to the eyepiece.
- In **compound telescopes**, both mirrors and lenses are used to optimize image quality and compactness.

2.3 Basic Components of a Telescope

Here are the main parts of a telescope and a simple explanation of each:

- **Optical Tube**: This is the main body of the telescope. It holds all the important optical parts like lenses or mirrors and keeps them in the right position. It also protects them from dust and light that can spoil the image.
- **Objective Lens or Mirror**: This is the main part that gathers light from distant objects. In refracting telescopes, it is a big lens; in reflecting telescopes, it is a big mirror. Its job is to collect as much light as possible and focus it to form an image.
- **Eyepiece**: The eyepiece is the part you look through. It magnifies the image made by the objective lens or mirror so you can see details more clearly.
- **Focuser**: The focuser lets you move the eyepiece in and out to make the image sharp and clear. It helps you adjust the focus for your eyes.
- **Finderscope**: This is a small telescope attached to the main tube. It helps you aim the telescope at the object you want to see, making it easier to find things in the sky.
- **Mount**: The mount holds the telescope steady and allows you to move it smoothly to follow objects in the sky. It can be simple or complex, depending on the type of telescope.
- **Tripod**: The tripod is the stand that supports the mount and the telescope. It keeps everything stable and at a good height for viewing.

2.4 Altazimuth Axis and Equatorial Axis in Telescopes

Telescopes use different mount types to move and track objects in the sky. The two main types are:

Altazimuth Axis (Alt-Az Mount)

- **How it moves:** Moves up-down (altitude) and left-right (azimuth).
- **Use:** Very simple to operate—great for beginners.
- **Pros:**
  1. Easy to use and understand
  2. Good for daytime and casual night sky viewing
  3. Affordable and lightweight
- **Cons:**
  1. Hard to track stars smoothly for long periods
  2. Not ideal for astrophotography
  3. Trouble tracking objects directly overhead (zenith)
- **Used for:** Terrestrial viewing, beginner telescopes, large telescopes with computer control.

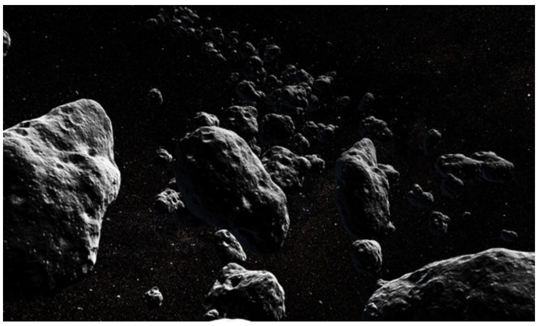
Equatorial Axis (Equatorial Mount)

- **How it moves:** One axis (polar) follows Earth's rotation; the other (declination) adjusts position.
- **Use:** Needs alignment with Earth's pole; better for tracking stars.
- **Pros:**
  1. Tracks stars easily using just one motor
  2. Great for astrophotography and serious observing
  3. Matches sky maps and star charts
- **Cons:**
  1. More complex and heavier
  2. Needs careful setup
  3. Larger mounts need counterweights
- **Used for:** Amateur and professional astronomy, astrophotography, research.

3 Asteroids

3.1 What are asteroids

Asteroids are the rocky remnants of material left over from the formation of the solar system and its planets approximately 4.6 billion years ago.
Asteroids orbit the sun in highly flattened, or "elliptical" circles, often rotating erratically, tumbling and falling through space.



3.2 Types of Asteroids

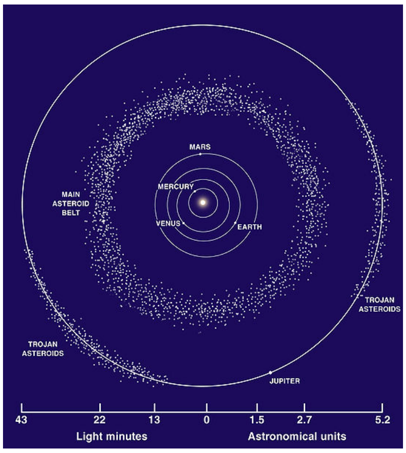
- **C-type (carbonaceous):**
  C-type asteroids are the most common type, making up about 75% of all known asteroids. They are mostly found in the outer part of the asteroid belt. These asteroids are rich in carbon, which gives them a very dark surface. They also contain a lot of water and other minerals. Because of their composition, C-type asteroids are thought to be very old and similar to the material that formed the early solar system. Their dark color is due to the high amount of carbon and organic compounds they contain.

- **S-type (silicaceous):**
  S-type asteroids are the second most common type, making up about 17% of all asteroids. They are mostly found in the inner part of the asteroid belt, closer to the Sun. S-type asteroids are made mainly of silicate rocks and metals like iron and magnesium. They are brighter than C-type asteroids because of their rocky, metallic content. Their surfaces are similar to stony meteorites found on Earth. S-type asteroids have a higher density and are less rich in carbon and water compared to C-types.

- **M-type (metallic):**
  M-type asteroids are less common than C-type and S-type asteroids. They are made mostly of metals, especially nickel and iron. These asteroids are found in the middle region of the asteroid belt. M-type asteroids are thought to be the remnants of the metallic cores of larger bodies that were broken apart by collisions. They have a shiny, metallic surface and are denser than both C-type and S-type asteroids.

3.3 Asteroid Belt

The asteroid belt is a region between Mars and Jupiter where millions of rocky bodies orbit the Sun. It includes objects of various sizes, the largest being Ceres, a dwarf planet. The belt likely formed from material that couldn't become a planet due to Jupiter's gravity. Despite its name, it's mostly empty space, with asteroids widely spaced. It separates the inner rocky planets from the outer gas giants and offers clues about the Solar System's formation.



3.4 The Main Asteroid Belt

Location & Structure

The main asteroid belt is a torus-shaped region between the orbits of Mars and Jupiter, roughly spanning 2.06 to 3.28 astronomical units (AU) from the Sun. It marks the boundary between the inner rocky planets and the outer gas giants.

Composition & Population

It contains millions of asteroids—rocky, metallic, and carbon-rich bodies—ranging from tiny pebbles to the dwarf planet Ceres, which is about 950 km in diameter. The four largest objects (Ceres, Vesta, Pallas, and Hygiea) contain over 60% of the belt's total mass.

Distribution

Despite popular images, the belt is mostly empty space; asteroids are, on average, about 965,600 km apart. The total mass of the belt is only about 3% that of the Moon.

Kirkwood Gaps

These are gaps in the belt's distribution caused by gravitational resonances with Jupiter, where asteroids are less likely to be found. Major gaps correspond to simple fractions of Jupiter's orbital period (e.g., 3:1, 2:1 resonances).

3.5 Asteroid and Small Body Groups

Trojans (Asteroids Sharing Jupiter's Orbit)

- Large groups of asteroids that share Jupiter's orbit around the Sun.
- They are found in two clusters: one 60° ahead of Jupiter (L4 point) and one 60° behind (L5 point).
- These points are called **Lagrange points**, where the gravity of Jupiter and the Sun balance out, allowing asteroids to stay in stable positions.
- The Trojans have been in these positions for billions of years and are thought to be leftover material from the early solar system.
- There are hundreds of thousands of these asteroids, and they can help scientists learn about how the solar system formed.

Kuiper Belt

- The Kuiper Belt is a region beyond Neptune, stretching from about 30 to 50 astronomical units (AU) from the Sun.
- It contains many icy bodies, including dwarf planets like Pluto, Haumea, Makemake, and Eris.
- The Kuiper Belt is the source of short-period comets, which have orbits that bring them close to the Sun more frequently.
- Objects here are mostly made of ice and rock, and the region is similar to the asteroid belt but much larger and colder.

3.6 Missions to study asteroids

NASA Lucy Mission

- **Objective**: Lucy is designed to explore a record number of asteroids, particularly the Jupiter Trojan asteroids, which share Jupiter's orbit around the Sun. These bodies are considered "fossils" of the early solar system.
- **Recent Milestone**: On April 20, 2025, Lucy performed a close flyby of asteroid 52246 Donaldjohanson, capturing detailed images and collecting data on its composition and surface features.
- **Future Plans**: Lucy will continue toward the distant Trojan asteroids, with additional flybys planned through the late 2020s.

ESA Hera Mission

- **Objective**: Hera is part of the Asteroid Impact and Deflection Assessment (AIDA) collaboration, focusing on the Didymos binary asteroid system. Its primary goal is to study the effects of asteroid deflection techniques, contributing to planetary defense strategies.
- **Recent Activity**: Hera performed a gravity assist flyby of Mars in March 2025 en route to the Didymos system.

China's Tianwen-2 (ZhengHe)

Objective: Launched in May 2025, Tianwen-2 is a combined asteroid sample-return and comet probe mission. It aims to rendezvous with a near-Earth asteroid, collect samples, and return them to Earth, as well as study a comet.

AstroForge Brokkr-2

Objective: Launched in February 2025, Brokkr-2 was a private mission intended to perform a flyby of a near-Earth asteroid and determine if the asteroid is metallic. The mission faced communication issues and was unable to complete its objectives

4 Asteriod mining

4.1 What is Asteroid Mining?

Asteroid mining refers to the extraction of valuable resources and raw materials from asteroids. These celestial bodies, remnants of the early solar system, contain a wide range of minerals and elements that are highly sought after for industrial and technological purposes.

Materials Found in Asteroids

- **Metals:** Precious metals such as platinum, gold, and rhodium, as well as industrial metals like iron, nickel, and cobalt.
- **Water:** Found in the form of ice, which can be converted into hydrogen and oxygen for fuel or used to support life in space.
- **Silicates:** Useful for construction in space or for producing advanced materials.

Methods of Mining

- **Surface Mining:** Extracting resources from the surface of asteroids.
- **Drilling:** Penetrating below the surface to access more concentrated materials.
- **Capture and Redirect:** Bringing small asteroids or asteroid fragments into a stable orbit for easier access and processing.

Challenges

- **Technical Hurdles:** Developing reliable mining equipment for microgravity and harsh space environments.
- **Economic Feasibility:** High initial costs of exploration and extraction technologies.
- **Legal and Ethical Concerns:** Questions about property rights, resource distribution, and environmental impacts.

4.2 Significance of Asteroid Mining

Asteroid mining holds the potential to revolutionize industries by providing an abundant supply of rare materials, reducing environmental strain on Earth, and paving the way for sustainable human presence in space. With advances in technology and international cooperation, it could become a cornerstone of the space economy in the future.

Access to Critical and Rare Resources

Asteroids contain substantial quantities of critical minerals and metals—such as platinum, gold, cobalt, nickel, and rare earth elements—that are essential for modern technologies, including electronics, renewable energy systems, and advanced manufacturing.

Environmental and Sustainability Benefits

Mining asteroids could reduce the need for destructive terrestrial mining, which often leads to pollution, habitat destruction, and social conflict. By sourcing metals from space, the environmental impact on Earth's ecosystems could be minimized, supporting sustainable growth and the clean energy transition.

Scientific and Strategic Value

Studying and mining asteroids can improve our understanding of the early solar system and planetary formation. Securing access to space resources is strategically important for national security and technological leadership, reducing reliance on unstable or hostile countries for critical materials.

4.3 Economic impacts of Asteroid Mining

Asteroid mining represents a frontier in resource acquisition, where minerals and other valuable materials are extracted from celestial bodies. With advancements in space technology and increasing resource demands on Earth, asteroid mining has transitioned from a speculative concept to a potentially transformative industry. This report explores the economic implications, challenges, and potential benefits of asteroid mining.

Economic Potential of Asteroid Mining

Asteroids are rich in resources, including precious metals like platinum, gold, and rare earth elements, as well as industrial materials such as iron, nickel, and cobalt. Some asteroids are also believed to contain water, which can be converted into rocket fuel, enabling further space exploration.

Market Value of Extracted Resources

The economic potential of asteroid mining is staggering. For example:

- **Precious Metals:** Platinum-rich asteroids could yield metals worth billions of dollars. A single asteroid, like 16 Psyche, is estimated to contain resources valued in the trillions.
- **Rare Earth Elements:** These are critical for the production of electronics and renewable energy technologies, addressing supply chain vulnerabilities on Earth.
- **Water Resources:** Extracted water can reduce the costs of space missions by providing in-situ resources for fuel and life support systems.

Economic Multipliers

Asteroid mining could create a multiplier effect in various sectors:

- **Space Infrastructure:** Development of mining operations will require advancements in robotics, spacecraft, and propulsion systems.
- **Global Supply Chains:** Increased availability of rare resources can stabilize markets and reduce geopolitical tensions over resource control.
- **New Industries:** Beyond mining, sectors like in-space manufacturing and interplanetary colonization would emerge, expanding economic horizons.

4.4 Challenges in the path of asteroid mining

Technical Challenges

Asteroid mining faces numerous technical hurdles:

- **Exploration:** Identifying viable asteroids with high resource density requires advanced telescopes and exploration missions.
- **Extraction Technology:** Mining in microgravity and the harsh space environment necessitates innovative machinery and techniques.
- **Resource Transport:** Safely transporting extracted materials to Earth or other locations is logistically complex and expensive.

Economic Viability

While the potential value of asteroid mining is immense, the initial costs are prohibitive:

- **High Initial Investment:** Developing and deploying mining missions involves significant capital expenditure.
- **Market Saturation Risk:** A sudden influx of certain materials could depress market prices, reducing profitability.
- **Legal and Regulatory Uncertainty:** The legal framework for space mining is still evolving, with questions about property rights and resource ownership remaining unresolved.

Environmental and Ethical Considerations

- **Space Debris:** Mining activities could increase the risk of space debris, posing threats to existing satellites and space stations.
- **Economic Inequality:** If concentrated in the hands of a few corporations or nations, asteroid mining could exacerbate global wealth disparities.

4.5 Benefits of Asteroid Mining to Earth's Economy

Alleviating Resource Scarcity

Asteroid mining offers a solution to the growing scarcity of terrestrial resources. By supplementing Earth's mineral supplies, it can:

- **Reduce Environmental Impact:** Lower dependence on Earth-based mining reduces deforestation, habitat destruction, and pollution.
- **Stabilize Resource Markets:** Increased resource availability can lead to more predictable pricing and reduced economic volatility.

Transformative Impact on Space Economy

Asteroid mining is a catalyst for the broader space economy:

- **In-Situ Resource Utilization (ISRU):** Enables sustainable space exploration and reduces the costs of interplanetary missions.
- **Creation of New Markets:** Space tourism, construction of space habitats, and energy generation (e.g., solar power satellites) would benefit from the availability of space-sourced materials.

4.6 A Path Forward: Building an Asteroid Mining Economy

Strategic Investments

Governments and private entities must collaborate to:

- **Fund Research and Development:** Investments in robotics, AI, and propulsion technologies are essential.
- **Encourage Public-Private Partnerships:** Cooperation can accelerate progress and distribute risks.

Establishing a Regulatory Framework

Clear and enforceable laws governing asteroid mining are critical to:

- **Ensure Fair Access:** Prevent monopolization and promote equitable resource distribution.
- **Promote Sustainability:** Minimize environmental risks and ensure responsible extraction practices.

International Cooperation

Asteroid mining is inherently global, requiring collaboration between nations to:

- **Share Technological Expertise:** Pool resources for mutual benefit.
- **Avoid Conflict:** Establish treaties to prevent disputes over asteroid ownership and exploitation rights.

4.7 Advancing Technologies in Asteroid Mining

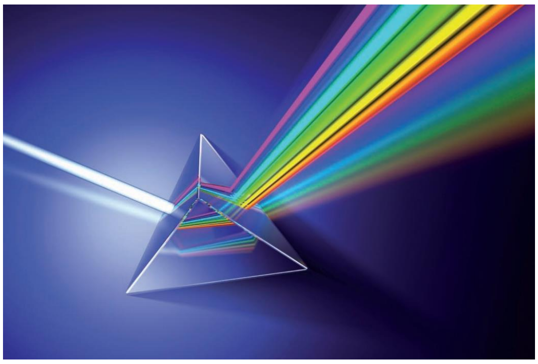
Asteroid mining is progressing rapidly with the development of innovative technologies designed to enhance the efficiency and feasibility of extracting resources from celestial bodies. These advancements are redefining the scope of space resource utilization.

- **Spectroscopy and AI-driven Analysis:** Modern spectroscopy enables precise identification of minerals on asteroids by analyzing their spectral signatures. Machine learning algorithms further refine this process by identifying patterns and predicting mineral compositions with high accuracy.
- **China's Multifunctional Space Mining Robot:** A cutting-edge robot developed by China integrates six legs, three wheels, and claw-like appendages for navigating the rugged terrain of asteroids. This multi-modal mobility ensures operational stability in low-gravity environments.
- **On-Site Processing Techniques:** Emerging technologies allow asteroid materials to be processed and refined on-site. These processes eliminate the need to transport raw materials to Earth, significantly reducing costs and logistical challenges.
- **Ion Propulsion and Asteroid Redirect Missions:** Advanced propulsion technologies, such as ion thrusters, enable efficient transportation of mined resources. Asteroid redirect missions can bring smaller asteroids or portions of larger ones into orbits that facilitate resource extraction and transportation.

With continuous technological advancements, asteroid mining is transitioning from an ambitious concept to a practical and economically viable industry. These developments not only improve the efficiency of space mining operations but also pave the way for sustainable space exploration and resource utilization.

5 Spectroscopy

Spectroscopy is a scientific technique used to study the interaction between matter and electromagnetic radiation (light) as a function of wavelength or frequency. It is a cornerstone method in physics, chemistry, astronomy, and planetary science for analyzing the composition, structure, and physical properties of substances.



5.1 How Spectroscopy Works

- When light interacts with a material, it can be absorbed, transmitted, or reflected.
- Different materials absorb and reflect specific wavelengths of light depending on their molecular and atomic structure.
- By analyzing the spectrum—the distribution of light intensity across different wavelengths—scientists can identify the presence and abundance of various elements and compounds.

5.2 Different Types of Spectroscopy

Spectroscopy encompasses a wide range of techniques used to analyze how matter interacts with different forms of energy. These techniques help determine a substance's composition, molecular structure, dynamics, and physical properties. Spectroscopy can be categorized by the nature of interaction (absorption, emission, scattering), spectral region, or the type of incident energy.

On the bais of Interaction

- **Absorption Spectroscopy:** This technique measures the amount of electromagnetic radiation absorbed by a substance at specific wavelengths. When a molecule absorbs energy, electrons or vibrational states are excited to higher energy levels. Common techniques include UV-Visible (UV-Vis), Infrared (IR), and X-ray absorption spectroscopy. These are widely used to identify functional groups, quantify solutes, and investigate molecular bonding environments.

- **Emission Spectroscopy:** In this method, atoms or molecules are first excited by an external energy source (e.g., heat or light) and then emit radiation as they return to a lower energy state. Emission spectra are unique to elements or compounds, making this technique valuable for qualitative and quantitative analysis. Techniques include atomic emission spectroscopy and fluorescence spectroscopy.

- **Scattering Spectroscopy:** Scattering occurs when incident light interacts with a sample and is redirected in different directions. The scattered light may carry information about vibrational or rotational transitions. Raman spectroscopy is a widely used form of inelastic scattering spectroscopy, providing highly specific molecular fingerprints and structural details.

On the bais of Electromagnetic Spectrum Region

- **Gamma-ray Spectroscopy:** Probes nuclear transitions and is widely used in nuclear physics and astrophysics to investigate radioactive decay, nuclear structure, and cosmic phenomena.

- **X-ray Spectroscopy:** Analyzes transitions involving core electrons. It is extensively used for elemental analysis, crystallography, and in medical diagnostics such as X-ray imaging and computed tomography (CT).

- **Ultraviolet (UV) Spectroscopy:** Sensitive to electronic transitions in atoms and molecules, particularly $\pi \to \pi^*$ and $n \to \pi^*$ transitions. It is commonly used in chemical and biochemical analysis, including drug testing and protein studies.

- **Visible Spectroscopy:** Measures light absorption and emission in the visible range (400–700 nm). It is essential for analyzing solution color, concentration determination, and studying pigments and dyes.

- **Infrared (IR) Spectroscopy:** Probes molecular vibrations and rotations, enabling the identification of functional groups in organic and inorganic compounds. Widely used in chemistry, environmental science, and materials analysis.

- **Microwave Spectroscopy:** Examines rotational transitions in polar molecules. It provides insights into molecular geometry and is applied in physical chemistry, atmospheric studies, and astrochemistry.

- **Radio Wave Spectroscopy:** Covers techniques such as Nuclear Magnetic Resonance (NMR) and Electron Paramagnetic Resonance (EPR). These techniques reveal detailed molecular structure, electron environments, and dynamics in both solution and solid-state samples.

On the basis of Energy Source

- **Electron Spectroscopy:** Instead of photons, these techniques use electron beams to investigate materials. Electron Energy Loss Spectroscopy (EELS) and Auger Electron Spectroscopy (AES) are commonly used for surface analysis, band structure probing, and studying electronic excitations.

- **Neutron Spectroscopy:** Neutron beams interact with atomic nuclei, providing insights into atomic motion and magnetic properties. This technique is especially useful in condensed matter physics for examining crystalline and amorphous materials.

- **Acoustic Spectroscopy:** Involves sound waves (typically ultrasonic) to study the mechanical and structural properties of materials, such as elasticity, viscosity, and particle size in colloids or suspensions.

Some Specialized Techniques

- **Nuclear Magnetic Resonance (NMR) Spectroscopy:** NMR utilizes radiofrequency waves in the presence of a strong magnetic field to analyze the magnetic properties of atomic nuclei. It provides high-resolution structural information of organic compounds and is widely used in chemistry, medicine (e.g., MRI), and drug development.

- **Fluorescence Spectroscopy:** This emission technique relies on the ability of certain substances to absorb light at one wavelength and re-emit it at a longer wavelength. It is highly sensitive and used extensively in biochemical assays, environmental monitoring, and medical diagnostics.

- **Raman Spectroscopy:** Based on inelastic scattering of monochromatic light, typically from a laser. It reveals vibrational, rotational, and other low-frequency modes in molecules. Raman is complementary to IR spectroscopy and is often used for chemical fingerprinting, especially in biological and pharmaceutical fields.

Summary Table: Common Spectroscopy Types

Some of the common spectroscopy techniques are summarized in the following table.

Technique	Main Principle	Typical Use Case
UV-Vis Spectroscopy	Absorption	Qualitative/quantitative chemical analysis, DNA/protein quantification
IR Spectroscopy	Absorption	Identification of molecular bonds and functional groups
Raman Spectroscopy	Scattering	Characterization of molecular vibrations, stress/strain in materials
NMR Spectroscopy	Magnetic resonance	Molecular structure elucidation, metabolic profiling, MRI
X-ray Spectroscopy	Absorption/emission	Elemental mapping, material and structural analysis
Electron Spectroscopy	Electron interaction	Surface composition, oxidation states, nanomaterials
Neutron Spectroscopy	Neutron interaction	Crystalline structure, diffusion studies, magnetic analysis
Fluorescence Spectroscopy	Emission	Trace analysis in biology, medical imaging, diagnostics

Table 1: Summary of Common Spectroscopy Techniques

5.3 Significance of Spectroscopy

Spectroscopy is a foundational technique in science and technology, with its significance rooted in its ability to reveal the composition, structure, and properties of matter by analyzing how it interacts with electromagnetic radiation.

Identification and Analysis of minerals

- Every element and molecule has a unique spectral signature—distinct patterns of light absorption or emission at specific wavelengths. This allows scientists to unambiguously identify and quantify elements and compounds in a sample, even at trace levels.
- Spectroscopy is critical for chemical analysis, enabling the detection of unknown substances and the study of molecular structures and electron configurations.

Wide-Ranging Applications

- Astronomy: Spectroscopy allows astronomers to determine the composition, temperature, motion, and other properties of stars, planets, and galaxies by analyzing their light spectra. It is essential for studying distant objects and understanding the universe's evolution.
- Environmental Science: Used to detect pollutants and monitor air and water quality by identifying specific chemical signatures.
- Medicine and Biology: Enables non-invasive diagnostics (e.g., blood analysis, tissue imaging), protein structure studies, and disease detection.
- Materials Science: Used to characterize new materials, study molecular interactions, and ensure quality control in manufacturing.

Fundamental Research and Discovery

- Spectroscopy has been pivotal in developing quantum mechanics and understanding atomic and molecular behavior.
- It provides insights into physical and chemical processes, driving innovation and discovery in nearly every scientific discipline.

Precision and Sensitivity

- Modern spectroscopic techniques can detect substances at extremely low concentrations and provide detailed information about molecular dynamics, energy levels, and interactions.
- High-resolution instruments allow for the analysis of complex mixtures and subtle spectral features, advancing research and technology.

5.4 Spectroscopy of Celestial Objects

Spectroscopy is a fundamental technique in astronomy, enabling scientists to study celestial objects by analyzing the light they emit, absorb, or reflect across the electromagnetic spectrum. This method provides a wealth of information about the universe that cannot be obtained through imaging alone.

Procedure involved in spectroscopy of planets

Spectroscopy of celestial objects is accomplished by collecting light from astronomical sources and dispersing it into its component wavelengths to produce a spectrum. This spectrum is then analyzed to extract information about the object's composition, motion, temperature, and other physical properties.

Step-by-Step Process

1. **Light Collection**
   Telescopes are used to gather as much light as possible from distant celestial objects, focusing it onto the entrance of a spectrograph.

2. **Dispersion of Light**
   The focused light enters a spectrograph, where it is dispersed into its component wavelengths using a dispersive element:
   Prisms: Separate light by refraction, bending different wavelengths by different amounts.
   Diffraction Gratings: Use interference to spread light into a spectrum; these are more common in modern astronomy due to their efficiency and precision.

3. **Recording the Spectrum**
   The dispersed light is projected onto a detector, typically a charge-coupled device (CCD), which records the intensity of light at each wavelength.
   Historically, photographic plates were used, but electronic detectors now provide higher sensitivity and dynamic range.

4. **Calibration**
   Calibration is crucial for accurate measurements:
   Wavelength Calibration: Observing emission lines from a gas-discharge lamp with known wavelengths (e.g., Neon or Argon) to assign wavelength values to the recorded spectrum.
   Flux Calibration: Observing standard stars to correct for instrumental and atmospheric effects, ensuring the measured intensities reflect the true brightness of the object at each wavelength.

5. **Data Analysis** The resulting spectrum is analyzed to identify absorption or emission lines, measure their positions (for velocity and redshift), and their strengths (for composition and abundance).

What Information Does Spectroscopy Reveal?

- Chemical Composition: Each element and molecule emits or absorbs light at specific wavelengths, producing unique spectral lines. By examining these lines, astronomers can identify the elements and compounds present in stars, planets, nebulae, and galaxies.
- Physical Properties: Spectroscopy reveals temperature, density, pressure, and magnetic fields of celestial objects by analyzing the characteristics of their spectral lines.
- Motion and Velocity: The Doppler effect causes spectral lines to shift if an object is moving toward or away from us (blueshift or redshift). This allows astronomers to measure the speed and direction of stars, galaxies, and gas clouds, and to study the expansion of the universe.
- Stellar and Galactic Evolution: By tracking changes in spectra over time, scientists can study processes such as star formation, supernova explosions, and the evolution of galaxies.
- Atmospheric and Surface Analysis: Spectroscopy can determine the composition of planetary atmospheres and surfaces, detect exoplanet atmospheres, and search for biosignatures or signs of habitability.

Application of spectroscopy in astronomy

- Stars: Spectra reveal a star's composition, temperature, luminosity, rotation speed, and even the presence of companion stars or exoplanets.
- Planets and Moons: Spectroscopy identifies atmospheric gases and surface minerals, helping to assess habitability and geological history.
- Nebulae and Galaxies: The technique measures the velocity, density, and composition of interstellar gas and dust, and helps map the structure and evolution of galaxies.
- Exoplanets: By analyzing starlight filtered through an exoplanet's atmosphere during a transit, astronomers can detect molecules such as water vapor, methane, or oxygen, which are important for assessing habitability.

6 Optical Spectroscopy

Optical spectroscopy is a broad set of analytical techniques that study the interaction between light and matter within the ultraviolet (UV), visible (Vis), and infrared (IR) regions of the electromagnetic spectrum, typically ranging from 190 nm to 3000 nm. These techniques are fundamental to fields such as chemistry, physics, materials science, biology, and astronomy for analyzing composition, structure, and physical properties of substances.

6.1 Principle of Optical Spectroscopy

Optical spectroscopy is based on the absorption, emission, reflection, or scattering of electromagnetic radiation by atoms or molecules. When light interacts with a sample, certain wavelengths are absorbed or emitted based on the energy transitions between electronic, vibrational, or rotational states. By measuring light intensity as a function of wavelength, a spectrum is generated that encodes detailed information about the sample's molecular or atomic structure.

6.2 Instrumentation and Setup

A typical optical spectroscopy system consists of the following components:

- **Light Source:** May be monochromatic (e.g., lasers) or broadband (e.g., tungsten or deuterium lamps), depending on the application.
- **Sample Holder:** Holds the sample in the optical path. Common holders include cuvettes for liquids and mounts or slides for solids and thin films.
- **Dispersive Element:** A prism or diffraction grating separates incoming light into its constituent wavelengths for spectral analysis.
- **Detector:** Captures the light intensity across the spectrum. Typical detectors include photodiodes, photomultiplier tubes (PMTs), and charge-coupled devices (CCDs).
- **Spectrometer:** Integrates the source, dispersive element, and detector to produce and analyze the spectrum.

6.3 Working of Optical Spectroscopy

1. **Light Generation:** A suitable light source emits photons directed toward the sample.
2. **Sample Interaction:** The sample interacts with the light through absorption, emission, transmission, or reflection, depending on its properties.
3. **Spectral Separation:** The light is dispersed into its individual wavelengths using a diffraction grating or prism.
4. **Detection:** The resulting spectrum is recorded by a detector, measuring the intensity at each wavelength.
5. **Analysis:** Peaks in the spectrum correspond to transitions in the sample and can be interpreted to identify elements, functional groups, and molecular structures.

6.4 Applications of Optical Spectroscopy in Astronomy

- Chemical Composition of Celestial Objects
  By analyzing the absorption and emission lines in spectra, astronomers can determine the elements and molecules present in stars, planets, nebulae, and galaxies. This has enabled the identification of rare elements and the study of chemical evolution across cosmic time.

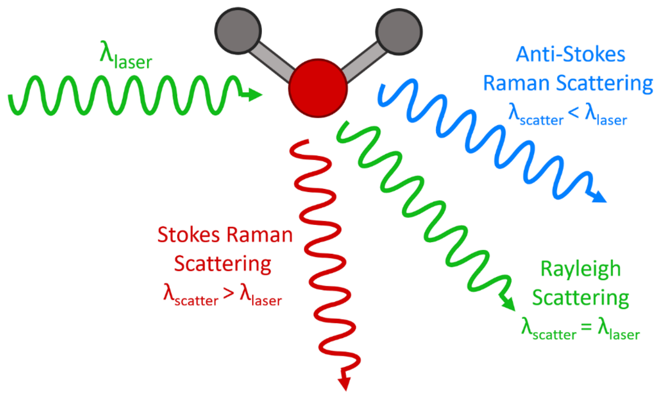
- Physical Properties: Temperature, Pressure, and Density
  The strength, shape, and ratios of spectral lines reveal the temperature, pressure, and density of stellar atmospheres, interstellar clouds, and other astronomical environments.

- Radial Velocity and Motion
  The Doppler shift of spectral lines allows astronomers to measure the velocity at which objects move toward or away from us. This is crucial for studying binary stars, galaxy rotation, and the expansion of the universe.

- Distance Measurement
  Spectroscopic redshifts are used to determine the distance to galaxies and quasars, playing a central role in mapping the large-scale structure of the universe.

7 Raman Spectroscopy

Raman spectroscopy is a powerful non-destructive analytical technique used to investigate vibrational, rotational, and other low-frequency modes in molecules and materials. It provides a molecular fingerprint for the identification and characterization of substances based on inelastic light scattering.



7.1 Principle of Raman Spectroscopy

When monochromatic light, typically from a laser, interacts with a sample, most photons are elastically scattered (Rayleigh scattering). However, a small fraction of around $\sim$1 in 10^7 photons undergoes inelastic scattering, resulting in an energy shift corresponding to molecular vibrational energies. This is known as **Raman scattering**.

- **Stokes Scattering:** Photons lose energy to the molecule, resulting in lower-frequency scattered light. The molecule transitions to a higher vibrational state.

- **Anti-Stokes Scattering:** Photons gain energy from the molecule, resulting in higher-frequency scattered light. The molecule transitions to a lower vibrational state.

These energy shifts are plotted as a Raman spectrum (intensity vs. wavenumber shift), which is characteristic of the molecular structure.

Polarizability Requirement: For a vibrational mode to be Raman-active, it must involve a change in the polarizability of the molecule's electron cloud. This contrasts with IR spectroscopy, which requires a change in dipole moment. Therefore, Raman and IR are complementary techniques.

7.2 Instrumentation

A typical Raman spectrometer comprises the following components:

- **Laser Source:** Provides monochromatic light in the visible, near-IR, or UV range.

- **Optical Components:** Lenses and mirrors to direct and focus the beam onto the sample and collect scattered light.

- **Filters:** Notch or edge filters to suppress Rayleigh scattering and isolate the inelastically scattered light.
- **Spectrometer:** Disperses the collected light by wavelength, typically using a diffraction grating.
- **Detector:** Usually a CCD (Charge-Coupled Device) to capture the Raman signal.

Advanced configurations may include a microscope for *micro-Raman spectroscopy*, allowing spatial resolution down to $\sim 1\ \mu\text{m}^2$.

7.3 Types of Raman Spectroscopy

- **Resonance Raman Spectroscopy (RRS):** The laser wavelength is tuned to coincide with an electronic transition in the sample, greatly enhancing the Raman signal.
- **Surface-Enhanced Raman Spectroscopy (SERS):** Uses roughened metal surfaces or nanoparticles to enhance weak Raman signals by factors of 10^6 to 10^{14}.
- **Tip-Enhanced Raman Spectroscopy (TERS):** Combines Raman with atomic force microscopy (AFM) for high-resolution, nanoscale chemical mapping.
- **Micro-Raman Spectroscopy:** Integrates Raman with microscopy for localized analysis and mapping of heterogeneous samples at the micrometer scale.
- **Stimulated Raman Spectroscopy (SRS):** Utilizes pulsed lasers to achieve faster, high-sensitivity imaging for biomedical applications.

7.4 Applications in Astronomy

- **Planetary Surface and Mineral Analysis**
  Raman spectroscopy is used on planetary missions to identify minerals, salts, and hydrated compounds on the surfaces of planets, moons, and asteroids. Its sensitivity allows for the detection of various minerals such as sulfates, chloride salts, layered silicates, and oxides, even distinguishing between different hydration states.
- **Exoplanet and Atmospheric Studies**
  Raman spectroscopy is being developed to study the atmospheres of exoplanets. By analyzing the light that passes through or is reflected from an exoplanet's atmosphere, scientists can detect molecular signatures and gain insights into atmospheric composition, chemistry, and potential habitability.
- **Analysis of Returned Extraterrestrial Samples**
  Raman spectroscopy is employed to analyze samples brought back to Earth by missions such as Stardust, Hayabusa, Hayabusa2, and OSIRIS-REx. Its non-destructive nature allows scientists to determine the molecular and mineralogical composition of these precious materials without damaging them.
- **Astrobiology and Organic Molecule Detection**
  The technique is adept at detecting organic molecules, including polycyclic aromatic hydrocarbons (PAHs), which are of astrobiological interest for understanding the origins of life and the chemical evolution of the universe.

7.5 Advantages over other Spectroscopy Techniques

- **Minimal Sample Preparation:** No need for pellets or thin films, unlike IR.
- **Water Compatibility:** Raman is ideal for aqueous solutions where IR would be limited due to strong water absorption.
- **Spatial Resolution:** Micro-Raman systems allow precise mapping of heterogeneous samples.
- **Non-Destructive:** Raman analysis does not alter or damage the sample.

7.6 Challenges and Solutions

- **Weak Signal:** The Raman effect is inherently weak; this is addressed by techniques such as SERS or resonance Raman.
- **Fluorescence Interference:** Fluorescence can overshadow the Raman signal. Using near-IR lasers or fluorescence quenching agents can help mitigate this issue.
- **Thermal Damage:** Prolonged or intense laser exposure can damage sensitive samples. Solutions include reducing laser power or using pulsed lasers to minimize heating.

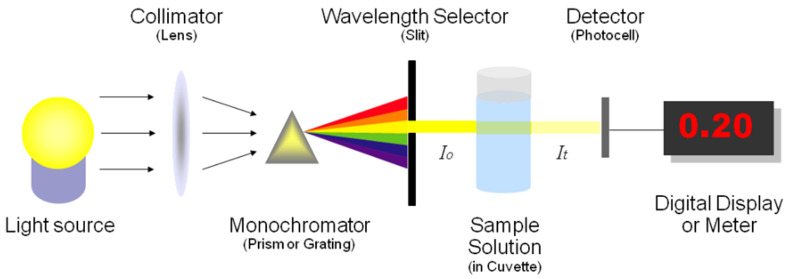
8 Spectrophotometer

8.1 What is Spectrophotometry?

Spectrophotometry is a method used to determine how much light a substance absorbs at various wavelengths. It works by passing a beam of light through a sample and measuring the amount of light that is absorbed by the sample.

8.2 Why is Spectrophotometry Used?

Spectrophotometry is used to quickly and accurately determine the concentration of a substance in a solution. It also helps identify and analyze chemical compounds based on how they absorb light. This technique is widely used in fields like chemistry, biology, medicine, and environmental science for quantitative analysis. It is also useful in research and industry for studying the properties and composition of various materials.



8.3 UV Spectrum (Ultraviolet Spectrum)

- The UV spectrum is the part of the electromagnetic spectrum with wavelengths from about 10 to 400 nanometers, shorter than visible light and longer than X-rays.
- UV light is invisible to humans but can be seen by some insects.
- It is present in sunlight and is divided into UV-A, UV-B, and UV-C types.

8.4 Electromagnetic Spectrum

- The electromagnetic spectrum is the full range of all types of electromagnetic radiation, arranged by wavelength or frequency.
- It includes radio waves, microwaves, infrared, visible light, ultraviolet, X-rays, and gamma rays, from longest to shortest wavelength.

8.5 Absorbance and Reflectance

- **Absorbance:** How much light a substance takes in (absorbs) at a certain wavelength.
- **Reflectance:** How much light bounces off the surface of a substance.

8.6 Solvents and Solutions in Spectrophotometry

- The solvent should be clear and should not interfere with absorbance.
- **Water** is commonly used because it is transparent in the UV-Vis range.
- **Ethanol and other organic solvents** are used when the analyte is not soluble in water.
- **Buffer solutions** maintain a constant pH, which is important for accurate measurements.
- The analyte is dissolved in a pure solvent to form a uniform solution for analysis.

8.7 Measuring Transmittance and Absorbance in Detail

In spectrophotometry, transmittance and absorbance are essential for understanding how a sample interacts with light. Transmittance is the ratio of the intensity of light that passes through a sample (I) to the intensity of the incident light (I_0), given by the formula:

$$T = \frac{I}{I_0}$$

It is usually expressed as a percentage, where 100% means all light passes through (the sample is fully transparent), and 0% means no light passes through. This measurement helps determine the transparency or clarity of substances like liquids, solids, and gases.

Absorbance, on the other hand, measures how much light is absorbed by the sample. It is calculated using the formula:

$$A = \log_{10}\left(\frac{1}{T}\right) = \log_{10}\left(\frac{I_0}{I}\right)$$

An absorbance of 0 means all light passes through, while higher values mean more light is absorbed. As transmittance decreases, absorbance increases, and this relationship is logarithmic. Therefore, small changes in transmittance can lead to significant changes in absorbance.

In practice, a spectrophotometer shines light of a known wavelength through a sample and measures both the incident light (I_0) and the transmitted light (I). From these measurements, it calculates the transmittance and absorbance, allowing scientists to analyze the sample's concentration, identity, or other properties.

8.8 Components of a Spectrophotometer

- **Light Source:** Provides the initial beam of light that will pass through the sample. Common sources include tungsten lamps for visible light and deuterium or hydrogen lamps for ultraviolet light. The light source needs to be stable and cover the required wavelength range.
- **Monochromator:** Selects a specific wavelength of light from the broad spectrum produced by the light source. It typically uses prisms or diffraction gratings along with slits to isolate and transmit only the desired wavelength to the sample.
- **Sample Chamber (Sample Holder):** Holds the sample, usually in a cuvette, in the path of the selected light. The chamber ensures the sample is positioned correctly for consistent and accurate measurements.
- **Detector:** Measures the amount of light that passes through the sample. The detector converts the light signal into an electrical signal, which is then used to calculate absorbance or transmittance.
- **Display (Readout/Output Device):** Shows the measurement results, such as absorbance or transmittance values, often in digital form for easy reading and analysis.

9 Spectrophotometer Designs

9.1 Types of Spectrophotometers

Single beam spectrophotometers

- Must be blanked after each wavelength change.

Scanning spectrophotometers

- Can rapidly scan through a range of wavelengths and create an absorbance spectrum.

Double beam scanning spectrophotometers

- Have two sample holders.
- Oscillate the beam between the sample and the blank, allowing for continuous and automatic comparison.

Other scanning spectrophotometers

- Use microprocessors to store data from scanning the blank at all desired wavelengths.
- After replacing the blank with the sample, they scan in the same way.
- The microprocessor compares absorbance values and generates a spectrum.

9.2 Scan speed

- Depends on the instrument's response rate.
- If the speed is too fast, it causes a **tracking error**, where absorbance peaks shift from their actual positions.

9.3 Photodiode Array Detector (PAD) Instruments

- Use a PAD instead of a photomultiplier tube (PMT).
- Can determine a sample's absorbance over the entire UV/Vis range almost instantly.

Working of PAD Instruments

- Each diode in the array responds to a specific wavelength and changes voltage when exposed to light.
- The sample receives all the light from the source.
- The monochromator is placed after the sample and separates the transmitted light.
- The separated light is sent to the PAD.

Function

- The computer calculates transmittance for each wavelength.
- Generates the absorbance spectrum by analyzing the amount of light transmitted at each wavelength.

9.4 Cuvette

A cuvette is a small, clear container used in spectrophotometry to hold liquid samples. It allows light to pass through the sample for measurement. Cuvettes are usually made of glass, plastic, or quartz—quartz is used for UV light, while glass or plastic works for visible light. They typically have a 1 cm path length, which helps in calculating absorbance. Keeping the cuvette clean is important for accurate results.

Performance Characteristics

- **Calibration**
    1. Brings the instrument readings into range with accepted values.
    2. Involves determining:
        * Wavelength accuracy (agreement between selected and actual wavelength).
        * Photometric accuracy (agreement between measured and reference absorbance values).
- **Stray light**
    1. Light that reaches the detector without sample interaction.
    2. Can affect readings and should be minimized.
- **Linearity**
    1. Relationship between light intensity striking the detector and the detector's response should be proportional.
    2. Linearity may be affected by:
        * Stray light,
        * Problems in the detector, amplifier, monochromator, or readout device.
- **Noise**
    1. Random electrical signals that cause spikes in the data.
    2. Can interfere with measurements at low concentrations.
- **Resolution**
    1. The ability to distinguish individual peaks in the absorbance spectrum.
    2. For quality cuvettes absorbance variation lies within 1 percent of measurement.

10 Our DIY Spectrometer

We made our model of spectrometer that uses light to analyze the composition of the minerals.We used basic tools available to us to make a working spectrometer that can perform the spectroscopy of the liquid sample and then analyzing the spectrum to understand the mineral composition.We tried various designs and ideas and then finally made the model after numerous trials and errors.

10.1 Components

- **Torch**:We used torch to act as a light source to provide the white light to illuminate the sample. We haven't used laser as it is monochromatic source of light which can't be used to generate spectrum.
- **Convex Lens**:We used three convex lenses in total in our model.It helps to focus the scattered light to a single point which helps in getting the concentrated source of light.
- **Glass tube**:We used glass tube to hold the liquid sample which act as a cuvette in our model.
- **Diffraction Grating**:We used diffraction grating of 600 nm lines to generate the spectrum of light obtained after passing through the solution.
- **Raspberry Pi Camera**:To obtain the image of the spectrum obatined we used the raspberry pi camera. The camera catures the pattern and then helps to get the data regarding the spectrum of a sample which is further processed to get the mineral composition.

10.2 Design

There are essentially two main parts of the spectrometer which is dynamically connected.First part consist of the sample and the other consist of the movable system of lens, diffraction grating and pi camera.

1. First there is a torch on the holder to which provides the parallel beam of light which is attached to the opening hole of the cardboard box conatining the sample.
2. Further there is a carboard box holding the glass tube containing the sample whose inner walls are painted black in order to absorb the stray light.
3. On the other side of the box there is another hole which act as a joint for the second part.This joint is detachable which makes the two parts independent yet connected.
4. After that there is a system of lens,diffraction grating,lens in a cardboard box which forms the spectrum of light coming from the source.
5. At the end of the box Raspberry Pi Camera is installed which takes the image of the pattern obtained from the final lens. The camera is further attached to the Rasberry Pi circuit and then to the screen.

10.3 Working

1. Light from the torch falls on the glass tube containg sample solution and scattered.
2. This scattered light is passed through the lens to make it concentrated at a point.
3. Light coming from the lens is passed through the difffraction grating which forms the pattern.
4. This light is again passed through another lens which forms the spectral paatern on the screen.
5. This light is then captured by the pi camera which takes the image of the pattern and forms the spectral pattern on the screen.
6. From the pattern obtained we analyze the composition of the mineral.

10.4 Challenges faced

We faced many difficulties and issues while making the model.Some of them are:

- **Low intensity light**
  The light obtained from the torch has less brightness and intensity and much of the light get scattered which makes it useless for our purpose.

- **Problems with the solids minerals**
  Firstly we decided to do the spectroscopy of solid sample but then the light doesn't get reflected properly from that and was not detected properly.

- **Lens and grating issues**
  Light after coming from sample was not easily concentrated on the focus and the spectrum obtained was not proper initially. For this we made the system movable so that it can be focussed easily.