U.S. DEPARTMENT OF ENERGY | Office of NUCLEAR ENERGY

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Versatile Acoustic and Optical Sensing Platforms for Passive Structural Monitoring

Advanced Sensors and Instrumentation Annual Webinar

October 31 – November 1, 2018

Daniel Homa, Presenter
Virginia Tech
Gary Pickrell
Virginia Tech

Project Overview

- Goal
  - To develop an acoustic based distributed sensing system capable of monitoring phenomena such as strain, temperature, pressure and corrosion to better evaluate the aging and degradation of structural components in nuclear facilities
  - The first-of-its-kind sensing system will be developed with unprecedented resolution, versatility, reliability, and economic viability
- Objective(s)
  - Develop radiation tolerant silica and single crystal sapphire acoustic fibers waveguides (AFWs) and Bragg grating (AFBGs) sensors
  - Design and construct a fused silica and single crystal sapphire acoustic fiber Bragg grating sensing systems
  - Conduct testing of optimized acoustic fibers and sensors exposed to radiation and benchmark performance with optical fibers and sensors

Project Overview

- Participants (2018)
  - Virginia Tech (University Lead)
    - Materials Science and Engineering: Gary Pickrell (Lead PI), Dan Homa (Manager), Zach Hileman (M.S.)
    - Electrical and Computer Engineering: Anbo Wang (PI), Jiaji He (Ph.D.), Qingzhao Kong (Postdoc), Ruixuan Wang (Ph.D.)
  - Oak Ridge National Laboratories (National Lab Collaborator)
    - Nuclear Security and Isotopes Technology Division: Alexander Braatz
  - Prysmian Group (Industry Collaborator)
    - Materials Technology Group: Brian Risch

Accomplishments

- Schedule
  - First Year milestones completed on time
  - Project is on/ahead of schedule
  - No changes/problems to report

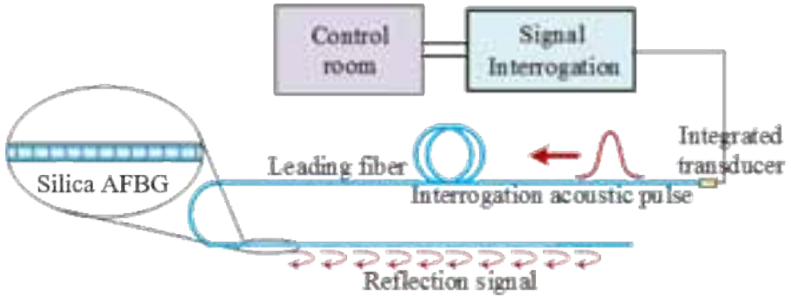
GANTT CHART		Project Year 1				Project Year 2				Project Year 3			
Task #	**Task Name**	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1	Project Management and Planning												
M1	**MILESTONE 1**		√										
2	Acoustic Fiber Waveguide Realization and Improvement												
M2	**MILESTONE 2**				√								
3	Sensor Design and Fabrication on Fused Silica Fibers												
M3	**MILESTONE 3**												
4	Radiation Exposure Testing of Fused Silica Based AFBG Sensors												
M4	**MILESTONE 4**												
5	Sensor Implementation on Sapphire Fibers												
M5	**MILESTONE 5**												
6	Radiation Exposure Testing of Sapphire AFBG Sensors												
M6	**MILESTONE 6**												
7	Laboratory Scale Performance Testing in Simulated Application												
8	Prepare and Submit Final Report												
M7	**MILESTONE 7**												

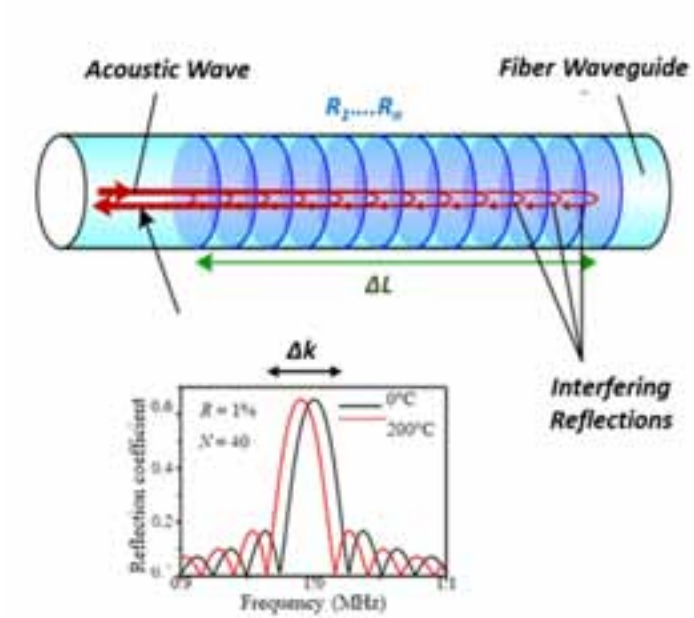
Accomplishments

- M3CA-17-VA-0702-042: Complete Project Management Plan for Versatile Acoustic and Optical Sensing Platforms for Passive Structural System Monitoring
  - Completed on time (12/31/2017)
- M2CA-17-VA-VT-07020043: Theoretical Analysis of Acoustic Fiber Waveguides and Acoustic Fiber Bragg Gratings
  - Completed on time (9/30/2018)
- M3CA-17-VA-VT-0702-044: Experimental Demonstration of Acoustic Signal Generation and Detection on an Acoustic Fiber Waveguide
  - Completed on time (9/30/2018)
- M2CA-17-VA-VT-0702045: First Annual Progress Report on Versatile Acoustic and Optical Sensing Platforms for Passive Structural Systems Monitoring
  - On schedule (12/31/18)

Accomplishments

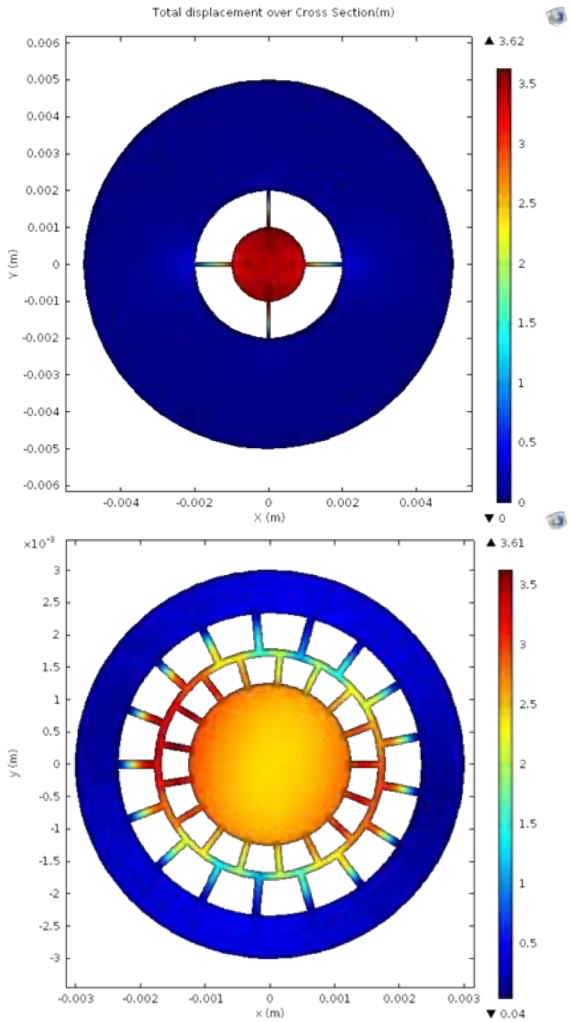
- "System" design approach
  - Acoustic fiber waveguide (AFW)
  - Acoustic fiber Bragg grating (AFBG)
  - AFW and AFBG testing station
    - Acoustic excitation and detection
  - Sensor interrogation system
    - Acoustic excitation and detection
    - Signal demodulation and sensing algorithms
    - "User-friendly" interface
  - Acoustic coupling components
    - Transducer-horn assembly
    - Acoustic signal amplifier
  - Performance testing
    - Radiation exposure





Accomplishments

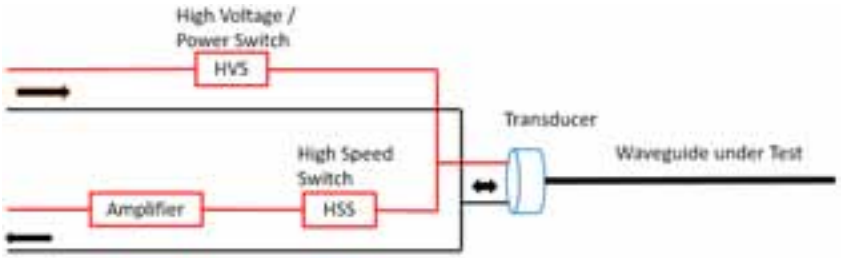
- Theoretical analyses for the optimization AFW design
  - Develop the theoretical models and techniques for efficient AFW design
  - Simulated the performance of an array of structures and materials
    - Single material
      - Silica and sapphire
    - Multi-material
      - Glass clad ceramic/metal core
  - Development of “suspended core” acoustic waveguide
    - Novel dual cladding structure introduced to “confine” and “shield” acoustic wave guided in core
    - Large power confinement demonstrated via simulations

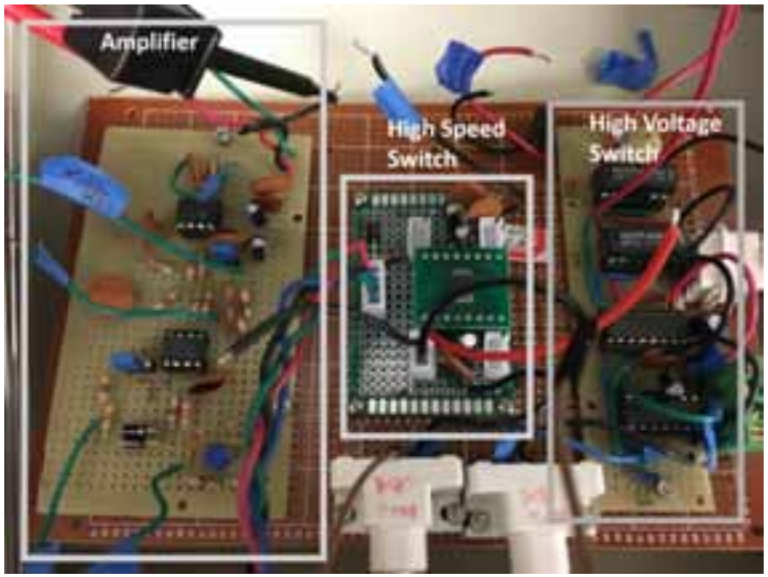


M3CA-17-VA-VT-0702-043: Theoretical Analysis of AFW and AFBG (completed on time)

Accomplishments

- Acoustic Signal Generation and Detection System
  - Designed and constructed an acoustic interrogation system for material and waveguide testing
  - Strong excitation signal / high noise floor
  - High voltage/power switch stops the high level of noise after the excitation signal passes.
  - High speed switch protects the amplifier by stopping the strong excitation
    - Required to quickly open after excitation to capture the reflections

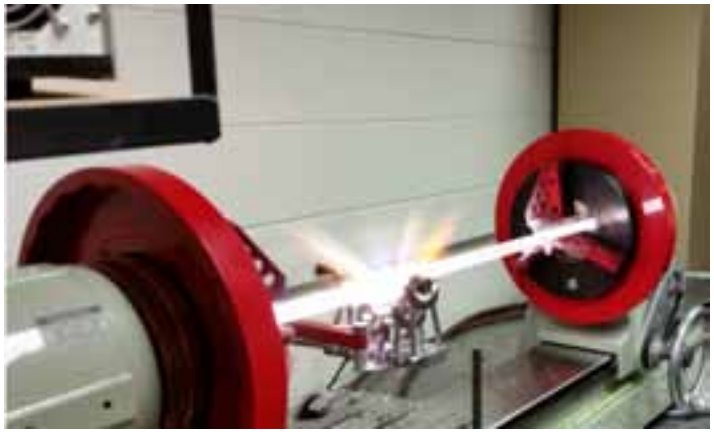


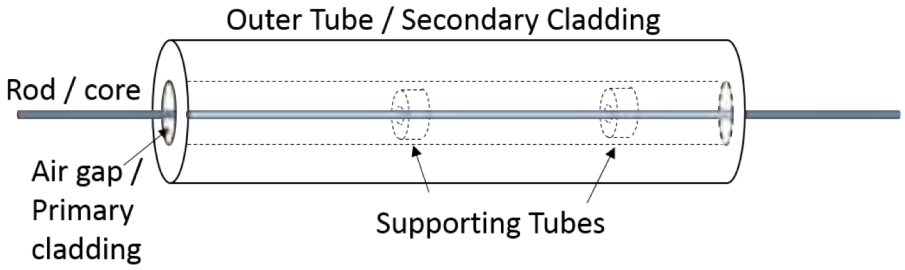


M3CA-17-VA-VT-0702-044: Experimental Demonstration of Acoustic Signal Generation and Detection…(completed on time)

Accomplishments

- AFW design and fabrication
  - Fabrication of “suspended core” acoustic waveguide
    - All fused silica construction
  - Fabrication via automated glass-working lathe
    - Initial experimentation prior to transitioning technology to commercial draw tower
    - Support ring structures introduced along the length of the waveguide
  - Demonstration of “manufacturability” is a priority

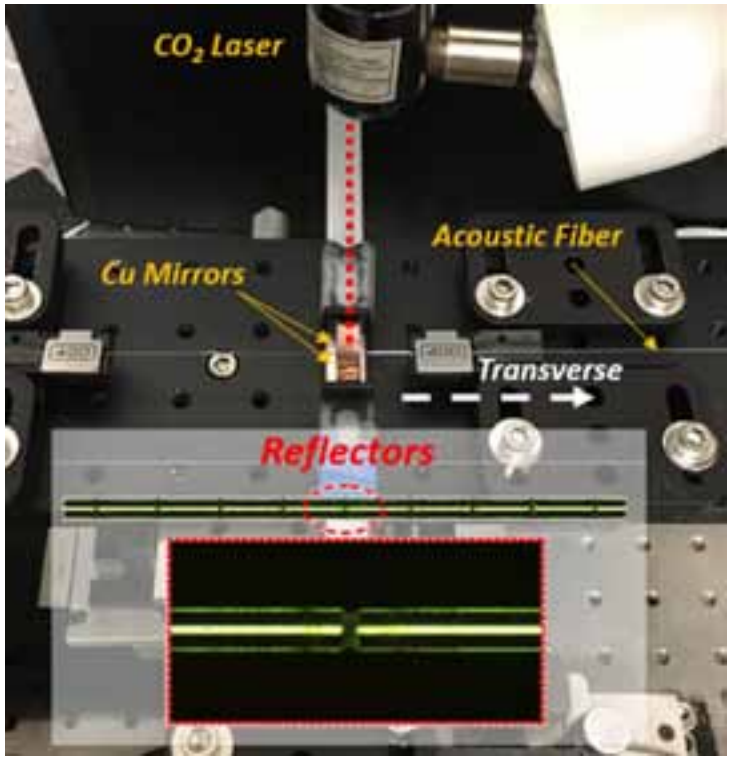




M3CA-17-VA-VT-0702-048 Reflector Element Fabrication and Testing (on schedule, 03/31/2019)

Accomplishments

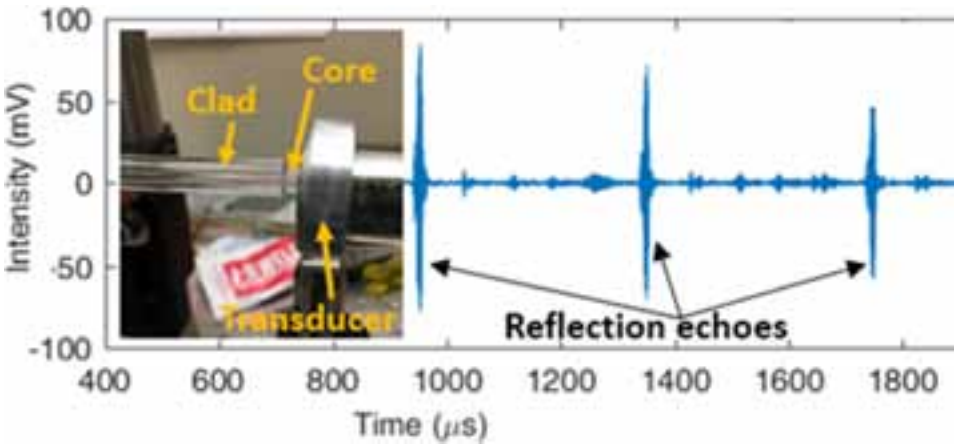
- AFBG fabrication approach and system
  - Designed and constructed the system and processes for the fabrication of AFBG reflectors in fused silica AFW via CO_2 laser inscription
    - Inscribed periodically located reflectors to form the AFBG
    - Circumferentially inscribed via two copper mirrors
  - Successfully fabricated AFBGs in a “suspended core” fused silica acoustic waveguide

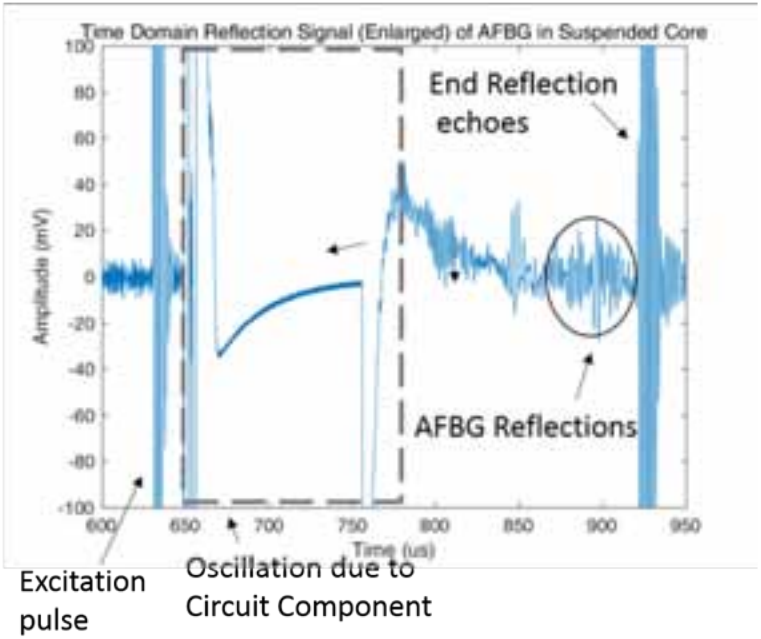


M3CA-17-VA-VT-0702-048 Reflector Element Fabrication and Testing (on schedule, 03/31/2019)
M3CA-17-VA-VT-0702-047 Design of Single Reflector Element and …. Fused Silica AFBG Sensor (on schedule, 06/30/2019)

Accomplishments

- Acoustic interrogation of waveguide and reflector
  - Successful interrogation of bare single material AFWs and an all-silica “suspend core” AFW
    - Acoustic signal directly coupled to the core
  - Successful interrogation of the weak AFBG reflectors in all fused silica “suspend core” AFW



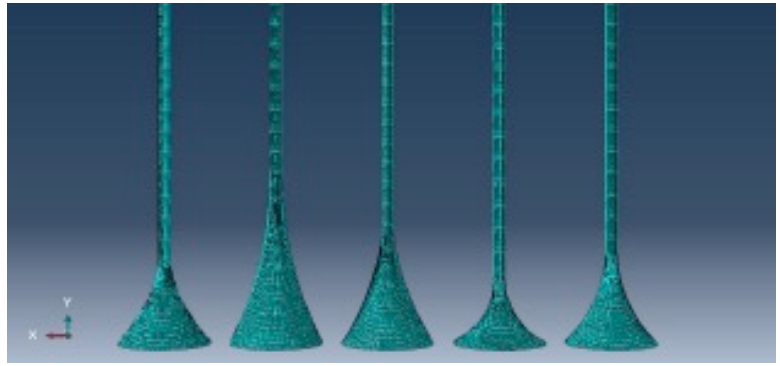


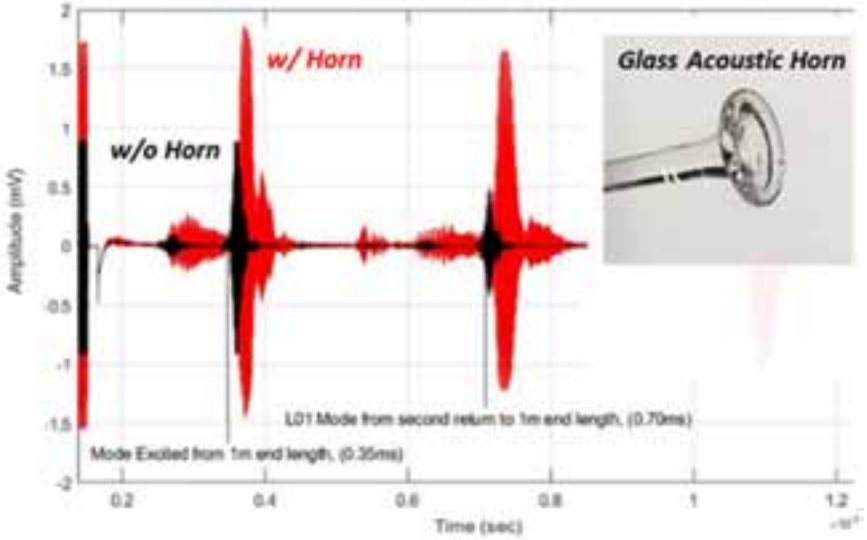
M3CA-17-VA-VT-0702-044: Experimental Demonstration of Acoustic Signal Generation and Detection…(completed on time)

M3CA-17-VA-VT-0702-048 Reflector Element Fabrication and Testing (on schedule, 03/31/2019)

Accomplishments

- Theoretical analysis and design of acoustic horn
  - Developed general framework for the design and analysis of system components
    - Finite element analysis performed via Abaqus software
  - Novel fused silica horn prototypes were successfully fabricated on a glass-working lathe
  - Improved coupling efficiency and a reduction in signal decay was demonstrated with “hollow” horns
  - Transducer-horn assembly designs have been investigated





M3CA-17-VA-VT-0702-049 Construction and Testing of the Fused Silica AFBG Sensing System (06/30/2019)

Accomplishments

- Sensor interrogation system design and construction
  - Initial interrogator design reviews were completed
    - System components were identified and acquired
  - A preliminary interrogation system was fully assembled and tested
    - Available for traveling-wave parameter setup and generation
    - Real-time high speed data acquisition and control

M3CA-17-VA-VT-0702-049 Construction and Testing of the Fused Silica AFBG Sensing System (on schedule, 06/30/2019)

Technology Impact

- *The successful demonstration of the first-of-a-kind, low-cost, fully-distributed, multi-parameter sensing platform will contribute to the advancement of 3D sensor network monitoring solutions for nuclear energy systems.*
- *The versatile and commercially viable sensing system fill the gap between low cost electronic sensors and high performance fiber optic sensors.*
- *The research products generated from this project will provide technologies that support the efficient and clean energy production necessary for energy independence.*
- *The diverse and multi-disciplinary research setting provides both faculty and students with the opportunity to cultivate a broad and diverse skillset that will provide benefit to the nuclear sciences, as well as the overall scientific community.*

Conclusion

- *Accomplishments for the first project year*
  - *Developed the theoretical modeling techniques for the efficient design and optimization of AFWs and AFBGs*
  - *Successfully designed, constructed and demonstrated an acoustic generation and detection system for laboratory testing*
  - *Fabricated and characterized a prototype fused silica AFW and AFBG*
  - *Design and constructed an acoustic sensor interrogation system*
- *The accomplishments are consistent with the project goals, objectives and schedule.*

Questions?

Contact information

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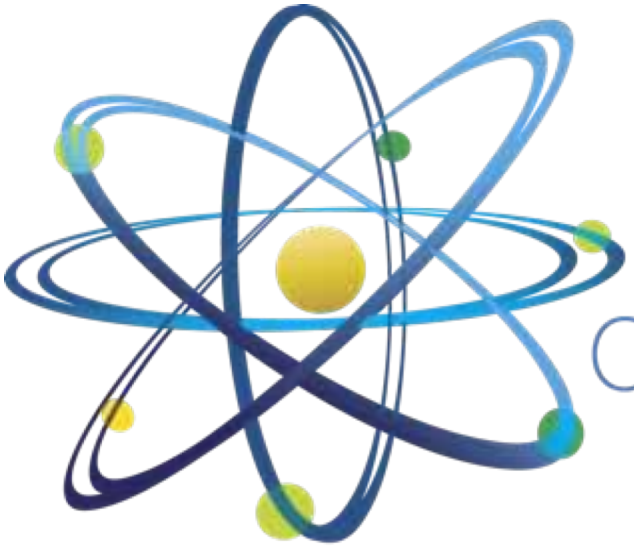

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