**Preeminent Role of AI in chemical sciences: Development, Formulations and Applications**

**Mr. Ritwik D. Uikey, Mr. Tahir Nasir Sheikh**

Department of Chemistry, RTM Nagpur University, Campus Nagpur-440033, M.S. India

Email: ritwikuikey@gmail.com phone: +919953877689

**Preamble**: Artificial Intelligence (AI) plays a significant and transformative role in various aspects of chemical sciences. Its applications are diverse and range from enhancing research and discovery to optimizing industrial processes key areas where AI is making an impact in chemical sciences:

1. **Drug Discovery**: AI is revolutionizing the drug discovery process by speeding up the identification of potential drug candidates. Machine learning algorithms can analyze vast amounts of chemical and biological data to predict the properties of molecules and their potential effectiveness as drugs. This saves time and resources by focusing on the most promising candidates, ultimately accelerating the drug development process.
2. **Materials Science**: AI is employed to design and discover new materials with specific properties. By using AI-driven simulations and predictive modeling, researchers can explore various material compositions and structures to find materials with optimized properties for specific applications, such as energy storage, catalysis, or superconductors.
3. **Computational Chemistry**: AI techniques are utilized to optimize computational chemistry workflows. Machine learning algorithms can assist in predicting molecular properties, simulating chemical reactions, and optimizing molecular structures, making computational chemistry more efficient and accurate.
4. **Process Optimization:** In chemical manufacturing, AI is used to optimize processes, control variables, and minimize waste. By analyzing real-time data from sensors and historical process data, AI can identify patterns, make predictions, and suggest adjustments to improve efficiency and reduce costs.
5. **Toxicology and Environmental Impact Assessment:** AI models can predict the toxicity of chemicals and assess their potential impact on the environment. These predictions aid in prioritizing the evaluation of chemicals and help in the design of safer and more environmentally friendly compounds.
6. **Personalized Medicine:** AI can analyze a patient's genetic and molecular data to tailor medical treatments to individual characteristics. This includes optimizing drug dosages and predicting potential adverse reactions based on a person's unique genetic makeup.
7. **Spectroscopy and Analytical Chemistry**: AI techniques can enhance the analysis of complex spectroscopic data. These algorithms can identify patterns and correlations in spectra, enabling more accurate and efficient identification of chemical compounds in mixtures.
8. **Data Mining and Literature Analysis:** AI is used to mine vast amounts of scientific literature, patents, and research papers, helping researchers stay up-to-date with the latest advancements and gain insights from a broader range of sources.
9. **Predictive Maintenance:** AI-driven predictive maintenance is applied to chemical equipment and plants to anticipate and prevent equipment failures, minimizing downtime and maintenance costs.
10. **Robotics in Chemical Labs:** AI-powered robots can automate repetitive tasks in chemical laboratories, such as sample handling, measurements, and data recording, freeing up researchers' time for more complex tasks.

 AI's ability to process and analyze large datasets, recognize patterns, and make accurate predictions has a transformative impact on chemical sciences, leading to more efficient research, improved material design, and better processes in various chemical industries.

**A. Drug Discovery**:

1. **Target Identification and Validation:** AI can analyze biological data and identify potential drug targets by mining large datasets of genetic and proteomic information. It helps researchers understand the mechanisms of diseases and identify specific proteins or genes that could be targeted to develop new drugs.
2. **Drug Design and Optimization:** AI assists in designing and optimizing drug candidates by simulating interactions between molecules and biological targets. Machine learning algorithms can predict the binding affinity and selectivity of compounds, leading to the identification of more potent and specific drug candidates.
3. **Virtual Screening:** AI-powered virtual screening methods can rapidly analyze vast chemical libraries to identify compounds that are likely to bind to a target of interest. This process accelerates the early stages of drug discovery, allowing researchers to focus on the most promising candidates.
4. **De Novo Drug Design:** AI algorithms can generate entirely new molecules with desired properties, allowing researchers to explore chemical space more efficiently and potentially discover novel drugs that would have been missed using traditional methods.
5. **Predicting Drug-Drug Interactions and Side Effects:** AI models can predict potential drug-drug interactions and adverse effects, helping to prioritize the safest and most effective combinations of drugs for specific patient populations.
6. **Personalized Medicine:** AI analyzes patient data, including genetic information and clinical records, to develop personalized treatment plans based on an individual's unique characteristics. This approach enhances the effectiveness of treatments while minimizing side effects.
7. **Drug Repurposing:** AI can analyze existing drugs and their known mechanisms of action to identify potential new uses or applications. Drug repurposing saves time and resources compared to developing entirely new compounds from scratch.
8. **Optimizing Clinical Trials**: AI can analyze clinical trial data to optimize trial designs, identify patient populations most likely to benefit from the treatment, and predict trial outcomes more accurately. This improves the efficiency of clinical trials and increases the chances of successful drug development.
9. **Natural Product Discovery:** AI assists in analyzing natural compounds from various sources, such as plants or marine organisms, to identify potential drug candidates that have been used in traditional medicine or have shown promising biological activities.
10. **Drug Manufacturing and Formulation**: AI-driven optimization of drug manufacturing processes can improve efficiency, reduce costs, and ensure product quality and consistency.

 The integration of AI in drug discovery not only accelerates the process of finding potential drug candidates but also improves the overall success rate of drug development. It enables researchers to explore vast amounts of data, make data-driven decisions, and ultimately discover safer, more effective and innovative medicines for a wide range of diseases.

**B. Materials Science**:

1. **Materials discovery and design:** AI can accelerate the process of discovering new materials with desired properties by predicting the behavior of materials under different conditions. Machine learning algorithms can analyze vast amounts of data from material databases, scientific literature, and simulations to identify patterns and correlations between material composition, structure, and properties. This enables researchers to design materials tailored for specific applications, such as superconductors, catalysts, and lightweight composites.
2. **Predictive modeling and simulations:** AI-powered simulations can accurately predict the behavior of materials at different scales, from atomic interactions to macroscopic properties. These simulations provide insights into a material's performance under various conditions, saving time and resources that would otherwise be spent on extensive experimental testing.
3. **Optimization of material properties:** AI algorithms can optimize material properties by exploring the vast design space to identify the ideal material composition and structure. This approach allows researchers to fine-tune materials for specific functionalities, enhancing their performance in real-world applications.
4. **Data-driven materials research:** AI enables data-driven materials research, where large datasets are analyzed to uncover hidden patterns and relationships. This data-centric approach facilitates the discovery of new materials and the understanding of complex material behaviors.
5. **Accelerated research and development:** With AI, researchers can automate certain tasks, such as data analysis, literature review, and experimental design, speeding up the research and development process. This acceleration is particularly beneficial in high-throughput experimentation, where large numbers of materials are tested in a short period.
6. **Personalized materials:** AI can be used to create personalized materials based on individual requirements. For example, in the medical field, AI can help design biomaterials compatible with a patient's unique physiology, reducing the risk of rejection in implant procedures. Identifying material candidates for specific applications: AI algorithms can assist in identifying potential material candidates for specific applications or industries, such as renewable energy, electronics, aerospace, and healthcare.
7. **Materials informatics:** AI techniques, such as machine learning and deep learning, can be employed to extract valuable information from materials databases and predict novel properties based on existing data. This aids researchers in making informed decisions about which materials to explore further.

 The integration of AI in material sciences has the potential to revolutionize the field by accelerating materials discovery, optimizing material properties, and enabling the development of innovative materials that can address complex challenges across various industries.

**C. Computational Chemistry**:

1. **Drug Discovery:** AI can analyze vast chemical databases to identify potential drug candidates, predict their interactions, and optimize molecular structures for better efficacy.
2. **Property Prediction:** Machine learning algorithms can predict chemical properties, such as solubility, reactivity, and toxicity, which are crucial for designing new compounds.
3. **Molecular Simulation:** AI techniques, like neural networks and genetic algorithms, can accelerate molecular dynamics simulations, making them more efficient and accurate.
4. **Quantum Chemistry**: AI helps tackle complex quantum mechanical calculations, reducing computational costs and improving the accuracy of predictions.
5. **Reaction Optimization:** AI algorithms assist in optimizing reaction conditions and pathways, speeding up the discovery of new chemical reactions.
6. **Material Design**: AI-driven approaches aid in designing new materials with specific properties, revolutionizing material science.

Overall, AI in computational chemistry accelerates research, reduces costs, and enables the discovery of novel compounds and materials that could have profound impacts on various industries and scientific fields.

**D. Process Optimization:**

1. **Data Analysis:** AI can process large volumes of data from sensors, machines, and other sources to identify patterns, anomalies, and inefficiencies in processes.
2. **Predictive Maintenance:** AI can predict equipment failures or maintenance needs based on historical data, allowing proactive maintenance and reducing downtime.
3. **Process Modeling:** AI can create complex models of processes, enabling simulations and "what-if" scenarios to identify the most efficient operational parameters.
4. **Real-time Monitoring and Control:** AI algorithms can continuously monitor processes and adjust variables in real-time to optimize performance and resource utilization.
5. **Energy Efficiency:** AI can optimize energy consumption by analyzing data and identifying opportunities to reduce waste and improve energy-intensive processes.
6. **Supply Chain Optimization:** AI can analyze supply chain data to optimize inventory levels, distribution routes, and production schedules, leading to cost savings and improved delivery times.
7. **Quality Control:** AI-driven systems can monitor product quality during production, identifying defects or deviations from desired specifications.
8. **Resource Allocation:** AI algorithms can optimize the allocation of resources, such as labor, raw materials, and equipment, to maximize productivity and minimize costs.

**E. Toxicology and Environmental Impact Assessment:**

1. **Toxicity Prediction:** AI can analyze chemical structures and biological data to predict the toxicity of various substances, enabling rapid screening of potentially hazardous compounds.
2. **Environmental Monitoring:** AI-powered sensors and data analysis can continuously monitor air, water, and soil quality, detecting pollutants and providing real-time data for environmental impact assessment.
3. **Risk Assessment:** AI algorithms can integrate data from multiple sources to assess the risks associated with exposure to specific chemicals or pollutants, helping in decision-making and regulatory processes.
4. **Environmental Modeling**: AI can create complex models to simulate the dispersion and fate of pollutants in the environment, aiding in understanding their behavior and potential impact.
5. **Drug and Chemical Development:** AI-driven approaches can assess the potential environmental impact of new drugs and chemicals during the development phase, promoting the use of safer and more sustainable compounds.
6. **Remediation Strategies:** AI can assist in identifying effective remediation strategies for contaminated sites, optimizing cleanup efforts and minimizing environmental damage.
7. **Species Protection:** AI can help identify and monitor endangered species, track population trends, and assess the impact of environmental changes on biodiversity.
8. **Policy and Regulation:** AI can provide data-driven insights to policymakers, enabling evidence-based decision-making for environmental protection and toxicological regulations.

 By leveraging AI's capabilities in data analysis, pattern recognition, and predictive modeling, toxicology and environmental impact assessment can benefit from more comprehensive and efficient approaches to safeguarding human health and the environment.

**F. Personalized Medicine:**

1. **Disease Diagnosis and Risk Prediction:** AI algorithms can analyze patient data, including genetic information, medical history, and lifestyle factors, to assist in more accurate disease diagnosis and predict an individual's risk of developing certain conditions.
2. **Precision Treatment Selection:** AI can analyze vast amounts of patient data and scientific literature to recommend the most effective treatment options for specific patients, taking into account their genetic makeup and other individual factors.
3. **Drug Discovery and Development:** AI-driven approaches can accelerate drug discovery by identifying potential drug candidates and predicting how they will interact with specific patients' biology, increasing the likelihood of successful treatments.
4. **Biomarker Identification:** AI can identify biomarkers that indicate the presence or progression of a disease, aiding in early detection and personalized treatment monitoring.
5. **Tailored Drug Dosage:** AI algorithms can optimize drug dosage for individual patients, accounting for factors such as age, weight, metabolism, and other physiological characteristics.
6. **Prognostic Models:** AI can develop prognostic models to predict a patient's response to treatment and disease outcome, helping healthcare providers make informed decisions.
7. **Imaging Analysis:** AI-powered image analysis can assist in diagnosing and monitoring diseases through the interpretation of medical images, such as MRI, CT scans, and X-rays.
8. **Patient Risk Stratification:** AI can stratify patients into risk groups based on their susceptibility to certain conditions, allowing for personalized preventive measures and early interventions.

 AI's ability to analyze vast datasets, identify patterns, and make data-driven predictions makes it a valuable tool in personalized medicine, leading to more effective and tailored healthcare approaches that improve patient outcomes and quality of life.

**G. Spectroscopy and Analytical Chemistry**:

1. **Data Analysis:** AI algorithms can efficiently handle large and complex datasets produced by various spectroscopic techniques. They can identify patterns, trends, and correlations that might be challenging for traditional data analysis methods.
2. **Spectral Interpretation:** AI models, such as machine learning and neural networks, can assist in identifying and characterizing spectral peaks, allowing for faster and more accurate identification of compounds or elements in a sample.
3. **Automated Peak Fitting:** AI can automate the process of peak fitting, which involves de-convoluting overlapping spectral peaks to determine individual component contributions, streamlining the analysis process.
4. **Real-time Monitoring:** AI can be integrated into analytical instruments to provide real-time monitoring and feedback during experiments, enhancing process control and ensuring data quality.
5. **Prediction and Optimization:** AI models can predict spectroscopic outcomes based on experimental parameters, aiding in experimental design and optimization for desired results.
6. **Chemo-metric Analysis:** AI techniques can perform advanced chemometric analyses, such as multivariate data analysis, principal component analysis (PCA), and partial least squares (PLS) regression, facilitating sample classification and quantification.
7. **Spectral Imaging:** AI-driven spectral imaging enables the identification and visualization of various components in a sample, enhancing the understanding of complex structures and distributions.
8. **Smart Instrumentation:** AI can enhance the capabilities of analytical instruments by enabling self-calibration, self-diagnosis, and adaptive control, leading to improved accuracy and reproducibility.

 AI's integration in spectroscopy and analytical chemistry empowers researchers and analysts to extract more meaningful insights from data, streamline workflows, and make informed decisions, ultimately advancing scientific research and various applications in diverse industries.

**H. Data-Mining and Literature Analysis:**

1. **Information Retrieval:** AI-powered search algorithms can quickly and accurately retrieve relevant information from vast databases and literature repositories. Natural Language Processing (NLP) techniques enable more precise queries and help find relevant articles, papers, or data.
2. **Text Mining:** AI-driven text mining techniques can extract valuable insights from unstructured textual data. These methods include entity recognition, sentiment analysis, and topic modeling, which help researchers identify key concepts and trends from a large corpus of literature.
3. **Knowledge Extraction:** AI can automatically extract valuable information from scientific papers and literature, such as relationships between different concepts, citation patterns, and emerging trends, aiding researchers in staying up-to-date with the latest advancements.
4. **Literature Summarization:** AI algorithms can generate concise summaries of research papers, providing a quick overview of the main findings and key takeaways, saving time for researchers during the review process.
5. **Trend Analysis:** AI-powered tools can analyze a large volume of literature to identify emerging research trends and hot topics, helping researchers and decision-makers stay informed about the latest developments in their field.
6. **Data Linkage:** AI can facilitate the linkage of information from different sources, enabling the integration of diverse datasets and enhancing the depth and quality of data mining results.
7. **Personalized Recommendations:** AI algorithms can provide personalized recommendations for relevant research papers and articles based on a user's interests and reading history, streamlining the literature discovery process.
8. **Quality Assessment:** AI can assist in evaluating the quality and credibility of research papers by assessing factors such as citation counts, journal impact, and author reputation.
9. **Cross-Disciplinary Insights:** AI-driven literature analysis can facilitate the exploration of connections between different scientific disciplines, fostering interdisciplinary collaborations and knowledge exchange.

 AI's integration in data mining and literature analysis enables researchers to navigate the vast sea of information more efficiently, extract valuable knowledge, and gain deeper insights into their fields, ultimately advancing scientific research and innovation.

**I. Predictive Maintenance:**

1. **Data-Collection and Monitoring:** AI-powered sensors and IoT devices can continuously collect data from industrial equipment, allowing real-time monitoring of key parameters, such as temperature, vibration, and pressure. This data is crucial for identifying anomalies and potential issues.
2. **Anomaly Detection:** AI algorithms can analyze the data collected from equipment and identify abnormal patterns or behavior. By detecting anomalies early on, maintenance teams can take preventive actions before a failure occurs.
3. **Predictive Analytics:** AI can perform advanced analytics on historical data, identifying patterns and trends that indicate potential equipment failures. This helps in forecasting maintenance needs and scheduling maintenance activities proactively.
4. **Condition Monitoring:** AI-driven condition monitoring systems can assess the health of equipment and predict the remaining useful life of critical components. This enables maintenance teams to optimize maintenance schedules and reduce downtime.
5. **Failure Pattern Analysis:** AI can analyze historical maintenance records to identify recurring failure patterns. This information helps in root cause analysis and designing more effective maintenance strategies.
6. **Prescriptive Maintenance:** AI can provide prescriptive maintenance recommendations, suggesting the best course of action based on data analysis. This includes recommendations for repair, replacement, or adjustments to prevent failures and optimize equipment performance.
7. **Remote Diagnostics:** AI-powered predictive maintenance systems can remotely diagnose equipment issues, reducing the need for physical inspections and enabling maintenance teams to address problems quickly.
8. **Machine Learning for Maintenance Models:** AI techniques, such as machine learning, can develop sophisticated maintenance models based on data from multiple sources. These models can continuously learn and adapt to changing operational conditions, improving prediction accuracy over time.
9. **Cost Optimization:** AI-driven predictive maintenance helps optimize maintenance costs by reducing unplanned downtime, minimizing emergency repairs, and optimizing spare parts inventory.

 The role of AI in predictive maintenance is to transform maintenance practices from a reactive to a proactive approach, improving equipment reliability, reducing downtime, and enhancing operational efficiency for various industries, such as manufacturing, energy, transportation, and more.

**J. Robotics in Chemical Labs:**

1. **Automated Sample Handling:** AI-powered robotics can handle and process samples in chemical labs, reducing the need for manual intervention and ensuring consistent and accurate sample handling.
2. **High-Throughput Screening:** AI-driven robots can perform high-throughput screening of compounds, enabling faster and more efficient testing of chemical reactions, drug candidates, and materials.
3. **Reaction Optimization:** AI algorithms can optimize chemical reactions by analyzing data from various experiments, identifying the best reaction conditions, and suggesting adjustments to improve yields and selectivity.
4. **Laboratory Safety:** AI-controlled robots can execute hazardous tasks, minimizing the exposure of lab personnel to dangerous chemicals and environments, thereby enhancing laboratory safety.
5. **Analytical Instrumentation:** AI can be integrated into analytical instruments to automate data collection, analysis, and interpretation, leading to faster and more reliable results in areas such as spectroscopy, chromatography, and mass spectrometry.
6. **Quality Control:** AI-powered robotics can perform real-time quality control, continuously monitoring chemical processes and product characteristics to ensure consistency and adherence to standards.
7. **Machine-Learning for Predictive Insights:** AI and machine learning algorithms can analyze vast amounts of chemical data to predict properties, reactions, and material behavior, aiding in the discovery of new compounds and materials.
8. **Smart Lab Infrastructure:** AI can optimize the overall workflow and resource allocation in chemical labs, ensuring that equipment and instruments are used efficiently and reducing downtime.
9. **Reproducibility and Standardization:** AI-driven robotics can ensure the reproducibility of experiments by precisely following predefined protocols, reducing experimental variations and enhancing research reliability.
10. **Data Integration and Knowledge Management:** AI can help integrate data from various sources, including scientific literature and experimental results, creating a knowledge base that supports decision-making and scientific discovery.

 By combining AI and robotics, chemical labs can achieve higher throughput, accuracy, and safety, ultimately accelerating research and development processes, fostering innovation, and expanding our understanding of chemistry and its applications.

**State-of-the-Art:**

**Drug Discovery:** AI is employed to predict molecular properties, screen chemical databases, and design new drug candidates more efficiently.

**Material Science:** AI helps identify and optimize novel materials for various applications, such as batteries, catalysts, and semiconductors.

**Computational Chemistry:** AI techniques aid in solving complex quantum mechanical problems, accelerating molecular simulations, and predicting chemical reactions.

**Process Optimization:** AI optimizes chemical processes, reducing energy consumption and waste generation in industries like pharmaceuticals and chemicals.

**Spectroscopy and Analytical Chemistry:** AI enhances data analysis, automates interpretation of spectroscopic data, and improves chemical analysis techniques.

**Toxicology and Environmental Impact:** AI models are employed to predict chemical toxicity and assess environmental risks.

**Drug Repurposing:** AI identifies new uses for existing drugs by analyzing their interactions and properties.

**Summary**:

 Artificial Intelligence plays a transformative role in chemical science, revolutionizing various aspects of research, analysis, and development.

* **Drug Discovery:** AI expedites drug discovery by analyzing vast chemical databases, predicting molecular properties, and identifying potential drug candidates, significantly reducing the time and cost of the drug development process.
* **Materials Design:** AI enables the discovery and optimization of novel materials with desired properties through predictive modeling, accelerating advancements in fields like nanotechnology and materials science.
* **Reaction Prediction and Optimization:** AI algorithms can predict chemical reactions' outcomes and optimize reaction conditions, leading to more efficient synthesis routes and higher yields.
* **Spectroscopy and Analytical Chemistry:** AI enhances data analysis and interpretation in spectroscopy and analytical chemistry, providing more accurate and insightful results from complex datasets.
* **Predictive Maintenance:** AI-driven robotics facilitate automation and precision in chemical labs, improving sample handling, high-throughput screening, and reaction optimization, as well as enhancing safety and efficiency.
* **Process Control:** AI optimizes chemical processes by monitoring and adjusting variables in real-time, leading to improved productivity, reduced waste, and enhanced product quality.
* **Environmental Impact Assessment:** AI aids in evaluating the environmental impact of chemicals and materials, helping researchers and industries develop more sustainable practices.
* **Personalized Medicine:** AI analyzes individual patient data to tailor treatments and optimize drug dosages, enabling personalized medicine approaches for better patient outcomes.
* **Literature Analysis and Knowledge Extraction:** AI automates literature analysis, extracting valuable insights and trends from vast scientific publications, aiding researchers in staying updated with the latest advancements.
* **Cross-disciplinary Insights:** AI facilitates interdisciplinary collaborations, leveraging insights from different scientific domains, leading to novel discoveries and innovative solutions.

 AI's integration in chemical science enhances research, accelerates innovation, and enables more informed decision-making, ultimately driving advancements in medicine, materials, and environmental sustainability.

**Acknowledgments:**

Authors are thankful to Head, Department of chemistry, R.T.M. Nagpur University, Nagpur for providing platform to submit this paper and also thankful to our guide **Prof. Rajendra S. Dongre** and adorable parents for their guidance and moral supports.

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