From the Research Laboratories

MEASURING THE COLLISION TIME OF A BALL WITH HIGH COEFFICIENT OF RESTITUTION

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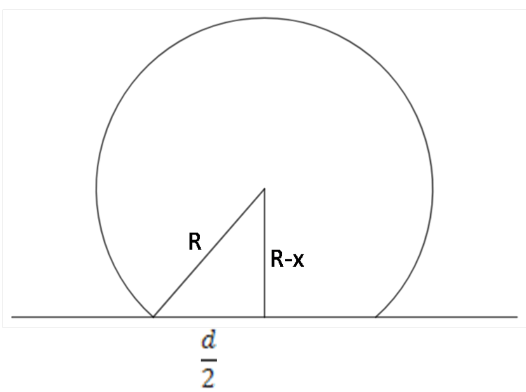
Abstract. The purpose of this paper is to measure the collision time of a ball with a high coefficient of restitution (SuperBall) with a hard surface. The manuscript discusses the theoretical model of the collision and approximations used; the direct methods for measuring the collision time - shooting with a high speed camera from the side; shooting with a high speed camera from below; verification of the theoretical model; measuring the voltage of a photodiode, and the non-direct methods used - component frequency analysis of the collision sound; measuring the spot left from the falling ball. Results and conclusions are highlighted.
Keywords: collision; coefficient of restitution; time; theoretical model; surface

Theoretical model

During the collision there are 2 forces acting on the ball – gravity and the normal force, which changes throughout the collision. We shall assume the total force is proportional to the deformation of the ball. Also due to the high coefficient of restitution (0.9) one can assume no energy is lost. We assume the ball remains spherical except for the deformed part, which is flat with the ground. This assumptions hold for drop heights less than 3m, after which the deformation of the whole ball significantly influences the spot measuring method.

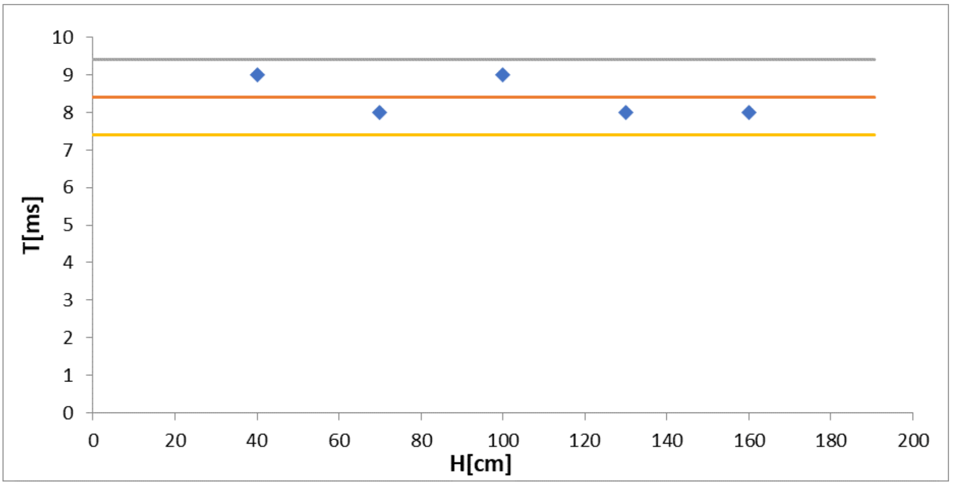


Shooting the collision from the side

A high speed camera of 1000 fps was utilised. The ball is dropped on a hard surface, with the camera shooting at the collision site. From the number of frames in which the ball is touching the surface one can infer the collision time.

Measurements were made for drop heights from 40 to 160 cm every 30 cm, with the collision time averaging at 8.4ms regardless of the drop height. This result leads us to hypothesize the ball acts as a harmonic oscillator.

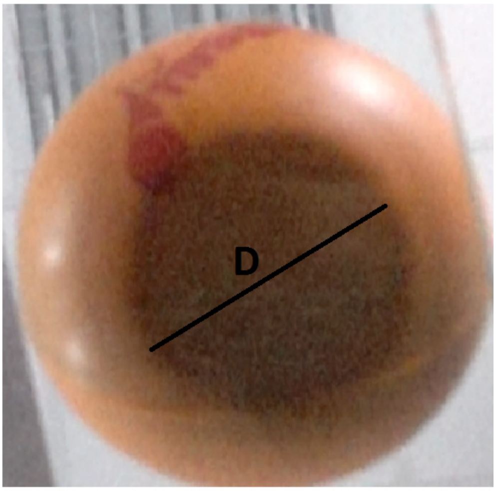
The error in the measurement is ±1ms, or the time between consecutive frames. It can be improved with increasing the frame rate. The graph below shows the collision time vs drop height, which is flat and averaging at 8.4ms.



Shooting the ball from below

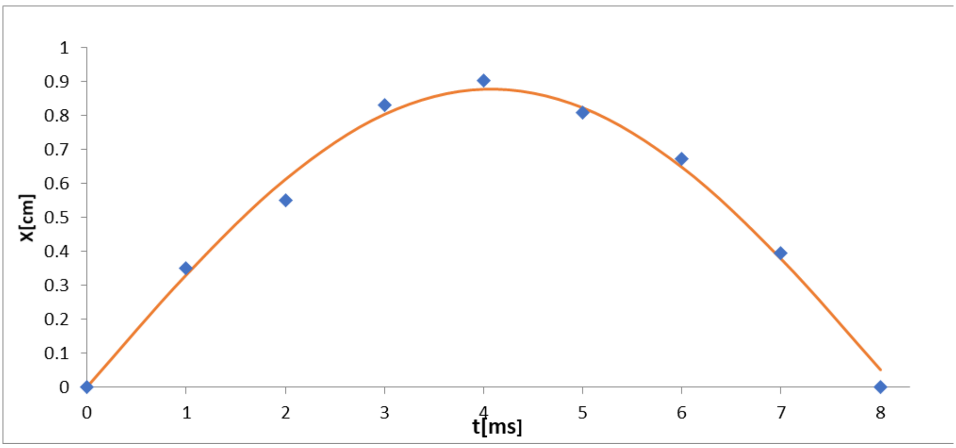
Purpose of the experiment: To obtain the relationship between contact area and time since the ball touches the surface. Using this, one can obtain the deformation of the ball vs time.

Setup: A glass surface is suspended from two sides, and the camera shoots from below. The ball is dropped and for each frame the diameter of the deformation is measured. Using the Pythagorean Theorem the deformation can be computed for each frame.



$$(R-x)^2+\frac{d^2}{4}=R^2$$

$$x=R-(R^2-\frac{d^2}{4})^{1/2}$$



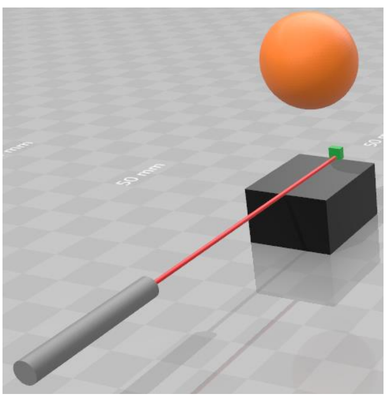
The graph shows the deformation of the ball vs time. If the ball acts as a harmonic oscillator this should be a sine wave. The red curve is the best fitting sine wave (using the least squares method), which adequately describes the experimental data. This proves the model of a harmonic oscillation and describes the collision well enough.

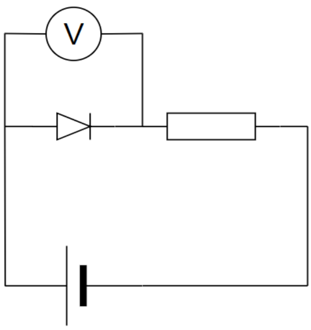
Measurements were made for drop heights in range from 30 to 130 cm, with data points for each measurements fitting well on a sine wave. Averaging the half periods of the fitted sine waves gives a collision time of 8.7ms, not far from the 8.4ms obtained from the previous method.

The error in this experiment is larger than the error in the previous one since it is hard to decide the first frame in which the ball touches the glass.

Measuring the voltage of a photodiode

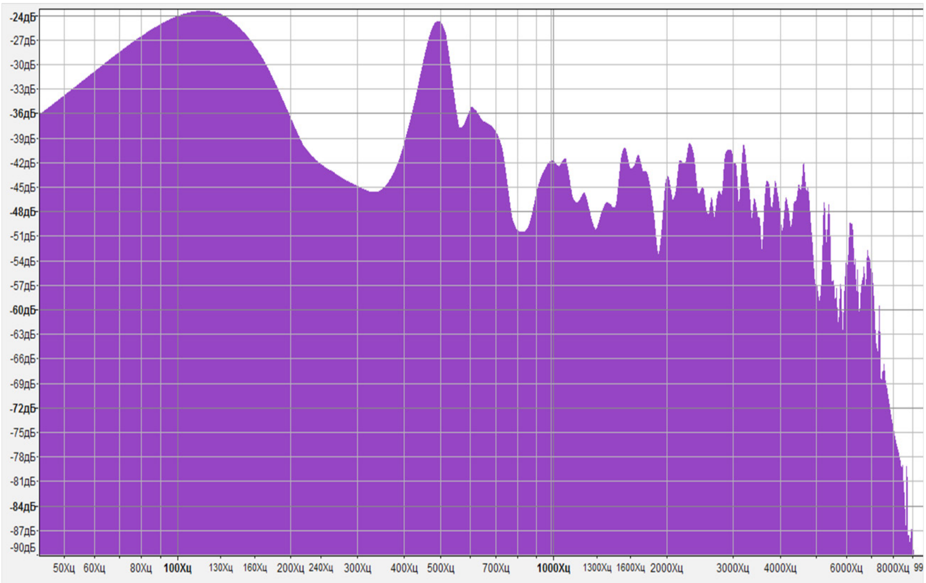
Setup: On the end of the surface a photodiode is attached, and a laser beam is focused on it, just grazing the surface. The ball is dropped on the laser beam, and during the collision the ball obstructs the laser beam. A high speed voltmeter (1000 measurements per second) can measure the peak in voltage, and thus we can measure the collision time. The experiment is restrained in accuracy by how accurately one can drop the ball onto the laser beam. Due to an imperfect drop there will be intervals of time in the beginning and end of the collision where the laser will shine on the photodiode even though the ball is still in contact with the surface. That is why instead of taking the average over many measurements, one should take the maximum time for each drop height. Using this method of data collection an average of 8.4ms is obtained, again in good agreement with the previous two methods.





Sound analysis

The ball is dropped on a hard surface and the sound is recorded. Sound spectrum analysis is performed. There should be a peak in frequency corresponding to the collision time.



A peak in the sound wave is obtained when the deformation of the ball is 0 and parts of the surface are moving the fastest. For one period of oscillation, or twice the collision time, there are 2 peaks in the sound wave. Therefore there is one peak per collision time

Thus the collision time $t = \frac{1}{f}$, where f is a frequency where the sound spectrum has a maximum.

From the previous experiments we know the collision time is between 8 and 9 ms, corresponding to frequencies between 111 and 125Hz. Between these two frequencies there should be a peak in intensity. The sound was recorded in echo-proof room. For all the drop heights the frequency peak in the desired range was approximately equal, and averaging at 117.86Hz (from approximately 100 measurements). Form this a period of 8.48ms is derived, which is the most accurate period so far. The increased accuracy comes from the accuracy of modern microphones, and the longer duration of the sound, which allows for a longer time interval on which Fourier analysis is performed.

Measuring the maximal deformation of the ball

A transparent file folder is filled with a thin layer of flour on which the ball can leave an impression. The diameter of this impression is measured, allowing us to compute the maximum deformation. Since we assume energy is not lost, then all the gravitational potential energy is transformed into elastic potential energy. Let the ball have mass m, coefficient of elasticity k and radius R.

From the law of conservation of energy:

$$mgh = k\frac{x^2}{2};\ h = \frac{k}{2mg} * x^2$$

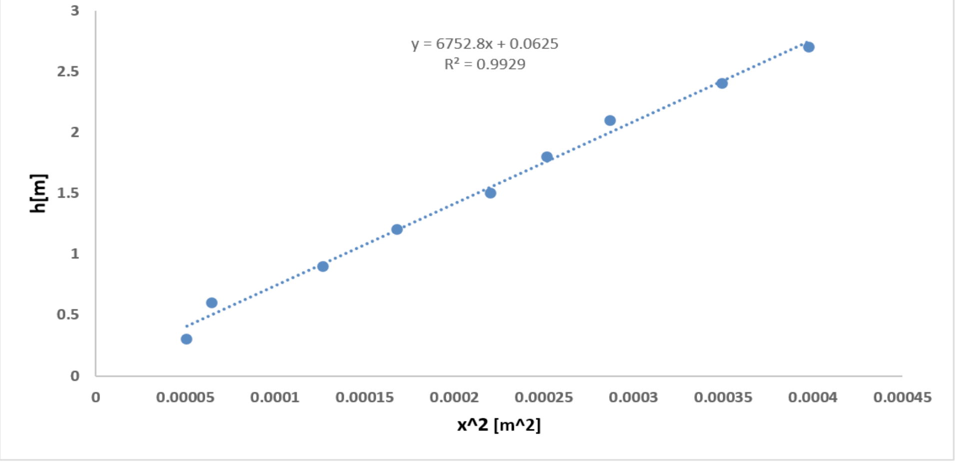
As in the previous experiment, we used the Pythagorean theorem to calculate the deformation *x*.

We can drop the ball from different heights and measure the diameter of the spot *d*, from which we can compute x^2. Plotting h vs x^2 should be a straight line with equation

$$h = \frac{k}{2mg} * x^2 = a * x^2 .$$

From here we can compute the coefficient of elasticity

$$k = 2mg * a$$



From the graph, we can see that the data are fitted by a line. Using the obtained value for the gradient of this line, the collision time can be computed knowing the mass of the ball and g, by the formula for a period of a spring pendulum:

$$T = 2\pi\sqrt{\frac{m}{k}} = 2\pi\sqrt{\frac{1}{2ga}}$$

The collision time is half of the oscillation period T, or

$$t = \pi\sqrt{\frac{1}{2ga}} \approx 8{,}6\ ms$$

The inaccuracy of this method comes from the inaccuracy due to measuring the diameter of the spot and the drop height. It relies on the assumption that energy is not lost during the collision. At higher collision speeds this would be inaccurate, however since the data points lie almost perfectly on the line of heights of up to 3m, then the model is accurate for drop heights of at least that.

Conclusion

This paper has proven that the collision of Super Balls with a hard surface can be modeled by a harmonic oscillator. By 5 different methods it has been shown that the collision time is between 8.4 and 8.7ms, with the most accurate one of all leading to 8.48ms. Each of the methods confirm that the collision time is independent of the drop height. These experiments are valuable since most of them can be easily reproduced by students of all backgrounds, and they teach the basics of data analysis and experimental methods.

Method	Collision time [ms]
Shooting from the side	8,4
Shooting from below	8,7
Photodiode	8,4
Sound spectrum analysis	8,48
Flour	8,6

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Chemistry: Bulgarian Journal of Science Education | Volume 29 Number 5, 2020 | Природните науки в образованието

MULTIPLE PERSPECTIVES ON ACADEMIC LABORATORY SAFETY COURSE IN COLLEGE SCIENCE EDUCATION

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Abstract. There has been comparable neglect of safety aspects and impacts in science and engineering curriculum design and development. It should become an integral part of the higher science education ecosystem. The academic scenario will be much greener if laboratory safety learning content is prescribed at college levels. It should address a multitude of laboratory safety issues in academic institutions, from laboratory design to technology, from conducting an academic audit to developing a sustainable safety culture. The right steps, such as proper coordination, monitoring by conducting inspections at regular intervals, and a robust accountability mechanism in implementing a safety training program, will ensure progress with favorable results. Developing the safety culture and focusing more on a deeper understanding of the risks is essential for efficient safety management. A practical and meaningful laboratory safety course in educational planning and management, promoted by proper motivation, academic guidance, and administrative support, is crucial. Commitment to safety and proper safety precautions based on knowledge, skill, and attitude would have a substantial impact on preventing many unnecessary accidental injuries due to carelessness or oversight. This article looks at the multiple perspectives on academic lab safety in a changing world. It highlights the recent resurgence of interest in the safety to give an idea of the subject's enormous scope and various safety-related topics.

Keywords: academic laboratory safety; curriculum design; lab accidents; loss prevention; safety culture

1. Introduction

The basic human survival needs include oxygen, water, food, sleep, and safety. Scientific research results have a profound impact on the modern world and changed lifestyles. Chemicals and chemical reactions are indispensable in a highly technological society of the 21st century. People need to work in humane and safe conditions in all the scientific laboratories as it is one of the defining pillars of scientific growth. The professionals must have their awareness of the sociological implications of their research and development work and observe a code of conduct to protect our environment for a better future. The societal and technological transformation, funding availability for the proper maintenance of laboratory facilities, training of safety personnel, and the recruitment of safety officers have driven the improvement in the practice of laboratory safety during the last three decades (Amburgey-Peters, 2002). The statistical data on laboratory incidents form a vital component in the quest to achieve safer scientific laboratories worldwide. However, the workplace safety survey conducted in 2013 indicates the significant laboratory risks causing minor to severe injury for the research scholars, and the employers should ensure the safety of the lab participants (Noorden, 2013).

We have to understand the factors causing lab accidents supported by scientific facts, and by eliminating the cause/s, one can limit the prospect of an incident and protect ourselves from potential dangers. The causes of laboratory accidents include the lack of experience or a working understanding of hazards, improper or unintended use of equipment, distractions or lack of attention to task, the use of broken, damaged glassware or equipment, and carelessness. We can trace these parameters to the fundamental lack of necessary chemical background and failure to make connections between academic concepts and laboratory safety (NRC, 2014). Academic lab accidents can result in loss of life, and multiple injuries, economic loss, property destruction, and harm to the environment. It is essential to identify the cause or causes, and accidents will be reduced by eliminating the causes.

The safety extension from laboratory scale to pilot plant to industrial-scale comes with scale-up operations involving several chemical plants, products, and processes (AICE, 1990; ICE, 1983). An unhealthy work environment such as hazardous chemicals, chemical waste, biological species, noise, metal fumes, and monotonous nature of work in the industries are known to cause disabilities and diseases (Freeman & Whitehead, 1982). Industrial safety has not received the required attention and importance, especially in small and medium scale undertakings. If we take proper steps to promote safety in an industrial setup, most of the accidents are preventable, helping with the healthy growth of the community (Kharbanda & Stallworthy, 1988).

The changes to transform chemical laboratory safety begins with the course of trying to review the current situation. Some undergraduate colleges do not have proper laboratories, training in safety aspects, a chemical safety plan for instruction, and a quality control mechanism. It is imperative to develop a sense of rights and the responsibilities of a learner, researcher, or professional worker in these laboratories. There is an increasing need to have an active educational program on safety to bring attitudinal change among all the stakeholders to enable them to contribute immensely to the overall safety through a series of efforts. The education on safety will help the learner to unlearn certain misperceptions, misconceptions, misunderstandings, incorrect assumptions, and help understand the real concepts and broader understanding of many other factors related to safety. We have to become conscious of the value of safe procedures and develop a proper mental attitude to promote safety in the laboratory. Proper education about laboratory safety has to be accorded on a priority basis to change the attitude towards safety (Schroder et al., 2016).

The various circumstances of the contemporary lab settings lead us to consider the fine line between safety and risk and open the door to a new vision of a unique rapid reaction world expecting the unexpected.[1)] Advances in the chemical sciences with the help of modern technology have resulted in an explosion of knowledge about safety. The advances in transient techniques have allowed us to understand certain realities of reaction dynamics. Some unexpected instantaneous incidents remind us that a concerted or stepwise mechanism links the past, present, and future. The existence of a well-established reaction mechanism for the solution of safety issues will enable a suitable action to what might otherwise end in danger. Laboratory safety research has become more critical in the last decade, as indicated by the increasing number of published papers in the field and their extreme relevance for human security. The research journals on different safety topics include the Journal of Safety Research, Biosafety, Structural Safety, Safety Science, Fire Safety Journal, Applied Biosafety, Journal of Chemical Education, Journal of Laboratory Chemical Education, and Journal of Chemical Health and Safety. The journal 'Loss Prevention Bulletin' published by the IChem, UK, publishes various process safety case studies related to laboratory and industrial safety, including near-miss cases.[2)]

Humans have prepared, found, or used over 50 million different chemicals, each with a distinct chemical composition, and chemical industry archives contain more than 62,000 commercial chemicals.[3)] Many products are manufactured worldwide for many purposes, from soft baby foods to powerful, destructive bombs. Many companies are introducing innovative products to meet the specific needs of customers in addition to standardized products. It is indeed difficult to collect, analyze, and assess the safety aspects of each of these products and find out protection methods for safe laboratory experience. The principle danger exists in ignorance of specific hazards and negligence during working and experiments with chemicals need to be looked at jointly with caution (Fig. 1.) The lack of available data on lab incidents and injuries may be due in part to an out-of-court settlement in many legal cases. It is not mandatory to report such accidents to concerned people or media in specific organizations. It is our responsibility towards the scientific community to report such accidents and to suggest preventive actions be taken to reinforce laboratory participants to follow safety principles regularly. There is a need to provide safety education that enables scientific understanding of issues, the primary reasons, and deduce solutions to various safety issues, including readiness to cope with an emergency. A systematic research study of various safety aspects with a molecular level perspective and the development of chemistry associated with them will reveal some unknown properties of certain chemicals and unpredictable reactions. The discussion above establishes the importance of the study of safety in science curricula. Its impact will be moderate for the conduct of chemical education. The necessary safety skills can be cultivated and developed by practice, but often neglected in the science curriculum.

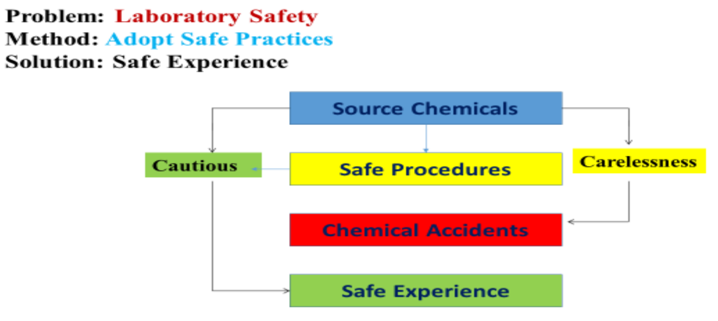

Fig. 1. Flowchart depicting linked steps in the overall safety net

This paper aims to draw the attention of general readers to the chemical laboratory safety aspects and impacts as one of the neglected topics in curriculum design. Our concern is to upgrade the academic laboratory safety infrastructure and follow the standard best practices to reconnect with the real reader in a more extended manner to think about the unintended consequences. This article is intended to promote safety awareness, encourage safe working practices in the chemical laboratory, and anticipate, evaluate, and recognize hazards that may occur during laboratory operation. It attempts to explain the nature of the safety issues and an extensive line of control and preparation for emergencies briefly. The discerning reader can get a complete picture or additional details through numerous cross-references of original work, review articles, books, or monographs. The text is divided into sections concerned with a brief history of laboratory accidents, understanding the safety aspects, enhancing laboratory safety, professional development approaches, towards a safer world of a laboratory, and conclusions and future directions. An academic laboratory safety course is published concerning the needs of modern scientific practice (Thimmappa, 2020). A subdisciplinary content on the 'Academic Laboratory Safety Course Outline' is presented in dedicated units, and the syllabus itself does have value. The idea is to fully explore the immense possibilities within the purview of the scientific facts and choose a better course of action in any given set of circumstances, which has severe consequences for the future of safe laboratory practices. The genuine spirit of creating a thinking framework allows people to imagine different risk possibilities and re-engineer all aspects of safety through the knowledge of chemical sciences. In addition to understanding the general and specific safety issues, tracking the distinctly different trajectories at the molecular level is paramount to reduce specific risks involved. The content of the paper is useful to audiences such as laboratory instructors, workers, teachers, and students. It will be of interest to the non-specialist readers, research scholars, educational advisers, curriculum writers, consultants, graduate-level students as well as some research-minded scientists in government laboratories and industry.

2.Understanding the Safety Aspects

It is necessary to provide a safe working environment in the workplace to promote science, engineering, and technology.[4,5] In this context, a proper study of safety-related broader issues, facilitating the sharing of scientific knowledge about safety management practice in the classroom, and laboratory demonstrations of concepts of safety become critical. Interdisciplinary approaches to laboratory safety have become paramount in addressing a broad range of safety issues at both local and global levels. Most industrialized nations have taken action to reduce the frequency of laboratory accidents and teach the students how to handle chemicals safely, avoid accidents, and do what to do in the event of an accident. It is now common to see laboratory spaces completely separated from offices in the layout of modern science laboratories. In the Indian context, the understanding of laboratory safety and its significance becomes critical considering the significant increase in the number of higher education institutions and universities in the recent past.[6] There is an acute shortage of necessary infrastructure and insufficient and inadequate safety devices except for a few established laboratories. Lack of adequately trained personnel as a result of a failure of safety management and planning also contributes to the problem. Further, many undergraduate students now take part in research activities, and this could involve risks with consequences such as physiological injury (disability and death), damage to standard equipment, financial loss, psychological impairment, and other long-term implications. Moreover, the disposal of toxic acids, solvents, and other chemicals of unknown toxicity would have a direct impact on air, water, and soil quality, posing environmental issues (NRC, 1995).

The awareness about laboratory safety is less due to the lack of interest in students and the administration and incredible diversity of solution chemistry. There are inherent engineering challenges in overcoming safety issues in several industrial processes and finding out the best methods to manufacture products or extract certain metals from their ores (Sax & Lewis, 1988). The mainstream media need to improve their presentation of safety matters written by journalists with specialized scientific knowledge and soft communication skills. A journalist's efforts should be aimed at arousing safety awareness among the readers and making them conscious of their responsibilities towards safe experimentation to obtain practical knowledge. The safety message in a forceful tone, clear terms from a magazine or newspaper, can prompt the readers to act intelligently and promptly to prevent laboratory accidents. The laboratory safety is necessary to prevent the adverse health effects of exposure to chemicals, personal injury or injury to fellow workers, laboratory equipment hazards - if not maintained properly, and damage to equipment. As there is increasing concern about the academic laboratory safety in the recent past, prudent practices in the laboratory provide a sense of confidence and social responsibility (NRC, 1981).

The government should support necessary safety measures, frame protection policy to promote safety in scientific laboratories, and monitor the proper adoption of sustainable safety practices. Regular cleaning activities within the laboratories in all higher education organizations should become a part of the educational program involving the practical components. Sustainable strategies for safety management include educating laboratory users to get aware of safety rules and regulations through posters, slide shows, awareness notes, banners, safety quizzes, and workshops, among others (Thimmappa 2006). Other learning resources on safety in the form of audiobooks or videos are impactful in education. It is crucial to read the fine details on the label carefully to find the summary of product characteristics and the critical safety information of the chemical we are about to use. In addition to having safety rules and regulations and extensive safety support systems, there has to be a massive safety sensitization program to bring an attitudinal change among all stakeholders. The participation of multiple participants is essential for effective safety management. A new perspective involving safety mission, detail orientation, and making intelligent decisions based on scientific evidence, observations, case histories, and knowledge will address various safety challenges and concerns in our professional lives every day (Sanders, 2005). Depending on the nature of the safety problem, we have to decide what is the best course of action that can be safely be used and should be followed. Users often waste precious time, and which may allow a controllable process to a harder to control stage (Cote & Wells, 1991).

It is essential to enhance our perception skills to go beyond the average human eye and train the brain to analyze more data in a much faster way to take proactive and immediate action of every aspect of safety, including unexpected effects (Weiss, 1986; O'Neil, 2013). There is a paucity of safety data available on new laboratory chemicals. The actual safety information on a diverse range of products should flow from suppliers (chemical manufacturers, importers, distributors) to employers and then to the workforce to ensure their safe handling under actual academic operating conditions with the professional operating ethos.[7)] The professional societies should provide a platform for the exchange and transfer of safety knowledge and information about research and development through their activities. A researcher should be made aware of various potential safety issues in instrument rooms with lasers, pressurized gas cylinders, cryogenic liquids, and high pressure/temperature reactors to improve overall safety. The interrelated safety aspects of lab practice such as prudent practices in practical work, precautionary measures in violent reactions, visual inspections of maintenance work, controlled conditions using safety devices, emergency techniques in fire accidents, first aid in physical injuries, professional help in health problems, and control mechanism in preventing environmental pollution are necessary to develop safety consciousness (LeFèvre & Shirley, 1997; Meyer, et al., 2007; NFPA, 2010). In light of overall safety development, we have to blend the right benchmark principles of safety into laboratory practice by controlling our thoughts and actions in the right safety spirit. The safety is the fundamental requirement to overcome the investigation challenges that demonstrate our quest to understand and discover the world through various natural and artificial mediums, methods, materials, and scientific interpretations, assessments, analyses, and expressions (Girolalmi, et al., 1999, Shriver & Drezdzon, 1986, Skoog et al., 1994).

3. Enhancing Laboratory Safety

The modern chemical laboratories are safer with all the safety measures in place, and with proper precautions for safety during the experimentation phase. Proper laboratory safety and a chemical hygiene plan help minimize the risk of chemical exposure, reduce the danger of lab work-related injury and illness, lower the risk to the environment, and comply with applicable regulations and standards. It is vital to increase reporting of laboratory incidents, provide safety training to react swiftly and with sensitivity to victims, and have a worldwide awareness campaign to reignite core values and safety precautions to develop a real safety culture.[8)] The safety program's specific objective should be to achieve the four E's- education, expertise, experience, and exposure to a range of safety aspects and develop, implement and maintain a particular standard of good laboratory practice. At the end of the safety program, the learner will understand and employ safety knowledge and have strong safety ethics in laboratory practice. They should have a technical background and the ability to understand, analyze, and explain the impact of laboratory safety-related incidents and suggest suitable safety measures in particular situations.

Each university should start a formal safety program development. Depending on the need and requirements of local affiliated colleges and intense involvement of industry experts on safety will help raise the bar on safety quality. There should be a robust linkage between the safety specialist in education institutes and those in industrial laboratories to strive for a more robust safety culture in an academic setting (Staehle et al., 2016). The primary emphasis is on bringing radical changes in the concerned departments and fixing higher education providers' accountability. It is crucial to maintain universal eligibility criteria for a safe scientific lab and high safety standards as a step towards the prevention of accidents. Conducting proper training and refresher courses by competent training authorities would help us to understand the nature and magnitude of the problem, the impact of safety measures, and the relationships between safe practices and the number of lab incidents. It is essential to ensure enough human resources and other technical assistance to adhere to global safety standards to reduce unnecessary risk or the magnitude of the risks involved. Improving professional standards and commitment to ethical values along with an efficient safety management system to implement safety measures to a sufficient level, will go a long way in addressing the problem of academic lab safety. National council for safety research and training can conduct meetings to reflect, discuss, and debate on thematic organization and presentation of topics in the safety course and arrive at a point to enhance the quality of learning activities and experiences. The laboratory activities must be consistent with the best standard practices, followed by the leading universities for many years to achieve our safety goals (RSC, 1986).

4. Professional Development Approaches

The different common types of chemicals present or produced in the chemical laboratory include toxic compounds, reactive species, carcinogenic agents, compressed gasses, corrosive chemicals, irritant fumes, lachrymatory vapors, flammable liquids, explosive substances, shock-sensitive compounds, pyrophoric chemicals, radioactive materials, and peroxide-forming reagents.[9,10] The various types of incidents include explosions due to mishandling, accidents during disposal of used chemicals, fire mishaps, injuries due to sharps, inhalation of toxic fumes, chemical/electrical/thermal burns, and UV/X-ray exposure (Luxon, 1992). There is a requirement to create a climate of safety for achieving distinct results, technological advances through educational professionalism and research work, which could be useful in the public interest, the institution, and the nation. Safety education in the right perspective should be actively encouraged in universities to enable a learner to make proper use of safety knowledge during the subsequent period of their scientific life while performing lab activities. The accidents caused by unsafe conditions can be improved by conducting regular safety audits and inspections, maintenance of equipment, encouraging reporting, and good housekeeping. In contrast, those due to unsafe acts can best be prevented from developing and establishing a better safety culture.[11)] This culture can be drawn up by making conscious efforts in the direction of thoughts, actions, habits, character, and destiny, each reinforcing the next.

The development of a safety culture includes personal, behavioral, and environmental factors that condition our mind to make the working environment safer and take steps to remedy unsafe situations. This transformation could involve changing perceptions and paradigm shift by overcoming deep-underlying thought patterns and significant concerns at the subconscious level. The persons with a well-trained and organized mind can work more efficiently and effectively and will be able to use the brain power to think, concentrate, and to perform meaningful experiments without giving scope for accidents to happen. There is an urgent need for laboratory safety education and awareness activities at the undergraduate level that can indeed be an enabler and a driver of positive change (Hill, 2016). The study of safety and achievement of educational objectives depends upon the practical content, how it is taught, rigorous follow-up, and evaluation.[12,13)] Higher education organizations need to be sensitized, and colleges should include safety aspects and impacts in training curricula and enhance the industry-institution interface. Students with strong safety education should be preferred for industrial jobs or safety research groups to minimize the risks through an organized application of safety knowledge.

The educational objectives of integrated safety development drive should include the following; i) to increase the level of awareness of laboratory safety among learners by providing safety knowledge and safety ethics ii) to present recent developments that can help reduce the number of laboratory accidents leading to severe injury or death iii) to show that chemical reactions can be useful to find concrete solutions to many significant problems without injuries from chemical events iv) to share the right information about chemical principles and techniques, phenomena, fundamental concepts, and chemistry core ideas relevant to develop a sense of the kinds of chemical and other laboratory hazards one might encounter v) to develop a proper safety consciousness through selection of relevant scientific content and educational methods, vi) to establish a safety management system and to instil more robust safety practices in chemical research (Stuart & McEwen, 2016) and vii) to promote chemical science to young learners with safe practices to minimize the risks of hazards through proper mentor-learner relationship.

The formal safety course could be taught to regular students as a standalone course or as an integral part of the general science curriculum. It is essential to activate and develop the right cerebral functioning with an emphasis on logical thinking, scientific reasoning, problem-solving ability, and creativity. Teaching lab safety for faculty members and other technical staff as a formal safety education is essential to minimize risks (Hall, 1993). The systematic safety education approach must be outcome-based or impact-driven by innovative ideas, management skills, and efficiency. The educational outcome could be measured by formal learning assessment modules involving objective type questions, concise answer, short answer, or long answer type questions on different aspects and impacts of academic laboratory safety. The questions must consist of a well-balanced composition involving easy, moderate, and challenging questions (E, M, and D in ~ 60, 30, & 10 %). This structure will enable a vast majority of students to answer the easy ones without much difficulty. The questions with an increased degree of difficulty should be such that only above average students can provide conclusive answers to these. The remaining questions should be such that the students who can apply knowledge learned in the regular class right in the examination hall can only respond to these. The proposed safety syllabus has been used before as a comprehensive material uniquely and educationally in classes of average strength fifteen using PowerPoint presentation methods and handouts distributed as supplementary materials to promote active learning. Students' responses to the interpretation of particular aspects of safety were excellent, as reflected in their active participation in classroom activities and their best performance in examinations.

Further safety information can be obtained from the relevant literature survey, safety data sheets (SDS) available in CDs/printed version, the Merck Index, Chemical Laboratory Information Profile (CLIP) in J. Chem. Ed. (ACS), online databases, audio-visual materials, and CD read-only memory products (CD-ROM form)[14-17]. A data bank of hazardous reactions was launched recently. Researchers can add their incident reports in this new chemical safety library service, helping to minimize dangerous reactions from being repeated.[18] In individual universities, the "Safety Quiz" has been introduced, and safety cell circulates 'Caution Notes' periodically for continual improvement. Surfing the internet sources to find some generic safety-related information

(PDF or PPPs) and participating in global scientific conferences will allow us to switch between different themes in unconventional learning. Compiled information on various websites with their distinctive features along with detailed safety reports, interconnected conceptualized paintings, illustrative pictorializations, and captured photographs can make a huge impact in scaling up learning levels. Further, audio-visual aids, cartoons, charts, diagrams, films, graphs, and models can be applied in the teaching-learning process to see things from a broader perspective. We have to look for factual safety information and ready to walk that extra mile to seek long-term solutions to safety problems (Haynes, 2017). The stages of safety-problem solving include recognizing that a problem exists, assembling information relevant to the problem, and selecting and implementing the best solution. Most chemicals are toxic, and dangerous chemical reactions include many more reactions than the reference library (Yoshida, 1987). If there is no published information on a chemical compound's hazardous properties, this does not mean that no hazard exists (Saxena, 1984). It is better to keep track of the safety news to be aware of any dangerous properties and potential safety problems in our functional domains to enable us to make more informed judgments. Incorporation of safety data, including new guidelines and new policy matters in a laboratory information management system (LIMS) under analytical and managerial level tasks, would help address more immediate challenges and adapting to safety regulations.[19)]

The safety issue should be handled with extreme care while participating in various lab activities. The science, engineering, and technology institutions take the lead in sensitizing the stakeholders about the various aspects of safety, reform their mindset, and educating them about safety culture are vital for the future. A regular theoretical training and practice sessions, including emergency action plans and response for the researchers to equip them with new skills required in safe laboratory operations and prudent practices, help reduce the number of laboratory accidents. It is essential to develop strategies for an unblocked thought process and imagination to view things in their true relation or relative importance, with increasing concerns of environmental consciousness in the stakeholders. The scientific community should not allow workers to perform any potentially dangerous activities in an ordinary laboratory unless special safety requirements are met, and adequate risk management measures are in place (Sax & Lewis, 1987). The safety signs and symbols have become a core part of our communications, and visual recognition carries profound significance. The forensic work for the investigative purpose could include establishing the cause of suspicious fires, academic hazard issues, hazardous equipment use, and analyzing the presence or absence of various toxic substances in body fluids and tissues after the incident. The recruitment of safety management executive and recognition of safety teachers as scholarly practitioners at the university level will undoubtedly boost the morale and confidence of those involved. The safety, storage, waste disposal, and emergency planning and response services must be managed at the institutional level. The research activities related to safety problems are necessary to understand processes at the molecular level that cause them. Scientists and engineers have studied the spread of fire or gas inside the laboratories through computer simulations to find practical solutions for several issues involving fire or toxic gases. Creating a trained, expert, and motivated safety management task force in each university plays a pivotal role in promoting safety. A regular audit of laboratories for safety can alert us to accidents waiting to happen, and taking certain precautions during lab activities helps prevent many accidental injuries.

5.Towards a Safer World of Laboratory

Depending on the stage of development of an institution and available resources, established laboratories (10 + years), young laboratories (5-10 years), and new laboratories (under five years) have to be considered for various safety development activities. The priority should be given to improving existing equipment, facilities, and construction of new ones to support safety-related activities. Further, establishing the integrated safety facility by providing critical safety infrastructure would help build bridges between institutes in proximity. Also, installing sophisticated surveillance systems can drastically transform the behavior of those working in the laboratories. An online, print, electronic, and outdoor media campaign may be necessary to have strict safety measures in the workplace. Student poster competition, safety-related activities, regular workshops, or crash courses on the basics of safety in academic laboratories, help promote a safe work environment. It will be more useful, relevant, intellectually stimulating, and more productive to have ‘bridging the gap’ course on safety in an undergraduate program in chemistry, chemical engineering, biotechnology, medical lab technology, microbiology, pharmacology, biomedical engineering, and materials science (ACS, 2017). Experimental studies at the interface of these subjects may encounter unexpected or new hazards. It is the authors’ responsibility to report any such hazards in safety notes while publishing the results of experimental work. We have to facilitate learning by providing supporting information in the form of student handouts (PPT) on the topic. The experienced teachers should supervise instructor notes (PDF) and experimental protocol. Also, it is essential to assess learner’s knowledge, attitude, and behavioral practices towards safe laboratory experimentation through a battery of tests. The safety curricula must be brought up to date continuously because of the rapid developments in the field. The globally harmonized system (GHS) of classification and labeling of chemicals toady is the single most resource for accessing information about chemicals.[20] Further, we have to meet the needs of the environment and contribute to finding processes that reduce environmental hazards and consumes less energy.

Online centralized safety management systems by the university grants commission or the national safety council can also minimize the number of safety-related incidents in wet chemistry laboratories. However, the active participation of university officials, safety managers, researchers, activists, enthusiasts, and the academic community is essential. Further, starting a universal safety portal (USP) to record lab incidents and lessons to learn more about the academic lab safety and helping the researchers with the much needed valuable data or analysis is also required. There should be an electronic system to provide alerts, and automatic updates of advances in safety-related research activities around the globe to face the new challenges. The way forward includes government support in technology adoption and safety infrastructure development, optimal utilization of resources, engaging professional management, and promoting safety-related research activities. Promoting safety culture within an organization ensures a comfortable working environment, and practical experimentation can be quite safe under carefully controlled conditions.

The area of chemical research holds the potential to produce many new compounds or elements, which has significant consequences for understanding safety under extraordinary conditions. The design of molecules with targeted chemical, electrical, and optical properties for application in drugs, vaccines, and those with mechanical, magnetic, and thermal properties for application in materials science poses a significant risk of causing minor to severe injury. New research may reveal sudden, unexpected chemical processes caused by the impact of nanoparticles leading to safety-related issues. The discovery of new biological species, including pathogenic fungi, bacteria, and virus have far-reaching consequences in changing our safety knowledge. The global committee on lab safety (GCLS) has to be set up to act as a coordinating body for safety awareness activities throughout the world, and a newsletter can publish, review and promote the exchange of safety ideas and the dissemination of information on the lab safety all over the world. The idea of universal basic safety (UBS) requires severe deliberation and subsequent implementation in every citizen's interest, leading to improved work environment and productivity. The government and the private sector should jointly respond to the agenda of universal safety systems through public-private partnership (PPP) models to support safety initiatives and to achieve an improved level of safety.

6. Conclusions

A brief history of laboratory accidents in the recent past indicates the gravity of the safety problem on multiple experimental platforms. The academic lab safety is a neglected topic in chemistry, chemical engineering, chemical technology-related subject curricula, and it is essential to incorporate safety course in such programs. Knowing the sources and reasons of lab incidents is a definite aid to avoiding accidents by taking proper preventive actions. The article is concerned with and outlines the academic laboratory safety issues that exist in higher education institutions and highlights multiple analytical perspectives of safe lab practice. Laboratory safety is a significant aspect of every laboratory session that requires safe laboratory procedures and training for all users to develop safety-related skills, safety knowledge, and proactive attitudes. It is vital to prevent adverse health effects from exposure to chemicals, personal injury or injury to fellow workers, and damage to standard equipment. It is crucial to recognize chemical hazards that may occur during laboratory operation and apply controls to minimize the risks of these hazards and to reduce the number of incidents significantly. The difficulties in chemical safety are that each chemical has a different risk, and the users usually cannot analyze the level of risks involved. Further, the risks are not necessarily how they are perceived. A chemical may react violently with the evolution of heat or produce flammable/toxic products. It is a thinking and visualization about the eventuality and consequences with the reasons for the worst possible situation in laboratory operations and taking a quick and wise decision to favorable incident transformation in the direction of safety. The discussion on the roadmap for a paradigm shift through a change of mindset should occur at the user level, and safety should be at the forefront of our consciousness. A laboratory safety management plan (LSMP) should be designed as a baseline preventive model for teachers at the tertiary level that can be replicated elsewhere in schools, colleges, and universities.

The research community should use common pool resources for safety-related development activities and better resource management to safeguard lab user rights. The funds need to go into well-thought-out projects to make a visible impact. The chemical labs had to be housed in one place and redesigned wherever required, keeping in mind the significant safety aspects and ecological impacts. Apart from the commitment to the safety of the university, it also requires a deep understanding of the challenges of safety in academic laboratories to create a culture of safety. It is essential to take sufficient proactive steps during experimentation, including initial attention, closer inspection, keen observation, immediate inference, empirical evidence, quicker recognition of potential danger, and taking immediate action applicable for tackling the emergencies. The safety teachers have to become scholarly practitioners and professionals through the development of pedagogical content knowledge (PCK) and best practices (ACS, 2001). In the pre-laboratory session, elaborate instructions on the safety protocol, while performing the laboratory activities should be provided. In the post-laboratory experience, students should be asked to discuss appropriate safety measures taken to experiment safely and efficiently (Corwin, 1999; Grant & Meyer, 1996). It is essential to store the SDS sheets of the common chemicals used in a particular laboratory electronically or in a filing cabinet. The recent trend of a lab on a chip (LOC) to scale down the size of the analytical or preparative platform would undoubtedly help address safety issues.

The electronic surveillance system by installing the closed-circuit television (CCTV) camera network with enhanced surveillance features at various lab locations can have a significant impact on work life. A machine-readable quick-response (QR) code that contains safety information about the individual chemicals must be made available in all the chemical science laboratories. The scan-based image platform on smartphones with Android and iOS operating systems will be a boon to laboratory users. Tangible safety initiatives are essential to driving good candidates to promote talent, training, education, experience, dedication, and delivery aspects of the right decision making at the right time to enable them to perform physical experiments. Apart from the increased primary focus on infrastructural development, establishing a safety management system with the integration of proper attitudes towards safety at the university level would have a direct impact on research. A joint research program on selected safety-related topics may provide insights to bring about a change in current academic laboratory security scenarios and provide opportunities for careers in safety science. An independent study of different safety characteristics of each chemical would throw light on possible physical risks, provide adequate information to foresee and prevent accidents by taking proper precautions for its safe handling.

It is time to set up the global level academic safety council and national level laboratory safety regulatory authority to frame safety policy, recommend improvements, monitoring safety standards, and incident reporting on scientific research/academic laboratories to foster growth and development in the area of fundamental and applied science, engineering, and technology. It is necessary to constitute a national academic safety council or safety enforcement directorate (SED) with safety experts to look into various aspects of laboratory safety. Establishing a laboratory accident fund can cater to injury or death and provide appropriate compensation. Formation of a safety resource center (SRC) with a national safety network with the necessary knowledge, skills, and information about safety devices helps in the implementation of safety objectives. The department of safety policy and promotion at the university level should monitor the various organizations through lab safety and compliance program. Multidisciplinary safety committees at the institute level should strictly enforce control in all science laboratories and demonstrate a new way of safety education, and reward quality over quantity will transform the way the university functions. A planning and construction division can manage and monitor funds for development projects responsibly. A resource center should be established in select universities to conduct regular refresher courses on safety. The extra and sustained efforts towards safety with the right intent and on a priority basis is the key to bringing in change. A sustained and systematic effort to nurture the safety culture by facilitating a favorable learning environment is required. It is crucial to share knowledge, skills, and attitude aspects with chemical safety communities and implement regulations through safety officer/inspector and faculty resource and action initiative (FR & AI). Further, incentive award for institutions or individuals for their outstanding contribution in the safety field would encourage innovativeness. It remains to be seen if the detailed roadmap for the future would lead to significant results while we ultimately act in the general interest of society. We can hope to have a considerable impact on work-life by further evolution in laboratory technology and practice resulting in enhanced safety culture and a decline in the laboratory fatalities in the coming years.

NOTES

1. https://www.smah.uow.edu.au/chem/ohs/UOW016874.html (accessed June 2020)
2. https://www.icheme.org/lpb (accessed June 2020)
3. https://www.wired.com/.../humans-have-made-found-or-used-over-50-million-unique... (accessed June 2020)
4. https://www.cdc.gov/niosh/homepage.html (accessed June 2020)
5. https://www.ilo.org/safework/info/instr/WCMS_183524/langen/index.htm(accessed June 2020)
6. https://www.mhrd.gov.in/sites/upload_files/mhrd/files/statistics/AISHE2011-12P_1.pdf (accessed June 2020)
7. https://www.chemicalindustryarchives.org › fact and fiction (accessed June 2020)
8. https://www.osha.gov/ (accessed June 2020)
9. https://www.cancer.org/cancer/cancer.../known-and-probable-human-carcinogens.html(accessed June 2020)
10. https://www.en.wikipedia.org/wiki/List_of_highly_toxic_gases (accessed June 2020)

11. www.labsafetyinstitute.org/LabSafetyGuidelines.html (accessed June 2020)
12. https://www.labmanager.com/lab-health-and-safety(accessed June 2020)
13. https://www.oshatrain.org/courses/studyguides/715studyguide.pdf (accessed June 2020)
14. http://www.cen.acs.org/articles/87/i31/Learning-UCLA.html (accessed June 2020)
15. https://www.sciencelab.com/sdsList.php (accessed June 2020)
16. https://www.safetystoragecentre.co.uk › Advice Centre (accessed June 2020)
17. https://www.epa.gov/iaq/ (accessed June 2020)
18. https://www.pistoiaalliance.org/projects/chemical-safety-library/ (accessed June 2020)
19. https://en.wikipedia.org/wiki/Laboratory_information_management_system (accessed June 2020)
20. https://www.ccohs.ca › oshanswers › chemicals › ghs (accessed June 2020)

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