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Interwoven, Navrachana University's peer reviewed interdisciplinary journal, weaves together a wide range of ideas to offer a layered mosaic of scholarly work. Peer reviewed journals are essential for academic work as they bring new rigor to make corrections and also a completely new perspective to the proposed idea.

Interwoven offers a platform to present scholarly articles that are disciplinary and non-disciplinary, and engage in a rich academic discourse. Non-disciplinary articles, because of their generalistic content provide a means for all readers to find a common ground to connect and get involved regardless of their expertise. Disciplinary work, on the other hand, is presented in a form that non-disciplinary readers can read, understand and participate in an academic discourse to reflect, reinvent and expand traditional disciplinary boundaries.

Aim and Scope

Interwoven is a double blind peer reviewed interdisciplinary journal of Navrachana University, published online biannually. The journal covers inherently general topics as well as specialized topics written for readers from wide backgrounds. The effort is to build a strong interdisciplinary academic and research culture in the society.

Regarding review process, there is a strong criteria established for an article to be considered for revision, acceptance or rejection. Every article undergoes check for Plagiarism. Each article is reviewed by three referees.

Interwoven has been granted an e-ISSN number (2581-9275). We strongly encourage faculty, scientists, postdoctoral fellows and research scholars to contribute their scholarly work in the form of research articles, review articles, perspectives, critiques, book reviews and articles in social research. We look forward to expand our authors and readers network and set a benchmark in the process of growth for students, faculty, University and the society at large by spreading awareness about various knowledge domains. We also encourage undergraduate and postgraduate students involved in dissertation work to write journal articles and promote new research ideas to expand their vision beyond standard academic curriculum.

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Impact of Prolonged Covid-19 Pandemic Lockdown on Residential Institute of Underprivileged Children and its Functionaries, Managed by an NGO - A Case Study

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Abstract

Closure of schools, colleges/universities, institutions across the world due to the outbreak of COVID-19 pandemic has impacted the education of children in an unprecedented manner. There are more than 2.2 billion children in the world who constitute approximately 28% of the world's population and children aged between 10 to 19 years make 16% of the world population.[1]. Though, NGOs/voluntary organizations, teachers & students are quickly shifting from traditional face to face education mode to online education mode using technology and less dependence of classroom education, there is a limitation of creating a replica of school system.[2,3,4,5]. The long-term closure of schools/colleges/institutions and uncertainty of re-opening, being quarantined due to infection or fear of infection has led to physical and mental health conditions of the economically weaker section and /underprivileged children.[2,6]. It is felt necessary to study the impact of COVID-19 lockdown on underprivileged children's education, and physical health. A study of Vadodara based NGO which is engaged in educational development of underprivileged children was undertaken to understand the impact on education, and physical health of the underprivileged children staying at the hostel premise of the NGO and how NGO functionaries and the children are coping up with COVID-19 pandemic challenges. For the study, NGO and the participants of the NGO were selected using

purposive sampling technique. The participant includes functionaries, teachers & children of the NGO. The total number of participants were thirty (*n=30*). The major findings are, 1) There is a substantial impact on the education of the children due to closure of schools, 2) Children are engaged more in extracurricular activities such as sports, art & crafts, music, dance, cultural programs, skill-based activities, pottery work, cooking, garden maintenance etc. to cope up COVID-19 lockdown boredom and keeping good mental and physical health, 3) Awareness has increased among the children, staffs, teachers, volunteers regarding hygiene conditions, good health, prevention against COVID-19 infection, 4) In-spite of availability of various facilities for education, extracurricular activities etc., at NGO's hostel premises, the children are missing school structure and school environment, 5) NGO has initiated to create more classrooms buildings, expanding IT infrastructure to support online teaching mode, and augmenting teachers to nearly replicate school structure at hostel premises.

Keywords

COVID-19 Pandemic, Lockdown, Underprivileged children, Non-Governmental Organisation (NGO), Health, Holistic Development

Introduction

In pre-covid-19 lockdown era, learning of the children predominantly involved more face-to-face interaction with the mentors and peer groups. Nationwide closure of schools and colleges for a prolonged period due to COVID-19 pandemic and lockdown have negatively impacted over 91% of the world's student population.[7]. 332 million children globally, have lived under extended lockdown and left vulnerable to mental and physical health issue.[8,9]. Schools for more than 168 million children globally have been closed which resulted COVID-19 education crisis.[9]. The home quarantine/confinement of children is associated with uncertainty and anxiety which is attributable to disruption in the education, physical activities and opportunities of socialization.[2]. Absence of structured school environment for a long duration result in disruption in routine, boredom and lack of innovative ideas for engaging in various academic and extracurricular activities. The children missed outdoor play, meeting friends and not able to engage themselves in the in-person school activities.[10]. The children have become more clinging, attention seeking and more dependent on their parents due to the long-term shift on their routine. Once the COVID-19 lockdown gets over, the children might resist going to school

and many will face difficulty in establishing rapport with their mentors after schools are reopened. Consequently, the constraints of movement imposed on them can have a long-term negative effect on their overall psychological well-being and holistic development [8]. Children are anxious regarding cancellation of examination and/or multiple postponement/changes of examination schedules, exchange program and academic events.[2,7].

COVID-19 impact on Education, mental and physical health of Underprivileged children

In many urban areas of India, the underprivileged children which includes street and slum children, children of construction labour mainly belong to short term or long-term migrant labourer family who have migrated from rural to urban (from other states and /or within states/region) for better life/earnings. They live in cramped houses or shabby dwellings, without proper sanitation facilities, clean drinking water, electricity etc.[11, 12]. Mainstreaming these children in development process is a big challenge in attaining the goal of universal primary education and inclusive growth in India. [13]. The underprivileged children who are economically, socially and regionally in an unfavorable situation compared to the rest of the population of the society, are always denied or deprived of the privileges available to the people of upper class.[5,14,15]. The underprivileged children have low motivation to learn, low cognitive abilities, low self-esteem, poor readers and slow learners. However, they have greater sense of independence and responsibility.[5,14,15]. The COVID-19 pandemic and lockdown the world has experienced, has worsened the pre-existing social inequality. In developing countries, with the impose of lockdown, the underprivileged children face acute deprivation of nutrition and overall protection. The prolonged stress could have a long-term negative impact on their immunity and holistic development [8]. In India, which has the largest child population in the world with 472 million children, the lockdown has significantly impacted 40 million children from poor families. [16]. Due to no earnings or loss of jobs of their parents/guardians in COVID-19 lockdown, the underprivileged children to face abuse and mental health issues with greater vulnerability and exposure to unfavourable economic, social and environmental circumstances.[17,18]. Due to closure of schools and limited resources of NGOs for organizing online classes, the underprivileged children are more affected in-terms of their education and overall well-being. A study is undertaken at the hostel premises of an NGO to understand the extent of impact on education, mental and physical health of the underprivileged children

staying at the hostel premises and how NGO functionaries and the children are coping up with the prolonged COVID-19 pandemic lockdown challenges.

Study of Vadodara based NGO

The focus areas of NGOs in general are education, community development, healthcare, nutritional food for children, sports & cultural activities, women empowerment, environment, relief activities, advocacy, financial support to bright children for higher studies, child labour protection, child abuse and sexual harassment, family planning etc.[11,19,20]. The main focus of the Vadodara based NGO selected for the study, is to up-lift the underprivileged section of the society and work towards educational and holistic development of the underprivileged children.[11,21].

Objectives of study

1. To study the educational set-up at hostel premises
2. To study the effects on children's education and health due to prolonged school closure because of COVID-19 pandemic and nationwide lockdown
3. To study the challenges faced by the functionaries of NGO during COVID-19 pandemic and how they are copping-up with the challenges
4. To study the initiatives and measures taken by the NGO functionaries to keep the children engaged for their better education, mental and physical health

Design of the study

A case study gives an indepth investigation of a single individual, group or an event to explore the cause of underlying principles and commonly used in social study. The researcher has chosen case study method in his research design to make an intensive study of the case to explore the impact of COVID-19 pandemic on residential institute of underprivileged children and its functionaries managed by an NGO

Procedure for selection of the case

Vadodara city being a fast-developing urban area of Gujarat state, population of underprivileged children who stays in slums/on streets is in the rise due to their migration with their parents/relatives from other states and/or from other part of the state for job opportunity and better life. Though there are no recent data available about the number of underprivileged children who stays in slums areas or on streets of Vadodara city, 2016 survey conducted by

National Child Labour Project Society in Vadodara, under Ministry of labour and Employment, found that 1,611 children between age group 6-14 were residing on the streets of Vadodara city. In Vadodara, the NGOs who are engaged in educational development of the underprivileged children of the society, have taken various initiatives towards the social upliftment of these underprivileged children through education. Purposive sampling helps to make most out of a small population of interest and arrive at valuable research outcome. Purposive sampling also helps in filtering irrelevant responses that do not fit into the context of the study. Therefore, the researcher has chosen purposive sampling technique to choose one out of three NGOs who have established residential facilities for the underprivileged children in Vadodara for their holistic development with education as main focus. The main reason of not covering other two NGOs are, a) majority of the children went back to their home during COVID-19 pandemic lockdown, b) permission for carrying out the study was not given by the gatekeeper due to COVID-19 restriction and fear of infection, whereas all the children and resident functionaries of the case selected for the study, stayed back in the hostel and permission obtained from the gatekeeper of the case, Srotoshwini Trust, a Vadodara based NGO, for carrying out the case study. The case was registered as an NGO in the year 2010 under Indian Society Act 1950, and are active for 10 years in the field of education of underprivileged children of Vadodara city. The NGO studied satisfy the stringent conditions of transparency, governance and demonstrate impact on beneficiaries and represent most mature Vadodara based NGO in the sector in-terms of size and scale.

Background of the case

Srotoshwini Trust, Vadodara was formed as an association in the year 2006 by a group of likeminded empowered women of Vadodara city and their main activities were promoting and performing cultural programmes, raising funds and donating to charitable organisations. In the beginning of 2010, the Trust registered as an NGO and started working for the educational and holistic development of the underprivileged children which includes street children, children living in slums, children belong to economically weaker section and children living at construction site of Vadodara city. In the year 2019, the Trust established a residential campus "Pathshala" in village Lasundra, Savli Taluka of Vadodara district with a capacity for 100 underpriviged children and nine resident functionaries, teachers and staff. As of June 2021, 94

underprivileged children, both girls and boys, are staying at "Pathshala" hostel premises. President of the Trust who stays in the hostel remarked during the interview,

The residential facilities along with various infrastructures for extracurricular activities for underprivileged children are necessary for the holistic development of these underprivileged children. The main aim of the Trust is to provide basic needs for education, nutritional food, medical support, extracurricular activities, soft skill development, career path counselling, livelihood generation training and mainly emotional needs, which are generally available to the mainstream children of our society.

Educational set up at Pathshala hostel

The NGO has developed their own curriculum and followed the syllabus of the Gujarat State Education Board. The children are attached with a school which follows Gujarat State Education Board syllabus and National Institute of open schooling (NIOS) education system. The president of the Trust said, "We preferred NIOS education system for these underprivileged children due to their age and learning level". NIOS, a non-formal education system set up by ministry of education, government of India in the year 1989, is one of the three boards at national level. The main objective of NIOS education system is to remove the obstacle related to age, financial, geographic, infrastructure and time. The children who are unable to attend conventional formal education can complete primary, secondary and higher secondary level examination through NIOS board and the examination certificate issued by NIOS board is considered at per with the certificates of formal education board such as CBSE/ICSE. In view of the above, all the children of Pathshala are enrolled with NIOS examination board. In addition to school teaching, which is presently closed due to COVID-19 lockdown, the paid teachers and volunteer teachers appointed by the NGO, visits hostel premises from 9 AM to 12:30 PM and impart teaching to the children according to the curriculum. The Trust has launched new initiative "UDAAN", a career counselling programme for the children of standards VIII to XII. This is now a part of the curriculum. The Trust has developed basic educational infrastructure, online teaching for standards VIII to XII children, sports infrastructure, art & craft section, livelihood generation training such as pottery, stitching, painting etc. Trust appoints teachers who are proficient in Gujarati and Hindi for majority of the children are studying in Gujarati medium and few in Hindi medium. For

managing the hostel activities, two resident teachers, two functionaries, two female supervisors, and two male security staffs are staying at hostel.

Sources of data

The study was conducted at NGO's "Pathshala" hostel premises at Lasundra Village. The sources of data were the resident functionaries, teachers & children of the NGOs and the documents of the NGO.

Nature of data

The nature of data - Qualitative

Participants of the study

The participants of the study were functionaries, teachers & students of "Pathshala" hostel managed by the NGO. Total participants were thirty (*n=30*). The details of participants are given in Table 1 below.

Sl.No	Description	Numbers of participants
1	Functionaries (Trustee members / managing committee members)	3
2	Teachers (paid & volunteers)	4
3	Children (*n1*)	23
4	Total:	30

Table 1: Details of participants

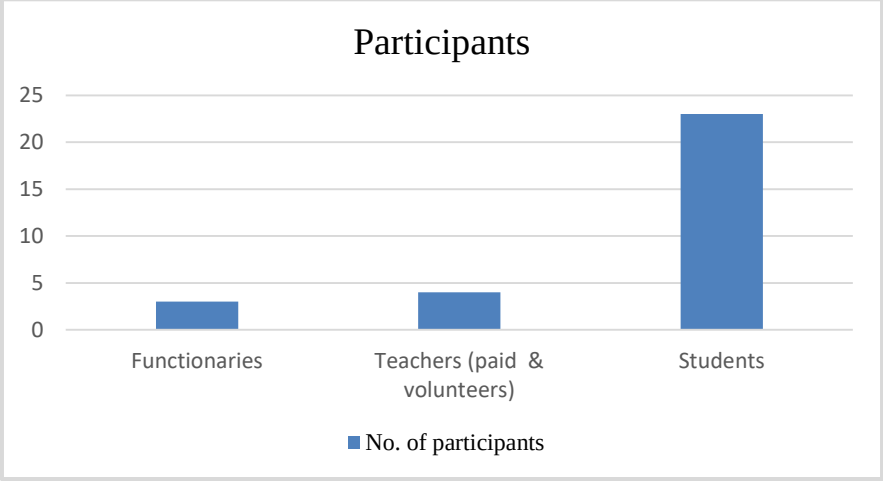

Figure 1: Number of participants

The class, age and gender of children (*n1=23*) is given in Table 2 below. The percentage of female and male children is given in Figure 3 below. Out of 94 children staying in the hostel, 47 children who are aged below 11 years and studying in class junior Kg to class III and 18 children who are of age 11-12 years but studying in class 3 or lower class depending on their knowledge level, were not covered in the study. 23 children of age between 8-18 years and studying in class IV-XI were selected from the balance 29 children using purposive sampling technique to have better insight and more precise research results, and also to filter out the irrelevant responses which do not fit into the context of the study. The details of children's gender, age and class are mentioned in Table 2 below.

	Age			Class			Total
	8-11	12-15	16-18	IV-VI	VII-IX	X-XII	
Girls	2	6	4	5	3	4	12
Boys	2	6	3	5	3	3	11
							n = 23

Table 2: Details of children's gender, standard and age

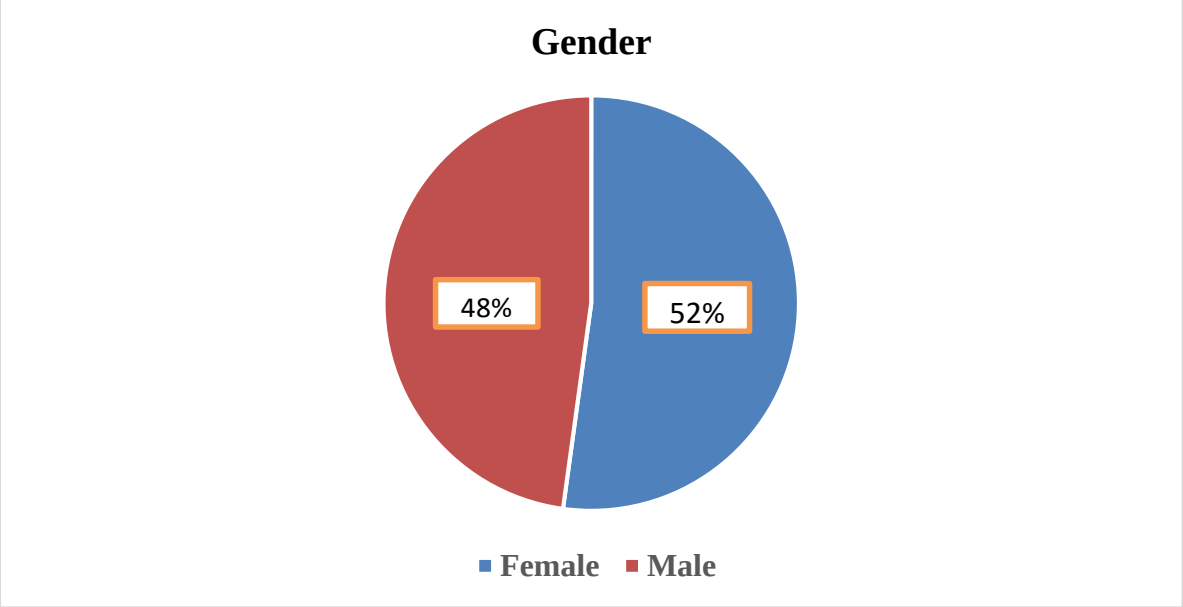

Figure 2: Percentage of female and male children

When the study was conducted in June 2021, 94 children, both girls and boys, were staying in the hostel. To have a reasonably accurate data, the sample sizes of girls and boys are made almost equal. The data collection period spanned from 4th June 2021 to 21th June 2021.The primary data collection tool used in the study is field notes.

Tools

The COVID-19 pandemic which is a global issue, is altogether a new experience/challenge for the residents of Pathshala hostel and the researcher. The researcher has used unstructured interview as tool to get qualitative data spontaneously from the participants. The other purpose of using unstructured interview is to develop questions during the interview which are based on the interviewee's responses. However, the researcher has used few pointers based on the objectives of the case study. English & Hindi languages were used for interviews with the functionaries and teachers. Gujarat and Hindi languages were used for interviews with the children. The researcher is reasonably proficient in English, Hindi and Gujarati language, hence no translator(s) are used for translation of data.

Data collection

Two-way data collection was made: a) Primary data collection by un-structured interview, b) Secondary data collection from quarterly newsletters, annual reports, brochures, and web site. The main pointers or the frame work within which the unstructured interview was conducted

are a) Effect on children education, b) coping up with mental stresses, c) keeping healthy, d) fear of COVID-19 infection, e) face-to-face teaching Vs online teaching, f) positive effect of COVID-19 lockdown etc. The unstructured interviews with functionaries and teachers were of 40 to 60 minutes each. The unstructured interviews with children were of 15 to 20 minutes each. The data collection period spanned from 4th June 2021 to 21th June 2021 and the site of the unstructured interviews was Pathshala hostel campus, Lasundra village, Savli Taluka, Dist. Vadodara.

Data Analysis

The data and documents collected in the study were analysed using the technique of content analysis.

Findings of the study

The major findings of the study are presented below.

Effect on children's education and health due to prolonged school closure because of COVID-19 pandemic and nationwide lockdown

The summary of findings of the effect on children's education and health due to prolonged school closure because of COVID-19 pandemic and nationwide lockdown, and how the children are coping up with the challenges are mentioned below.

- The education of the children is affected substantially due to closure of school. Children of class IX-XI are worried for re-scheduling of examination and/or cancellation of examination. They are of the opinion that there is a negative impact on their education level due to school closure. During the interview with Ajay, 18 years old boy, student of 1st year Diploma in Mechanical Engineering and class XI standard (NIOS system), mentioned,

  There is an impact in our education level due online teaching process of various engineering subjects and postponement of examinations on account of COVID-19 lockdown. Engineering drawing, practical courses are difficult to understand in online classes. The teachers completing the course rapidly without verifying our understanding level. We do not know when the examination will take place. We lost nearly one year.

Rani, 18 years old girl, studying in class XI also expressed her unhappiness during the interview,

I worked very hard to get more percentages in 10th examination. But no examination held. There is a mass promotion based on class performances. I got only 53 % whereas I worked very hard targeting more than 80 %.

- All the children are missing the school environment. They prefer face-to-face teaching over online teaching mode. Mamta, 16 years old girl and studying in class XI mentioned,

  We are missing the school environment, school teachers who teach us well, explain with examples, we also miss our friend with whom we can discuss our personal matters, we help each other in studies, we study together, eat together and play together. In-spite of many facilities are available at Pathshala hostel and the resident teachers are providing motherly care, school environment is different and a different feeling
- Children who are attending school's online teaching sessions facing difficulties due to one sided communication, disruption in audio and video quality, no repeat clarification from teacher due to paucity of time. During the interview with Jyoti, a 16 years old girl, studying in class XI, explained,

  Though online education started in COVID-19 lockdown, but we are facing difficulties in math and science. We are not able to understand. For us, face-to-face teaching would have been better.
- Though, more teachers have been augmented by NGO management and various facilities created at hostel premises for more extracurricular activities, children are eagerly waiting for opening of the school. Diva, 14 years old girl, student of class IV expressed her feeling during the interview,

  We are missing the bus travel from Pathshala hostel to school. It is a fun for us and a change of outlook. Playing 'Antaksari', scenery etc. during the travel are refreshing. We will prefer face-to-face teaching over online teaching.
- They are not much afraid of COVID-19 infection for they are not going outside the hostel campus, well aware of COVID-19 preventive measure, strictly following the COVID-19 protocol as per the guidance and advises of resident mentors/teachers
- They are worried about their parents/relatives for the fear of their COVID-19 infection. They talk to their parents / relatives once in a week which give them comfort about their

safety at home. Tejal, 14 years old girl and a student of class VIII shared during the interview

We are worried about our parents for they are staying in Village. They generally do not follow covid-19 precaution guidelines. They may get infected with COVID-19. They also can't visit us due to COVID-19 lockdown and fear of infection. We talk to our parents/relatives once in a week. We feel happy.

- The resident mentors / teachers / staffs are taking additional care and meeting their emotional needs which has alleviated their COVID-19 pandemic fear. Children are engaged more in extracurricular and livelihood /skill development training to cope-up the stresses arising out of prolonged COVID-19 lockdown
- During this COVID-19 lockdown period, they have learnt respect for the people, cooking, organic farming, gardening, hostel maintenance activities, understand each other better, team work, music, singing, soft skills, technical skills, use of digital devises, how to cope-up emergency situations etc. They consider these are the positive side of COVID-19 pandemic in-spite of staying in confined place for more than 14 months. During the interview with Hasina, 16 years old girl and student of class X explained,

  Though we are staying in a confined space i.e., in hostel premises for more than 14 months, we did not felt boredom for we are busy in extracurricular activities, competitions, dance performances, art & craft, painting, music, pottery making etc. We learnt how to cook, we learnt sewing machine operation, we learnt playing music, organic farming.

  Pran, 17 years old boy and student of 10^{th} standard mentioned during the interview,

  The most important benefit of COVID-19 lockdown is that we understood each other better, we learnt how to face the difficult situation as a team, how to handle and overcome pandemic situation such as COVID-19 which is a problem for the whole world. We learnt how to respect all whether younger than us or elder".

Challenges faced by the functionaries of the NGO during COVID-19 Pandemic and measure taken to cope up with the challenges:

- To synchronized with school's online teaching programme for class IX-XII during COVID-19 lockdown due to lack of digital devices, poor network connectivity, shortage of classroom etc.

- NGO's infrastructure development is mainly funded by the Corporates through their CSR funds. COVID-19 Pandemic was never envisaged by the NGO while making budget in the beginning of 2020 for the financial year FY2020-21, nor they had accrued fund for augmenting their existing IT infrastructure and other facilities to reap the benefit of school's online teaching programme.
- Teachers are facing difficulties in monitoring and assessing the children's learning performance in school's online education system
- Due to limited classrooms / space, children from different standards attend online classes in the same room
- Unable to replicate the school structure at hostel premises. Teachers need to teach multiple classes in a single batch and more than one subjects
- Keeping the children busy 24 hours a day is a most challenging job and that too for more than 14 months. During the interview with the functionary, F1, she remarked,

  "We, the resident mothers and supporting staffs, find it extremely challenging to manage 94 children for 24 hours. When the school was open, the children use to leave the hostel at 1 PM and returns from school at 7 PM. There was some time available with the resident mothers to take care of other activities. Now the children are inside the hostel premises for 24 hours and more than 14 months. We had to innovate new ideas to keep them busy and engaged them in study, extracurricular activities, competitions, hostel works etc.

- Idea creation to keep the children busy and nurturing their mental and physical health
- Creating awareness among children and staff regarding severity of COVID-19 pandemic and strict adherence to COVID-19 protocols as per the advices of Ministry of Health & Family Welfare (GoI, 2020) / World Health Organization (WHO,2020). One of functionary, F2, of the Trust explained the actions taken to prevent / avoiding COVID-19 infection as below,

  We conducted multiple awareness sessions at hostel on COVID-19 preventive measures. Strict implementation of measures suggested by Indian Council of Medical Research (ICMR) and World Health Organization [WHO] (2020). The basic precautions taken by all children, resident mothers / staffs, visiting persons are wearing

mask, social distancing, regular sanitizing / hand washing, cleanliness, not allowing children to go outside of the hostel campus, restriction on outsider's entry in hostel, periodic COVID-19 check / RTPCR test of children and other residents as and when required. We provide them nutritious food, Vitamin C tablet per day to boost the immunity.

- To arrange fund for augmenting online infrastructures, additional teachers, COVID-19 testing (RTPCR) for the children etc. The president of the Trust explained how they cope up with the challenge,

  The existing infrastructures were rearranged, curriculum revised, resident functionaries, hostel supervisors were engaged in teaching-learning process to mitigate the challenge to the extent possible

Actions implemented and new infrastructure / facilities planned by NGO to cope-up with present and post COVID-19 challenges – education, mental and physical health of children

- Created awareness among the children and resident staffs on various preventive measures to avoid COVID-19 infection. Provided COVID-19 immunity boosting vitamin tablets, nutritional foods etc.
- Strict adherence to COVID-19 protocol for all
- RTPCR testing for all the children and staff. Arranging vaccination (single or double as the case maybe) for children / staff
- Created online classroom set-up with digital devices (computers, smart phones, tablets), internet, audio system etc. for the children of 9th to 11th standard for attaining school's online teaching sessions
- Augmented teaching staff strength from eight (8) in pre-COVID-19 era to seventeen (17) to replicate school structure, career counseling for 10th and 11th standard students, soft skills training, livelihood generation training and engaging the children more in extracurricular activities such as sports, music, singing, dancing, art & craft, competitions, cultural performances etc.
- Involved children in gardening, Organic farming, cooking, equipment maintenance, pottery, skill-based training to keep them active and in good mental & physical health

- Encouraging children for interaction with parents / guardians to meet their emotional needs and alleviating fear about parents' wellbeing in COVID-19 pandemic
- New projects such as construction of more classrooms – one classroom for one standard, more IT infrastructure including smart TV, Network with more bandwidth, enhancing solar power generation capacity etc.

Analysis

Overall analysis of the findings is summarised below.

- Poor network connectivity, absence of suitable pedagogy, and the psychology of underprivileged children emerged as few critical impediments for effective implementation on online education mode and making online education mode a suitable substitute for face-to-face education mode
- Lack of past experience in handling COVID-19/similar global pandemic affected the education of the underprivileged children staying in Pathshala hostel
- COVID-19 pandemic which is a global challenge has made the NGO to reimagine their approach towards the education development programme and well-being of the underprivileged children
- Due to fund constraints and limitation of infrastructure facilities, the NGO could not respond quickly to COVID-19 challenges by creating a school like environment at Pathshala hostel campus
- Unfavourable conditions made the children, resident teachers, functionaries of Pathshala hostel to innovate new curriculum to keep the mental and physical health good and minimizing impact on education/loss of learning of the underprivileged children
- The children learnt new skills which are the positive side of COVID-19 pandemic

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Relation of Adult Neurogenesis in Alzheimer's Disease: A Review on Past, Present and Future Implications

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Abstract

Alzheimer's disease (AD) is a neurodegenerative disease attributed to the loss of neurons causing memory loss and cognitive decline. Many low-grade neurological insults are associated with AD but the ones that have been mostly studied are pathological build-up of amyloid protein ß and hyperphosphorylation of microtubule associated protein tau. Adult neurogenesis is the phenomenon of formation of new neurons in healthy brain via neural stem cells (NSCs). Loss of extrinsic signaling (physical activity, dietary intake) results in impaired neurogenesis during AD, making it a probable biomarker for AD. The alteration of proliferation, differentiation, migration, and integration processes are involved in neurogenesis is clearly evident during AD. Thus, the possible targets for the therapeutic purpose of AD, are interleukin-4 (IL-4), brain-derived neurotrophic factor (BDNF), interleukin-6 (IL-6), fibronectin type III domain – containing protein–5 (FNDC5) which helps to improve the proliferation and integration of the neural stem cells. Studies carried out in mice models suggest an intrinsic and extrinsic correlation of NSCs for the treatment of AD with an aim to reverse the neurodegeneration. The present review focuses on the novel markers like DCX, NeuN, Sox2, calbindin and Nestin involved in adult neuronal development and its role in pathophysiology of AD. Moreover, this review opens up new avenues for treating AD and developing molecular markers for it.

Keywords

Alzheimer's, amyloid ß, adult neurogenesis, therapeutic, biomarker

Introduction

Alzheimer's disease (AD) lays its origin from 1906 where Dr. Alois Alzheimer first identified Alzheimer's disease in a female patient named Auguste Deter [1]. Epidemiologically, AD affects approximately 5 million people in the US and this number is expected to rise by 35 million by 2050 [2]. In 2015, India reported 4.1 million cases of people living with dementia. Dementia affects 2.7 percent of the population in India, according to epidemiological studies conducted between 1996 and 2006, with Alzheimer's disease being the most common cause (1.3%) [3]. It was estimated in 2010 that 36.5 million people were living with dementia, with 7.7 million new cases each year and a new case of dementia every 4 seconds [4]. The World Health Organization (WHO) estimated that 0.379% of the world's population suffered from dementia in 2005 and its prevalence will increase to 0.441% in 2015 and 0.556% in 2030 [5]. Histological characterization of AD revealed extracellular deposits called cerebral plaques in neocortex and hippocampal region and are made up of a thick proteinaceous core containing the amyloid β (Aβ) peptide surrounded by dead and weakened neurons. The other histopathological hallmarks are the filamentous, hyperphosphorylated form of the microtubule-associated protein tau which forms neurofibrillary tangles in neurons of the same regions of the brain [6]. Although most cases of AD occur occasionally, about 5% of patients develop an early disease as a result of a completely penetrant autosomal dominant gene mutations (APP, APOE, PSEN1, PSEN2) [6]. Till now, evidence pertaining to the specific remedies in preventing Alzheimer's disease remains elusive [7].

As discussed, AD mostly affects the hippocampal area in the brain[8]. Hippocampus is one of the areas in the adult brain where evidence of neural stem cells (NSCs) are documented [9]. Adult NSCs are capable of producing new neurons throughout life in two major parts of the adult mammalian brain: the subventricular zone (SVZ) of the lateral ventricle and the sub granular zone (SGZ) in the dentate gyrus (DG) of the hippocampus [10] this process is called adult neurogenesis. This process consists of different stages such as neural stem cell proliferation, lineage differentiation, migration and the integration of the developing neuron in the pre-existing circuit of the brain. Adult neurogenesis is related to the physiological

functioning of the brain and degeneration. Zhao et al (2008) observed changes in the pattern of neurogenesis which were associated with many neuropsychiatric disorders.

In most cases adult neurogenesis is reduced during AD which is found in SVZ and SGZ. Concurrent studies show a dilemma in the decrease/increase neurogenesis in the brain of mice and human subjects affected with AD [11,12]. Furthermore, reduction of new born neurons causes cognitive defects in AD mice [13]. In line of this, the present review discusses the use of impaired adult neurogenesis in AD as a possible potential therapeutic biomarker for predicting the progression and effective treatment for the disease.

Pathophysiology of Alzheimer's disease

The early onset of familial AD is due to genetic mutations in the amyloid precursor protein (APP), presenilin proteins - PSEN1 and PSEN2 [14]. Apolipoprotein E (ApoE) is the strongest genetic risk factor for sporadic AD [6]. Alzheimer's disease (AD) is thought to occur when increase in the abnormal amounts of Aβ accumulate extracellularly forming amyloid plaques. Tau proteins accumulate within cells causing the formation of neurofibrillary tangles in the brain, affecting neuronal function, connectivity and causing progressive brain function loss [15] [16]. Moreover, microscopically the main attribute of AD is the loss in the cerebral cortex of neurons and synapses and the hippocampal portion of subcortical regions due to accumulation of misfolded Aβ and tau proteins [17,18,19]. These losses result in deterioration of the temporal and parietal lobes and severe atrophy in the affected area, including parts of the frontal cortex and cingulate gyrus. Studies using MRI and PET show that the size of affected brain regions in AD patients decreases as they progress from mild to severe cognitive impairment as compared with healthy older adults [20]. Aβ plaques are formed when amyloid precursor protein (APP) undergoes complex sequential proteolytic processing in the CNS through two main processing pathways called amyloidogenic and non-amyloidogenic processing pathways [21]. This APP which is a transmembrane protein is encoded by APP gene which has also gained attention due to high rate of mutation. Thus, misfolded plaques containing small peptides of 39-43 amino acids long are called beta-amyloid (Aβ). APP is important for nerve cell growth, survival, and damage recovery [22,23].

Several enzymes are known to cleave APP at several amino acid positions near C terminal. For instance, α-secretases acts on APP, 83 amino acids from its carboxyl terminus, which belongs

to ADAM protease family ("A disintegrin and metalloproteinase"). Whereas, the β-secretase enzyme contains two or more different complexes called BACE1 and BACE2 which cleaves APP at 99 amino acids from its carboxyl terminus. The third type of APP cleavage is provided by the enzyme complex γ-Secretase. Presenilin-1 and Presenilin-2 mediate the catalytic function of γ-Secretase and is encoded by PSEN1 and PSEN2 gene. APP is cut twice by γ-Secretase generating a 50 amino acid peptide which consists of the APP C-terminal end, and is named as the amyloid intracellular domain (AICD). The second γ-secretase fragment is slightly variable, but tends to be located at 57, 59, or 61 amino acids at the C-terminus of APP. Sequential processing with α- and γ secretases yields a large N-terminal peptide called soluble APPα (sAPPα) and a smaller 3kDa peptide called P3. β-secretase cleavage produces a large N-terminal peptide called soluble APPβ (sAPPβ) and a smaller C-terminal fragment called CTFβ. The γ-secretase cleaves CTFβ, and the Aβ peptide. Depending on the continuous activity of β-γ-secretase, the exact cleavage site of γ-secretase varies, resulting in Aβ peptides, which are usually 38-43 amino acids in length [24]. The α-secretase enzyme in the "nonamyloidogenic pathway" appears to exhibit neuroprotective activity by cleaving APP at the Aβ sequence and releasing the sAPPa fragment through the membrane [6]. Primarily in the hippocampus, neurofibrillary tangles consisting of paired helical filaments are present in the cytoplasm of neurons [25].

Neurofibrillary tangle formation in AD is directly related to protein dysfunction. Tau is a microtubule-associated protein that plays an important role in supporting axonal transport and promoting cellular stability. The main polypeptide of the paired helical filaments is the microtubule-associated protein tau. Tau levels in the AD neocortex are 7 times higher than in the control aged brain group, and this elevation is a result of abnormally phosphorylated proteins (Iqbal and Grundke-Iqbal, 2007). Hyperphosphorylation of τ reduces the binding of τ to microtubules and disrupts subsequent axonal transport [26]. Abnormally hyperphosphorylated tau has shown to have a neurodegenerative effect by inhibiting microtubule function, impairing axonal transport of neurons, and enhancing functional toxicity by forming paired helical filaments [6]. Apart from phenotypic markers, others like inflammatory processes, cytokines and growth factors (BDNF) are attributed to play a role in the pathophysiology of AD. Tissue damage is marked by an elevated immune response resulting in inflammation at the affected site which are considered to be the signs of secondary damage to the tissue [27]. Similarly,

changes in the distribution of various neurotrophic factors such as the brain neurotrophic factor (BDNF) and the expression of its receptors have been found to be associated with AD [28,29].

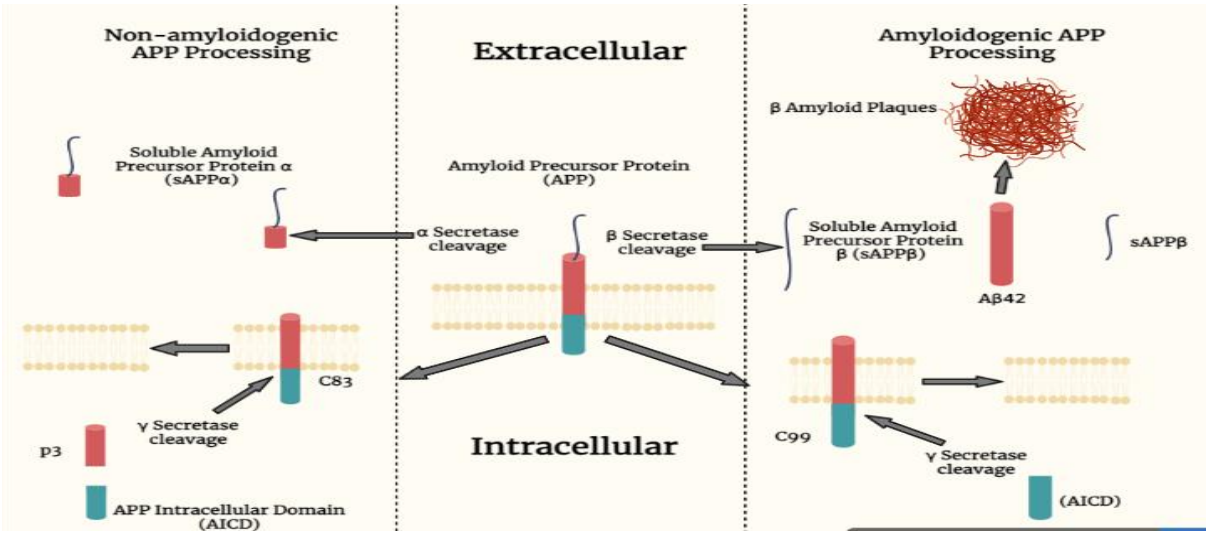

Figure 1: Generation of soluble APP peptides (sAPPα, sAPPß) is processed due to the cleavage by α-secretase, ß – secretase or γ – secretase. The C-terminal membrane anchored fragment (C83) yields P3 peptides by γ – secretase depicting the major secretory pathway which is non-amyloidogenic. The presenilin/nicastrin-mediated γ-secretase processing yields amyloid beta proteins, amyloid-beta 42 (Aβ42) from C99 fragment. Aβ42 is the major component of amyloid plaques.

Adult neurogenesis in the healthy brain

Traditionally, it was believed that no new neurons are produced after birth [30]. But in the late 50s new method on labeling techniques was developed for dividing cells with [H3]-thymidine, that incorporates into the replicating DNA during the S-phase of the cell cycle, and can be detected with the help of autoradiography [31]. Generation of new neurons has already been reported in the embryonic stages of mammalian CNS by Cajal et al, while using the above mentioned technique pioneering work done by Altman and colleagues demonstrated the adult neurogenesis in rats various brain regions, which includes the dentate gyrus [9], neocortex [32] and olfactory bulb [33]. Advancement in staining has been done by [34] where they have used BrdU a synthetic thymidine analogue, for the detection of neuronal proliferation in mammals.

Adult neural stem cells (NSCs) are responsible for the generation and differentiation of new neurons, which were first isolated from the adult CNS of rodents [35] and later from humans [36]. Combined retroviral-based lineage tracing and electrophysiological studies provided the most convincing evidence so far that newborn neurons in the adult mammalian CNS are continually

produced throughout adulthood [37,38,39.] However, human adult neurogenesis is currently under investigation and evidence marks the formation of new neurons throughout the human life, nevertheless the rate of production is too low compared to other mammals [40,12].

NSCs reside in two major parts of the adult brain: the subventricular zone (SVZ) of the lateral ventricle and the sub granular zone (SGZ) in the dentate gyrus (DG) of the hippocampus [41]. These NSCs can self-replicate and differentiate into multiple neural lineages such as neurons, astrocytes, and oligodendrocytes [10].

Based on three major factors like morphology, molecular markers and proliferative behavior, two types of neural stem cells were identified. The SGZ of hippocampus contains type 1 neural progenitor cells (NPCs) also abbreviated as radial like neural stem cells (rNSCs), contains radial projections that spans entire granule cell layer and ramifying in the inner molecular layer of DG. They can be detected by the molecular markers such as Glial fibrillary acidic protein (GFAP), Sox2 and Nestin. These stem cells are quiescent but gets activated due to environmental factors that generate the type 2 NPCs. These cells express Sox2, Nestin, Tbr2 and MCM2 except GFAP. These cells generate both astrocytes and DCX expressing neuroblasts that migrate into the granular cell layer and undergoes maturation. These maturing/surviving cells receive inputs from the entorhinal cortex (EC) and send axonal projections through the hilus towards the CA3 area of the hippocampus [42,43]. These newborn immature granular neurons in the DG receives GABAergic synaptic input around one week after birth followed by glutamatergic inputs by two weeks, and full maturation is achieved within 4 weeks in development [44]. Mature granule cells mostly become glutamatergic dentate granule cells (DGCs) and express neuronal nuclear antigen (NeuN) and calbindin [43,42].

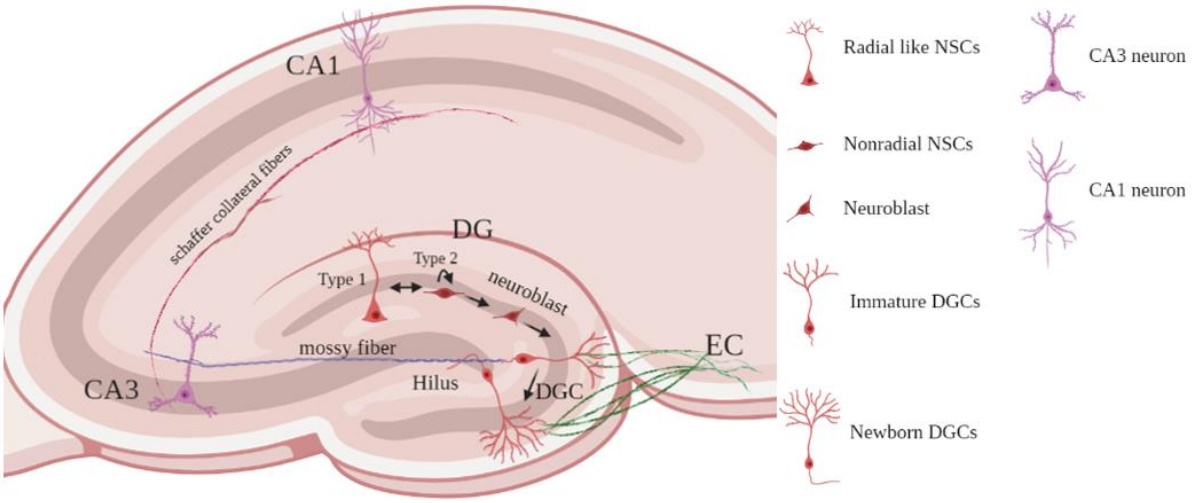

Figure 2: Neurogenesis in adult mammalian hippocampus: Radial-like neural stem cells (Type-1) which are quiescent stem cells that produce non-radial precursor cells (Type-2) which are actively proliferating and produce astrocytes and neuroblasts; Neuroblast cells migration into the granular layer; Differentiate into dentate granule cells; Maturation of Newborn dentate granule cells takes place and they receive EC input and send their axons to hilar interneurons, mossy cells, and CA3 pyramidal neurons.

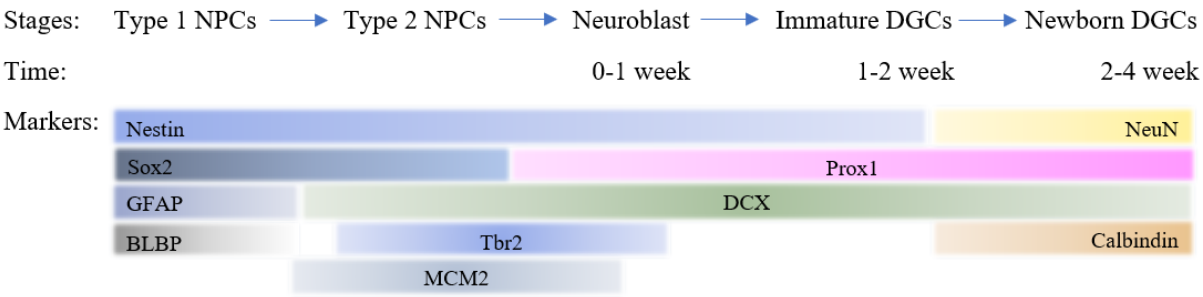

Figure 3: Stage specific markers of neuronal development in adult neurogenesis depicts time specific differentiation.

Adult neurons generated in these two neurogenic areas are integrated into existing neuronal circuits[39]. New adult neurons have a high input resistance and a subthreshold Ca^{2+} conductance, which enables new neurons for action potential firing with very small excitatory currents. This unique development may allow them to integrate easily into a mature brain without altering existing cognitive processes[44]. This integration plays important functions such as the migration of new neurons born in the SVZ migrate to the olfactory bulb via the rostral migration stream (RMS) and are encapsulated by the complex network of astrocyte tunnels in rodents [10,45] and in humans [46]. Decreased adult neurogenesis in SVZ in mice has been reported to induce abnormal olfactory and sexual behavior[47]. New neurons born in the SGZ are

integrated into the DG neural circuitry, which plays an important role in short-term memory generation. Impaired adult neurogenesis of SGZ in mice has been reported to impair new memory formation[48,49]. In particular, these new neurons are important for spatial memory formation[50]. Furthermore, new integrated neurons in the DG have also been important in memory consolidation during Rapid eye movement (REM) sleep in rodents [51].

Adult rats produce approximately 9,000 new neurons daily in the SGZ, with a survival rate of approximately 50%[52]. In an adult human, the data showed that 700 new neurons are added to the SGZ every day. About as many are also lost, keeping the total number of hippocampal cells roughly constant. The annual yield is almost 2%[53].

This process of neural stem cell proliferation, lineage differentiation, migration and integration of the developing neuron in the adult brain has been regulated by both intrinsic, genetic, epigenetic factors and extrinsic signaling pathways [54]. Membrane-bound extracellular factors and their intracellular signaling cascades have been identified in the regulation of the SVZ and SGZ neurogenesis, which includes Wnt, sonic hedgehog (Shh), Notch, BMPs, neurotrophins, growth factors (BDNF, FGF-2), various neurotransmitters (glutamate, GABA and dopamine), cytokines (IL-6), and hormones (estrogen, corticosterone) [44;54]. Further, intrinsic mechanisms including miRNAs, transcription factors and epigenetic regulators have been shown to be crucially involved in regulating neurogenesis in the adult mammalian brain [54]. Thus, future research trends will be based upon modulation of these factors, manipulating the production of new neurons, and improving the disease condition.

Association of Adult neurogenesis and AD

Adult neurogenesis reduces during normal aging in healthy brains and during Alzheimer's disease (AD). Hippocampal adult neurogenesis helps in cognition and memory formation [55]. Aging is the greatest risk factor for AD. The reduction of new born neurons during aging and AD leads to cognitive loss and impairment of memory [56]. The integration of the new neurons is impaired during aging. This is because of loss of extrinsic signals (physical activity, dietary intake) or reduced response of the precursor cells/stem cells to normal signalling during aging, or AD [57].

Adult neurogenesis of both SVZ and SGZ are affected during AD. The alteration of neuronal proliferation, differentiation, maturation and survival in both SVZ and SGZ is observed in

different transgenic adult mouse models of AD[42], in human iPSC cell lines [58], and clear reduction shown in the post-mortem of AD patients compared to healthy donors [59,13]. As discussed earlier there is a lack of evidence in the increase or decrease of new neurons in AD patients and some show increase in the generation of new neurons [43,60,61]. This alteration in outcome may be related to the observation of different stages of AD in relation to neurodegeneration. According to various hypotheses, enhanced new born neurons may arise in the affected brain as a homeostatic self-healing mechanism[62] ; and decreased neurogenesis might be contributing to the AD pathophysiology[63,64]. So, in the decreased condition of neurogenesis in AD, Amyloid-beta (Aβ) peptide, would deregulate new born neurons for facilitating disease progression [63]. The mechanisms of how the various Aβ species affect adult neurons remain unclear, and defining the pathophysiological environment of the AD brain remains an area of research.

By studying and targeting the molecular players involved in the different stages of adult neurogenesis it can be used as a potential biomarker for AD and creating an alternative therapeutic option for the treatment. Current therapeutics for AD only provide symptomatic relief but doesn't reverse the damage of neurodegeneration. Adult neurogenesis in the hippocampus could be an option to reverse the process of neurodegeneration. But scientists are still figuring out at what point in the disease, adult hippocampal neurogenesis plays a role in AD's pathophysiology. Also, studies show in rodents, there is no negative impact of increased neurogenesis in AD models[42], but there might be ethical concerns in humans. Adult neurogenesis is restricted in humans but there is a possibility to induce human neural precursor cells to generate new neurons, to cure neurodegenerative diseases, such as AD [11]. We can enhance neurogenesis either by stimulating the production of endogenous NSCs by manipulating the extrinsic and intrinsic signals or by providing exogenous NSCs. For instance, transplanting stem cells into the AD mouse model reversed cognitive deficits [65]. Additionally, more research is conducted to understand this stem cell therapy carried out in clinical trials pertaining to humans. Whereas, endogenous therapeutic targets would be to neutralize intracellular Aβ oligomers in the adult NSCs by using gene therapy, and at the same time restoring functional neurogenesis [11]. Another target to cure AD through adult neurogenesis could be interleukin-4. Studies have shown that interleukin-4 inhibits Aβ42 aggregation and restores the proliferative and neurogenic ability of NSCs by suppressing Aβ42 in zebrafish [66].

Other therapeutic approaches like increasing adult neurogenesis with the help of different modulators had neuroprotective effects on mice with cognitive impairment [67], so modulating neurogenesis could be helpful in reversing the process of AD. Studies show that the help of running/exercise promotes the rapid integration of new neurons in the aging brain through modulating neurotrophins, which promotes the plasticity of aging networks in the hippocampus [56]. In AD condition exercise also helps in enhancing neurogenesis and improved cognition along with reduced Aβ load and also increased levels of brain-derived neurotrophic factor (BDNF), interleukin-6 (IL-6), fibronectin type III domain – containing protein–5 (FNDC5), and synaptic markers which helps to improve adult neurogenesis survival and maturation [68].

Future directions:

The alteration of adult neurogenesis during AD, could be proposed as biomarkers for AD progression in humans, and new literature indicates impaired neurogenesis in the early stages of AD patients, i.e. prior to amyloid plaque formation, so it would be of potential to use adult neurogenesis as an early stage biomarker for AD [11,59]. Although AD is a multifactorial disease whose phenotypic characteristics revolves around the neuronal death. Multiple protein aggregates in the different stages of AD maybe a connecting link in neurogenesis impairment. Thus, by using advanced techniques like NGS, immunohistochemical localization and electrophysiological recordings will open new avenues for the treatment of AD. Hence, more research should be focused on extrapolating and unravelling the mechanistic base and targeting its therapeutic biomarker.

Conclusion

Current therapies for AD aim at symptomatic relief and are futile once neurodegeneration crosses a certain stage. Adult neurogenesis is a well-examined phenomenon and is still under exploration as a therapeutic mode for neurodegenerative diseases. Artificial induction of neurogenesis can be a much efficient treatment mode for AD as it can overcome the loss of neurons caused due to neurodegeneration and replenish the source of healthy neurons. However, further research is required to study the effect of induction of neurogenesis on an aging brain and its feasibility as a biomarker for Alzheimer's disease.

Glossary:

β-amyloid protein- Peptides of 36-43 amino acids in size that cause plaques in brains of people having Alzheimer's Disease.

Microtubules- polymers of tubulin protein that form cytoskeleton to support the eukaryotic cell.

Tau protein- microtubule associated proteins which are known to maintain stability of axons.

Neural stem cells- self-renewing cells in the nervous system that give rise to neurons and glia.

Dementia- A group of thinking and social symptoms that interferes with daily functioning.

Autosomal- located on one of the non sex chromosomes.

Cognitive- Involved in gaining knowledge and comprehension.

Familial- Family-related or occurring within a family.

Atrophy- Reduction in size of cell, organ, or tissue, after attaining its normal mature growth.

Neurotrophins- Neurotrophins are a family of proteins that promote the survival, development, and function of neurons.

Homeostatic- The process by which an organism tends to maintain stability while adjusting to the best conditions for survival is termed homeostasis.

Wnt- The Wnt signaling pathway consists of a group of signal transduction pathways that begin with proteins that transmit signals to cells via cell surface receptors.

Sonic hedgehog (Shh)- Sonic hedgehog is a protein that is encoded by the SHH gene. Different types of animals use this signaling molecule to regulate embryonic morphogenesis.

Notch signaling pathway- Notch is a highly conserved signaling pathway that is found in most animals.

Calbindin- it function is in mediating calcium absorption.

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Phytochemicals - a New Pipeline for Anticancer Drug Development

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Abstract

In spite of advance interventions and novel strategies, cancer is still one of the major causes of mortality worldwide. The constant increase in cancer patients, failure of conventional chemotherapeutics due to toxicity clearly demands an alternative approach. In past decades, scientific community is engrossed in the discovery of new agents from natural sources. The phytochemicals have recently gained the attention because of their potential to modulate cascades of molecular mechanisms that governs the tumor growth and progression. The protective effects of phytochemicals have gained attention due to less side effects and greater safety index. The present review summarizes the perspective of the scientific evidences as well as their potential druggability. The approach aimed to examine the current status of phytochemical compounds currently used to treat cancer and their potential at a preclinical and clinical level. It also addresses current challenges that lie ahead for their use. The methodology adopted for this review was comparative analysis of the papers published in the areas of antitumor plant-based products or plant compounds or dietary phytochemicals, anticancer phytochemicals or anticancer herbs. The analysis involved papers published from 2010 to 2020 for the recent understanding.

Keywords

Cancer, Secondary metabolites, Phytochemicals, Phyto-agents

Introduction

Cancer is a significant public health problem worldwide and is the second leading cause of death. Cancer is a large group of diseases that begin in any organ or tissue of the body when abnormal cells grow wildly, go past their usual limits to attack connecting parts of the body and/or spread to other organs. The latter process is called metastasizing and is a significant reason of death from malignancy. A neoplasm and malignant tumors are commonly considered for cancer. According to the World Health Organization (WHO), it is estimated that globally 9.6 million deaths occur due to cancer and its complications. Lung, colorectal, prostate, liver and liver cancer are well known types of cancer in men, while breast, cervical, thyroid, lung and colorectal cancer are well known among the women. The economic burden continues to grow due to lack of proper health management systems. The current treatment options available for treatments are chemotherapy and radiation therapy while sometimes surgical removal is also opted. The major disadvantage due to the chemotherapeutics is relapse of cancer, drug resistance and toxicity to the non-targeted tissues. These problems resist the use of the currently available chemotherapeutics drugs as it ultimately impairs the quality of life. Therefore, there is urgent need to search new lead anticancer agents with better potency and lesser complications. There are many scientific evidences available which shows that natural compounds are good sources for the development of new remedies for cancer.[1] There has been investigation that floral kingdom consists of approximately 250000 plant species and nearby 10% have been researched for the cancer treatment.[2] The plant derived analogues are present in different plant and have several pharmacological functions. There is wide research gap and investigation is needed to identify the molecules involved in cell signaling network and better assessment is needed in understanding their mechanism of action. Another research need is dosage concentration and frequency of intake at human trials. However, an important research need is testing in vitro dosage which are unachievable in human trials.[3-6] Phytochemicals serve as the promising candidate for the treatment of the cancer. For example, currently Taxol analogues, Vinca alkaloids and podophyllotoxins analogues has been used for the treatment. This paper aims to review the available biological actions of phytoconstituent in relation to cancer treatments. It also attempts to investigate the current concerns of chemotherapeutics being used in practice.

Challenges and introspection into the current cancer treatment regimen:

There are three major aspects for clinical trials with phytochemicals: 1) adjuvant for chemo and radiotherapy. 2) reduction of chronic side effects of chemotherapy, and 3) unwanted interaction with chemo and radiotherapy. The array of compounds like berberine, curcumin, epigallocatechin, quercetin, resveratrol and sulphorafane are currently in clinical trials on various cancers. The major classes of plant-based anticancer compounds clinically used include epipodophyllotoxin, camptothecin derivatives, vinca alkaloids, and taxane diterpenoids. However, there still remains the key concern of poor solubility, poor penetration in target cells, limited therapeutic potential and toxicity. In this regard, prodrugs, combination therapy with conventional chemotherapeutics, synthetic metal analogues and nano-formulations could be targeted to enhance the bioactivity. These major limitations can be overcome with the advent of nanotechnology and micro-encapsulation of phytochemical for targeted delivery, longer circulation period in the bloodstream and lesser side effects over free compounds. The combinational approach with mixture/single of phytochemicals and chemotherapeutic drugs induce synergistic effect and may be efficient at the lower dose compared to an individual drug which increases toxicity in normal cells. The use of cholesterol/sphingomyelin liposomal vincristine (Mariqbo®) for the treatment of acute lymphoblastic leukemia was approved by Food and Drug Administration (FDA).[7] Paclitaxel is considered to be a magic pill in chemotherapeutic not only used as a single drug but combined with other anticancer drugs. The hormone-refractory metastatic breast and prostate cancer is treated with Cabazitaxel (Jevtana®) approved by FDA.[8] These modifications in delivery system have increased accumulation of drugs in target cells and improved their cytotoxicity. When docetaxel combined with curcumin administered in mice having breast cancer showed reversal in drug resistance.[9] Recently it has been reported that the gingerol increased the sensitivity of cisplatin in gastric cancer and doxorubicin in liver cancer.[10-11]

An overview of Phytochemicals

Phytochemicals, or 'plant chemicals', are bioactive non-nutrient plant compounds that has ability to interact with at least one component of a living tissue introducing enormous scope of credible effects. They shield plants from destructive microorganisms and also from ultraviolet (UV) irradiation and extreme temperatures. Additionally, birds and insects are attracted to promote seed dispersal, pollination and germination. Phytochemicals are responsible for

colours to plants and range of flavours both pleasant and unpleasant when consumed. They are explicit to specific plants and parts of plants, and that they usually synthesis is increased during stressful events. Phytochemicals additionally provide health benefits when plant or its part are devoured. They consist of biomolecules essential for well-being (e.g., proteins, carbohydrates, vitamins, and minerals) and other supplements (e.g., phenolic acids, flavonoids, and other phenolics).[12] Phytochemicals are classified as primary metabolites and secondary metabolites. Primary metabolites comprise of the common sugars, amino acids, proteins, nitrogenous bases pyrimidines and purines, chlorophylls etc. Secondary metabolites include alkaloids, flavonoids, steroids, terpenes, lignans, saponins, phenolics and glucosides. The detailed classification is represented in Fig 1.

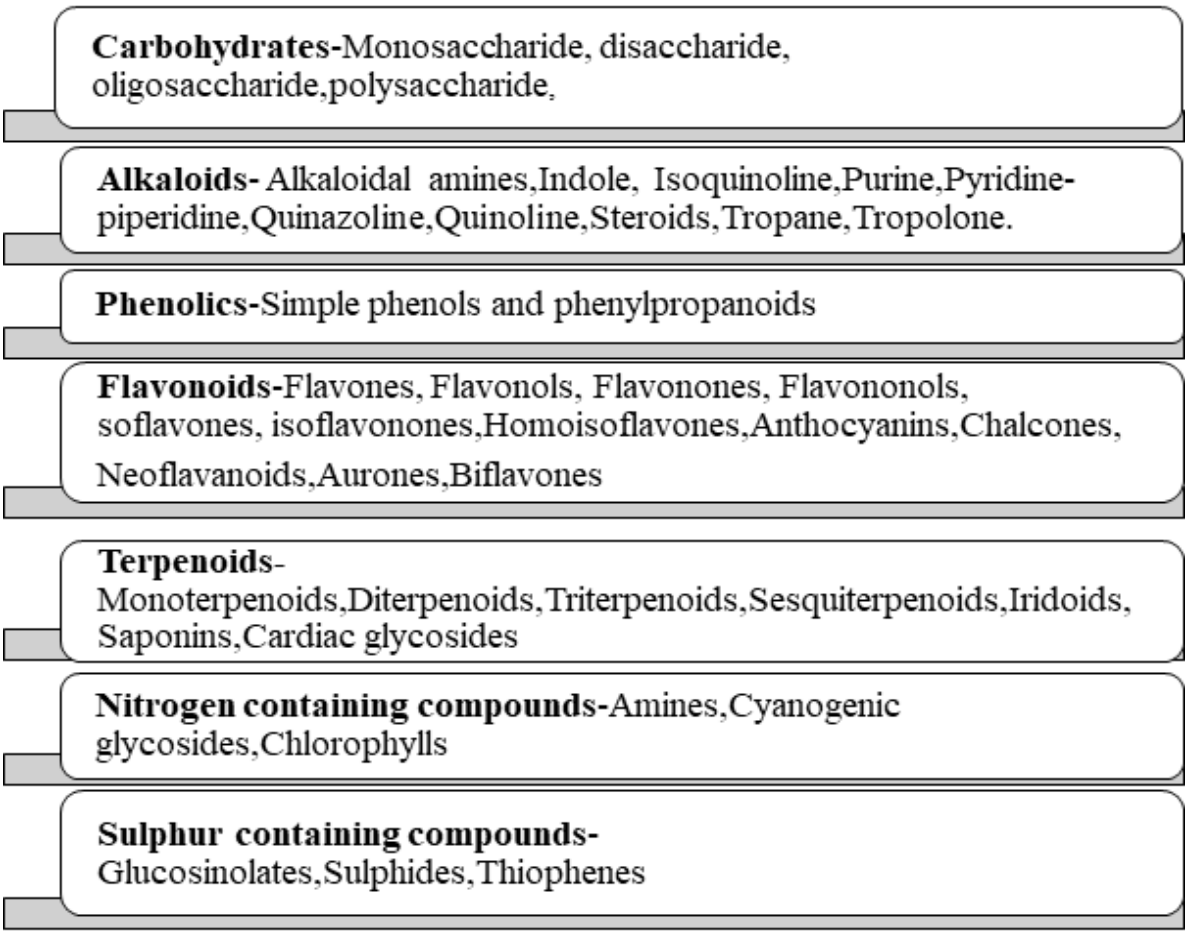

Figure 1: Classification of Phytochemicals

Role of Phytochemicals in cancer treatment

Plants are indispensable sources for anticancer drug development. Natural dietary phytochemicals are broadly utilized in in vitro, in vivo, and preclinical cancer prevention and treatment studies. In number of clinical trials have shown various degrees of success. Since ancient times plants and their formulations are used for its probable effects. In any case, therapy of plant-based compounds for the treatment of cancer can be followed back to 1950s. Some of the very first anticancer agents derived from plants are vinca alkaloids such as vinblastine, vincristine, and cytotoxic podophyllotoxins. Modern drug development program based on Ayurveda and has acquired acknowledgement in present healthcare settings. Plant derived natural products are nontoxic to normal cells and also better endured henceforth they have acquired consideration for modern drug discovery. Alkaloids, flavonoids, phenolics, tannins, glycosides, gums, resins and oils and their derivatives present in root, stem, bark leaf, and flower perform many pharmacological functions in human systems. Vinblastine, vincristine, taxol, elliptinium, etoposide, colchicinamide, 10-hydroxycamptothecin, curcumol, gossypol, ipomeanol, lycobetaine, tetrandrine, homoharringtonine, monocrotaline, curdione, and indirubin are astounding phyto molecules in this scenario.[13] The extraordinary potential of plant-based compounds for the treatment and counteraction of cancer is ascribed to their safety, low cost, and oral bioavailability. However, a couple of plant-based compounds induce some side effects. It also has been elucidated that phytochemical can modulate key cellular signalling pathways from initiation to progression by targeting different stages. The exposure of carcinogen at cellular, genetic and epigenetic levels triggers the multistep carcinogenesis process. The initial uptake of carcinogenic agent and its assimilation in tissues where its activation and detoxification occur, interaction with the DNA, results in genetic damage and transformation into neoplastic cells.[14] The tumour promotion on other hand is relatively expanded proliferation of cancerous cells regulated by mediators of cell signalling pathways like receptors, regulatory proteins, kinases and cyclins. The tumour promotion on other hand is relatively expanded proliferation of cancerous cells regulated by mediators of cell signalling pathways like receptors, regulatory proteins, kinases and cyclins. The final stage is progression of neoplastic transformation characterized by metastatic potential and migration to the distant location in the body. Thus this bidirectional communication between cells and their secondary sites serve as one of the promising target for the action of phytocompounds.[15] For instance, to name a few dietary phytochemicals like quercetin from onion, apple, lemon, Epigallocatechin

from green tea, genistein from soya bean, caffeic acid from coffee, resveratrol from red grapes, berries, Indol-3-carbinol from cruciferous vegetables have been proved in extensive range of anti-proliferation, cell cycle blockage, DNA repair alterations, apoptosis induction, free radical scavenging, anti-inflammation, activation of tumour suppressor genes, suppression of oncogenes, regulation of growth factors and hormones and inhibition of invasion, angiogenesis and metastasis.[16] The molecular connection between the phytochemicals and regulatory check points of cancer progression is illustrated in the fig.2. Several crude phytochemicals which are obtained from medicinal plants and has multifactorial effects on the many types of cancer are as depicted below.

Important phytochemicals and their effect on types of cancer:

1. Andrographolide

Species: *Andrographis paniculata*

Andrographolide is one of the diterpene lactone found in the Andrographis paniculata which is reported to exert the anti-proliferative activity on various human cancer cells.[17] The anti-cancer activity is modulated through cell-cycle arrest by induction of p27 accompanied with decrease in cyclin dependent kinase 4 (CDK4) expression. Further, the immunomodulatory activity was reported by increase in cytokine levels and enhanced natural killer cell activity. These demonstrate andrographolide as an opportunistic pharmacophore with potent anticancer/immunomodulatory activity.[18]

2. Berberine

Species: *Berberis vulgaris*

Berberine is a benzylisoquinoline alkaloid present in the roots, rhizomes, stem and bark of *B. vulgaris.* Berberine has multifaceted role like cell cycle arrest, autophagy, inhibition of cell invasion and metastasis, regulation in tumour microenvironment and immunomodulatory activity.[19] Also it has been demonstrated *in vivo* levels of catalase and glutathione peroxidase enzymes increased which proves berberine as a potent anti-oxidant.[20]

3. Crocetin

Species: *Crocus sativus*

Crocetin is a diterpenoid and natural carotenoid found in crocus flower. There are reports which shows that crocetin have significant effect on Breast, Cervical, Colorectal, Leukemia, Liver, Lung, Pancreas, Skin.[21] Crocetin exert anti-proliferative, anti-apoptotic, and decrease the

activity of RNA and DNA polymerase. It also decreases the lipid peroxidation with concomitant increase in GST, catalase and superoxide dismutase.[22-23]

4. Curcumin

Species: *Curcuma longa*

Curcumin is polyphenol extracted from rhizome of Curcuma longa also known as turmeric. Several studies demonstrated curcumin's anti-cancer activity on leukemia, breast, gastric, pancreas, colorectal, prostate, cervical, liver and lung.[24] The curcumin mainly exerts its activity by prompting apoptosis and restraining proliferation and invasion of tumors by suppressing cellular signalling pathways like including Wnt/β-catenin, PI3K/Akt, JAK/STAT, MAPK, p53 and NF-κB.[25]

5. Aloe emodin

Species: *Aloe barbadensis*

Aloe emodin *is* dihydroxyanthraquinone present in sap of aloe vera. It exhibits an array of deleterious effect on cancers like ovary, colorectal carcinoma, gastric carcinoma, liver, glioma, leukemia, breast, small cell lung cancer including reduction in cell viability, induction in cell cycle arrest, apoptosis, cell cycle arrest through downregulation of cyclin dependent and independent kinase. Additionally, emodin related compounds also served as adjuvants with chemotherapy in treatment of certain cancers.[26-27]

6. Magniferin

Species: *Mangifera indica*

Magniferin is xanthoid present in the peel, stalks, leaves, barks, kernel, and seed of mango fruit. Magniferin showed anti-proliferative effect on breast, prostate, pancreas, lung, colon, leukemia and cervical cancer.[28] Further it causes cell cycle arrest at G2/M phase accompanied with the inhibition of expression levels of proteins like ATR, Chk1, Wee1, Akt, and Erk1/2. It also relieves the oxidative stress, suppress metastatic potential, decrease the expression of MMP-7 and 9, and inhibit b-actin pathway by reversing epithelial-mesenchymal transition (EMT).[29]

7. Plumbagin

Species: *Plumbago zeylanica*

Plumbagin is a naphthoquinone isolated from roots of Plumbago zeylanica. There are reports which demonstrated the role of Plumbagin against gastric, breast, melanoma, promyelocytic leukemia cancer. It has been reported that plumbagin suppress malignant activity of tumour

cells through cascade of mechanism such as the inhibition of growth, invasion, metastasis and anti-angiogenesis.[30] Flow cytometric analysis of human cancer cell lines revealed that Plumbagin arrest cell cycle at G1 phase with concomitant inhibition of cyclin D1, cyclin E, and upregulation of p53.[31]

8. Piperine

Species: *Piper longum*

Piperine is an alkaloid transcendently found in the fruits and roots of Piper longum. Black pepper has been exploited as king of spices in Indian system of medicine for various ailments.[32] Piperine not only exhibits anti-proliferative activity but also regulates the fundamental proteins involved in the cancer progression. Piperine inhibits cell proliferation via cell cycle arrest, triggers reactive oxygen species production which in turn activates intrinsic and extrinsic apoptosis pathways. Piperine at the molecular level block the Akt phosphorylation leading to inhibition of angiogenesis and vascular endothelial growth factor (VEGF).[33]

9. Epigallocatechin

Species: *Camellia sinensis*

Epigallocatechin (type of catechin) is a polyphenol extracted from tea plant. The epigallocatechin mediates the anti-cancer activity via inhibition of nuclear factors associated with the inhibition of migration, invasion and angiogenesis. It has dual function of anti-oxidant and pro-oxidant potential which modulates the production of reactive oxygen species leading to epigenetic modification, regulation of histone acetylation and upregulation of apoptosis.[34-35]

10. Resveratrol

Species: *Vitis vinifera*

Resveratrol is trans-stilbenoid polyphenol present predominantly in grapes but also found in mulberries, blueberries, cranberries and peanut. Resveratrol activates apoptotic pathways which includes increase in levels of Bax and decrease in levels of Bcl-2 and cyclin D1. In addition to this it regulates cell differentiation, DNA repair, cell cycle arrest, autophagy, angiogenesis and metastasis.[36] It also modulates the balance of cyclins as well as cyclin-dependent kinases (CDKs) which inhibits cell cycle at G0-G1 phase. It activates the STAT3 which promotes the proliferation, survival, invasion, angiogenesis, and metastasis of tumour cells.[37]

Phytochemical	**Type of cancer**	**Biological action**
Andrographolide[38-39]	Breast, Liver, Lung, Ovarian, Cervical	suppression of heat shock protein 90, cyclins and cyclin-dependent kinases, metalloproteinase and growth factors, and the induction of tumour suppressor proteins p53 and p21.
Berberine[40-42]	Breast, Liver, Lung, Ovarian, Cervical, Prostate, Colorectal	Caspase activation; ROS production, Cytochrome c release; Bcl-2/Bcl-xL decrease, COX-2 downregulation
Crocetin[43-45]	Breast, Cervical, Colorectal, Leukemia, Liver, Lung, Pancreas, Skin.	suppression of Bcl-2 and up-regulation of Bax expression,
Curcumin[46-48]	Blood, Breast, Gastric, Pancreas, Colorectal, Prostate, Cervical, Liver, Lung, Skin	interfere with multiple cellular signalling cascades including Wnt/β-catenin signalling, phosphoinositide 3-kinase (PI3K)/protein kinase B (Akt) pathway, Janus kinase (JAK)/signal transducer and activator of transcription (STAT) signalling pathway, mitogen-activated protein kinase (MAPK) pathway, p53 signalling and nuclear factor-κB (NF-κB) pathway
Aloe emodin[49-50]	Ovary, Colorectal carcinoma, Gastric carcinoma, Liver, Glioma, Blood, Breast	cell cycle arrest through downregulation of cyclin dependent and independent kinase and suppression of Bcl-2 and up-regulation of Bax expression
Magniferin[51]	Breast, Liver, Lung, Blood, Prostate, Brain, Gastric, Kidney	down-regulation of inflammation, cell cycle arrest, reduction of proliferation/metastasis, promotion of apoptosis in malignant cells and

		protection against oxidative stress and DNA damage.
Plumbagin[52-54]	Breast, Liver, Lung, Blood, Prostate, Brain, Gastric, Kidney	Cell cycle arrest, DNA damage, apoptosis, and suppression of telomere and telomerase activity, inhibition of proteasome, Inhibition of COX-2 and STAT3 signalling pathway
Piperine[55-56]	Breast ,Lung, Prostate, cervical, Ovary, colorectal	induction cell cycle arrest, increased cell apoptosis, disruption of redox homeostasis, inhibition of angiogenesis, modulation in stress, and autophagy, influence on the Wnt/β-catenin and inhibition of PI-3K/Akt signalling pathways.
Epigallocatechin[57-58]	Breast, Lung, Pancreatic, Ovary, Oral, Prostate, Blood, Colorectal,	induction of apoptosis, inhibiting NF-κB activation and downregulate the key genes associated with angiogenesis, tumour metastasis and survival.
Resveratrol[59-60]	Breast, Colon, Liver, Lung, Prostate, Blood	induction cell cycle arrest, increased cell apoptosis, inhibition of COX-2 and STAT3 signalling pathway

Table 1: Summary of phytochemicals used in cancer treatment.

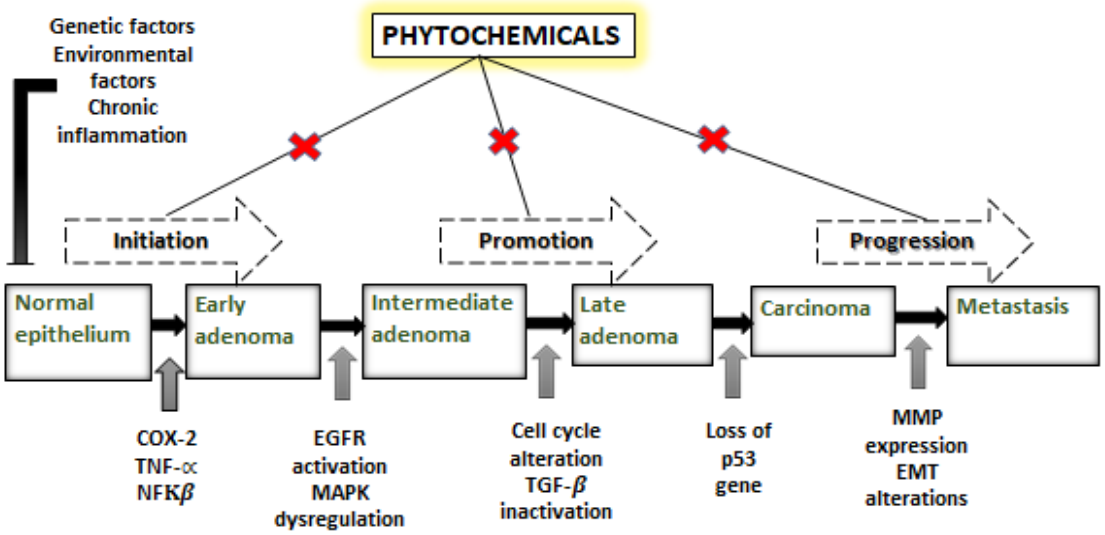

Figure 2: Phytochemicals alterate the key signalling pathways of cancer from initiation to progression.

Conclusion and Future perspective:

The high biodegradability and biocompatibility of phytocompounds have open the new avenues in cancer therapy. The phytochemicals can be categorized as signalling molecules and imposition of serving as phyto-chemotherapeutics is still needed to be investigated. The phytocompounds could be combined with the conventional therapies to enhance the potency and prevent tumour recurrence after achieving a successful treatment. The pleotropic properties of Phyto agents can be considered as pioneering adjuvant line of action that can be in combination with chemotherapeutics. In conventional approach of research, efficacy of phytochemicals is evaluated in vitro and then in vivo followed by mechanistic studies. This screening only suffices the cytotoxic effect on cancer cells. To overcome these limitations, the approach should be developed to predict the pharmacological activities by using OMICS analyses. Although there are many known phytochemicals having cytotoxic effects, but the exact molecular/cellular targets and systematic mechanisms for many of them is questionable. With the advancement of bioinformatics, the in-silico approaches to study the pharmacokinetics properties of molecules should be opted. So due to large scale use of traditional healthcare products and their demand by humans, it is very essential to scrutinize different formulations for anticancer therapy in vitro as well as in vivo.

Glossary:

- **Neoplasm-** an abnormal growth of tissue caused due to rapid cell division. It is also known as tumour.
- **Malignant tumors-** cancerous tumor
- **Chemotherapeutics-** drugs for treatment of cancer.
- **Adjuvant-** substance which help or aid to increase the potency of the drug.
- **Alkaloid-** a class of naturally occurring heterocyclic nitrogen bases in plants having pharmacological effects.
- **Flavonoids-** a class of complex polyphenolic compounds naturally present in plants.
- **Terpenoids-** also known as isoprenoids.
- **Tannins-** water soluble polyphenol naturally present in plants.
- **Apoptosis-** It's a programmed cell death.
- **Metastasis-** It's a process through which cancer cells spreads to other body parts.
- **Adenoma-** structurally unorganized neoplasm consisting of fibrous, glandular and fat tissues.
- **Carcinoma-** most common type of malignancy starts at inner or outer epithelium of the organs.

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Contribution of Phonon Anharmonicity in Negative Thermal Expansion Materials

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Abstract:

A crystal lattice of a solid consists of periodic arrangement of atoms. The atoms in the lattice vibrate about their allotted positions at normal temperatures. These atomic vibrations generate sound waves in the crystal lattice. According to the quantum theory, analogous to Photons-light particles, the particle *avatar* of these sound waves are called as Phonons. In reality, the vibrations of atoms in a crystal lattice deviate from their harmonic rhythm as a function of temperature. This anharmonic behavior affects the atoms ability to help flow heat seamlessly throughout the solid with varying temperature. This in turn is responsible to the fact whether and how much the solid should expand with increase in temperature. Present paper intends to understand the crystalline solids which shrink when heated instead of usual expansion. The cause of this so called 'Negative Thermal Expansion' can be explained by anharmonic behavior of the phonons. We present a few of the various approaches adopted in literature to study the contribution of anharmonicity in thermal expansion.

Keywords

Anharmonicity, Negative Thermal expansion, Grüneisen parameter, Phonon, Specific heat, Lattice dynamics

Introduction

The vibrations of atoms in a solid are interpreted as elastic waves or acoustic waves propagating through the solid. These vibrations rely on crystal symmetry, number of atoms per unit cell, chemical bonding and presence of crystal defects in a solid. The displacement of atoms in this oscillatory behavior will be greater at high temperatures. Forces holding these atoms in their equilibrium positions are proportional to their relative displacements mimicking their network with neighboring atoms by springs.

Phonons and Specific Heat:

When the temperature is raised above absolute zero there is a rapid increase in the specific heat from zero which eventually becomes constant (C=3NK; K= Boltzmann constant). Dulong and Petit stated that this value at high temperature is about 6 cal mole^{-1} degree^{-1}. According to Dulong and Petit law, a solid has 3R molar heat capacity at constant volume developed with the help of the equipartition theorem of Boltzmann. This model failed to explain the drop of specific heat value for solids at low temperatures and was overcome by involving quantum aspect introduced by Einstein[1].Einstein assumed that all the atoms in a solid vibrate at same frequency. The frequency of the atom can be effected by restoring force and mass of the atom. Einstein model replaced the classical law of equipartition with the mean energy of Planck's oscillator. The specific heat at constant volume for Einstein model where all the atoms of a crystal were assumed to be N harmonic oscillators having same frequency (ν) is given by,

$$C_v = 3NK_B \left(\frac{h\nu}{K_B T}\right)^2 \frac{exp\left({}^{h\nu}/_{K_B T}\right)}{\left[exp\left({}^{h\nu}/_{K_B T}\right) - 1\right]^2} \qquad (1)$$

At high temperatures, $T \gg {}^{h\nu}/_{K_B}$, above expression reduces to the Dulong-Petit value of the specific heat . On the other hand, at low temperatures i.e.$T \ll {}^{h\nu}/_{K_B}$, $C_v$tends to zero for T approaching to zero Kelvin and it increases with increasing temperature as required by third law of thermodynamics. This model was improved by Debye by assuming solid to be a continuous medium rather to be a discrete one and accounting for the range of frequencies in a solid instead of assuming same frequency of oscillation for all the atoms, as claimed by Einstein[2,3]. Debye Specific heat is given by

$$C_v = 3NK_B\left(\frac{3}{x_D^3}\int_0^{x_D}\frac{x^4e^4dx}{(e^x-1)^2}\right); x_D = {h\nu_D}/{K_BT} \quad (2)$$

$$= \frac{T_D}{T}\ ; T_D\ is\ Debye\ temperature$$

The above expression reduces to Dulong-Petit law at high temperatures whereas for low temperatures, Debye specific heat decreases as T^3. Figure1 shows the typical variation of $C_v$as a function of temperature for Debye model and Einstein models where all the harmonic oscillators vibrate at the same frequency.

To examine the Debye model, one can have a resemblance with a particle in a cubic box. Equation (2) suggests that T_D decides the complexity in the integration of above expression. The smallest dimension in a solid (i.e. a unit cell) decides the minimum wavelength of the atoms performing lattice vibration and thereby setting up a limit for maximum thermal vibrational energy for the atoms in a solid which in turn model into an independent normal mode vibration[4]. The internal energy possessed by the atoms in such a condition is expressed as

$$U_{thermal} = 3nN_AK_BT = 3nRT \quad (3)$$

Where n, N_A, K_B, T, and$R$ are the mole number, Avagadro number, absolute temperature and Universal gas constant respectively. The T_D defined in equation (2) describes the temperature at which ordered lattice vibration turns into an independent lattice vibration.

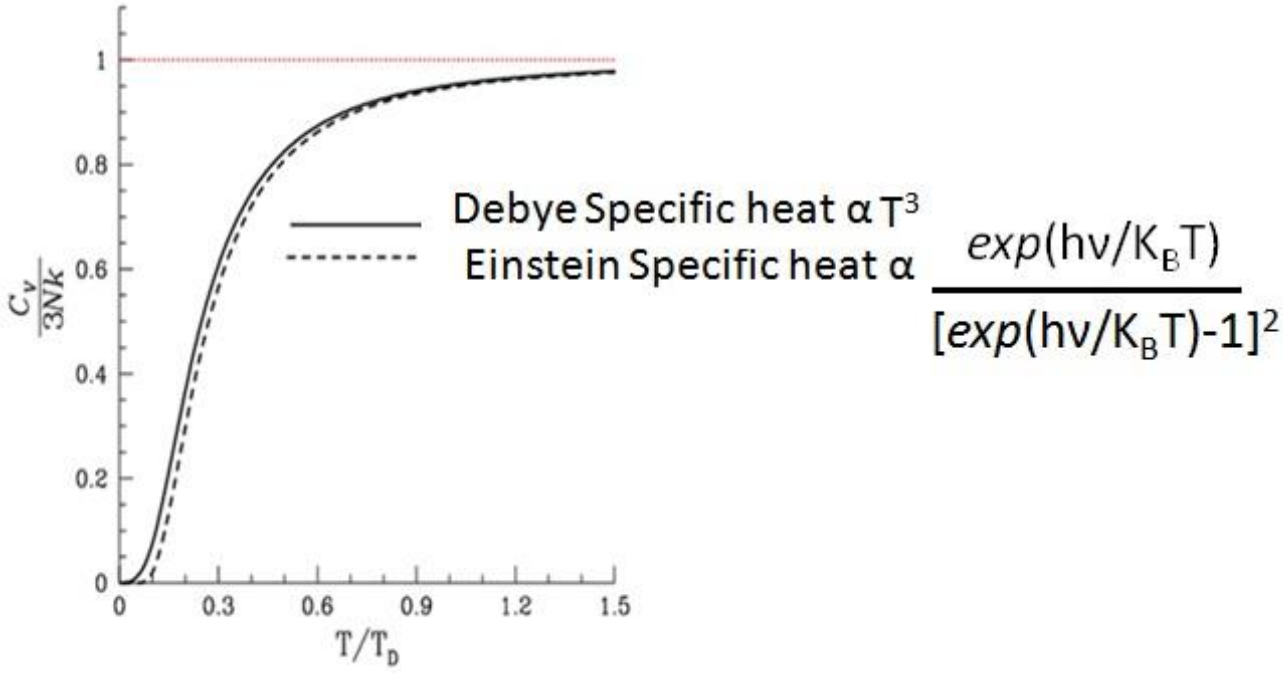

Figure 1: Comparison of Debye and Einstein Specific Heat Curve[5]

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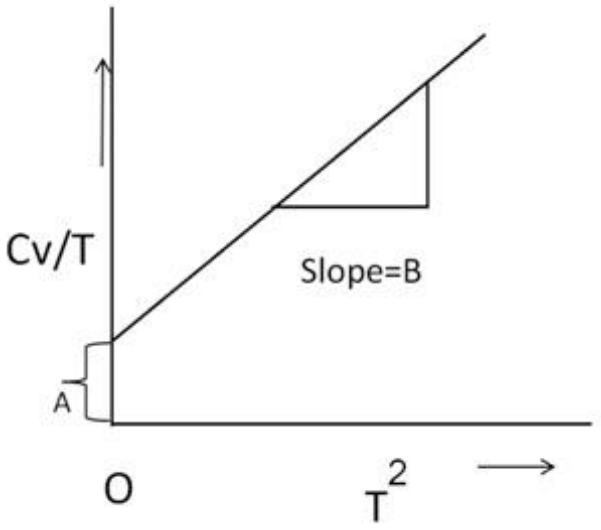

Figure 2: Debye Specific heat curve for metals[2]

In case of metals, the total contribution of specific heat involves specific heat of free electrons in addition to that of phonons and it is given by,

$$C_{V=}\ AT(C_{V_{(free\ electrons)}}) + BT^3(C_{V_{(phonons)}}) \qquad (4)$$

C_v/T verses T^2 graph (Figure2) shows that the linear plot which allows to determine Debye frequency by calculating the slope value (B) and intercept (A) determines the contribution to the specific heat by the electrons across Fermi level in a metal which is known as electronic specific heat coefficient[2].

Phonons and Heat Conduction:

In this section, we describe the heat conduction due to phonons in insulators. Thermal conduction in insulators occurs as a result of exchange of energy and momentum termed as phonon-phonon collisions. The thermal conductivity of a material is dependent on the specific heat per unit volume (C_V), phonon velocity(v) and phonon mean free path(l).When the atoms of a solid material experience purely harmonic forces then the phonon-phonon collision do not occur. This means that there will not be any scattering between the phonons even for a finite temperature. As a result, there is no occurrence of thermal resistance (i.e. infinite thermal conductivity) in the case of solids with harmonic approximation. By contrast, phonons get scattered with one another when the atoms in a solid experience anharmonic forces. The distribution of phonons gets disturbed for an anharmonic solid when there is a temperature gradient. Consequently, phonon-phonon interactions or scattering take place in the system in order to acquire their equilibrium distribution back. The rate at which the equilibrium distribution is regained decides the thermal resistance of the material. This rate of attaining equilibrium distribution is dependent on the phonon-phonon scattering. At low temperatures, only low energy phonons get excited. Such phonons corresponding to longer wavelengths experience scattering across the boundary of the material. In this case, C_V varies as T^3 as discussed in the above section and l is nearly constant. Moreover, the velocity of phonon is not sensitive with varying temperature. Consequently, the thermal conductivity varies as T^3 at low temperatures but once the temperature is reached to $\frac{T_D}{2}$, the thermal conductivity varies as $1/T$ since at high temperatures, C_V is nearly constant and l decreases with the magnitude of $1/T$.At high temperatures, phonon-phonon collisions dominate due to the anharmonicity established

in the solid material. Hence, "anharmonicity" of the lattice vibrations plays the vital role to the thermal resistance of a system[2]. In case of metals, free electrons are available in abundance which efficiently conducts heat transfer resulting into high thermal conductivity into metals.

Umklapp process helps to understand the mechanism of thermal resistivity conducted by phonons. The Umkalpp process commonly known as flipping over says that in the phonon-phonon collision the total momentum of the system is changed after the collision. When two different phonons with momentum $\hbar q_1$ and $\hbar q_2$ collide, the total momentum of the system is given as $\hbar q_3$with a difference of the material's lattice parameter vector (G). This phenomenon can mathematically express as follows:

$$k_1 + k_{1=}\ k_3 + G \qquad (5)$$

In case of normal scattering (N-process), total momentum is conserved. The vector G= 0 in this situation and there is no prominent variation in the direction of energy. Hence, such a normal process cannot contribute towards thermal resistance. By contrast, in Umklapp process (U-process), one can notice peculiar variation in the energy direction (in the direction of k-vector) resulting in thermal resistance of the system (Figure3). As shown, resultant phonon vector(k_3 vector)for N-process lies within 1st Brillouin zone of 1D k-space and this moves outside of 1stBrillouin zone (k_3') for U-process. The G vector describes the distance between two lattice phonons and G= 2π/a for 1D k-space[2].

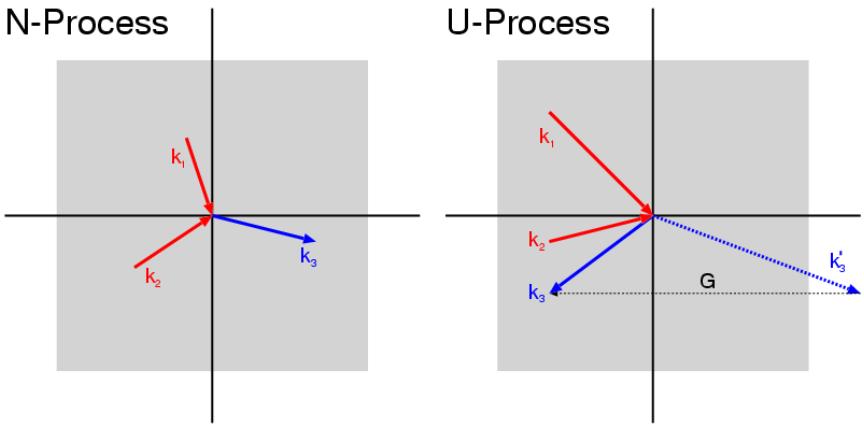

Figure 3: Umklapp process in a solid[6]

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Lattice Vibrations:

For a 1D lattice infinitely extended in the X-direction of identical atoms having mass m and interatomic separation a, the equation of motion of the nth atom can be represented as:

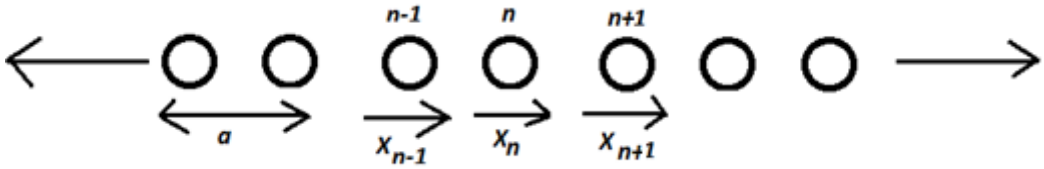

Figure 4: Monoatomic lattice vibrations in a 1D infinite solid[2]

$$m\frac{d^2x_n}{dt^2} = -f(x_n - x_{n+1}) - f(x_n - x_{n-1}) \quad (6)$$

Where, x_n, $x_{n+1}$and $x_{n-1}$are the displacements of the n^{th} atom and its nearest neighbor atoms at $(n\text{-}1)^{th}$ and $(n+1)^{th}$ positions. 'f' is the force constant of the interacting $(n\text{-}1)^{th}$ and $(n+1)^{th}$ atoms. The solution to the above equation takes the form of running wave as follows:

$$x_n(t) = Ae^{-j(\omega t - qna)} \quad (7)$$

$$x_{n+1}(t) = Ae^{-j[\omega t - q(n+1)a]} \quad (8)$$

$$x_{n-1}(t) = Ae^{-j[\omega t - q(n-1)a]} \quad (9)$$

Where ω and q describe the frequency and the wave vector of the elastic wave. Putting the above obtained solutions into the equation of motion, one can determine the frequency of the elastic waves called as dispersion relation given by,

$$\omega = \sqrt{\frac{4f}{m}}\sin\left(\frac{qa}{2}\right) \quad (10)$$

The atoms of an elastic wave are considered in accordance to the quantum laws. The quantized excitations in such an elastic wave due to the virtue of thermal vibrations are called Phonons.

The energy of the atoms of the elastic wave is taken as discrete since atoms are quantum particles and its smallest unit is termed as "Phonon". The medium can be approximated as a

continuum in the limit of long wavelength phonons ($\lambda >> a$) reducing the dispersion relation to $\omega = \sqrt{\frac{4f}{m}}\ (\frac{qa}{2})$(since qa<<1). The relation between frequency (ω) verses wave vector (q) (Equation 10) states that ω has a periodicity of q=2π/a. The unique values of ω are limited to a range of q within 2π/a. The range of q lying between -π/a to +π/a is called the first Brillouin zone[2].

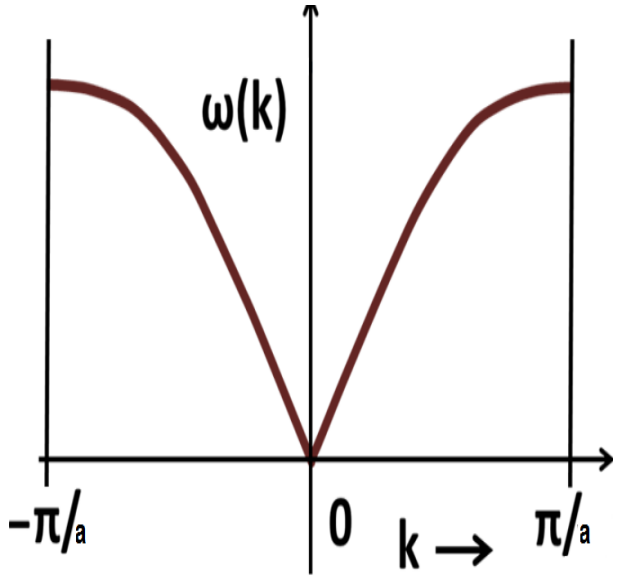

Figure 5: Dispersion Curve of a Monoatomic Lattice[7]

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In general, for an infinite lattice chain of two different types of atoms is considered then the dispersion relations are classified into ranges and can be expressed as follows:

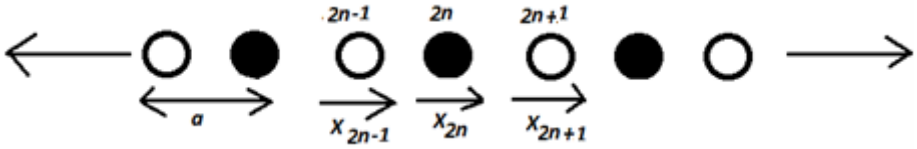

Figure 6: Diatomic lattice vibrations in a 1D infinite solid[2]

$$\omega_+ = \left[f\left(\frac{1}{M}+\frac{1}{m}\right) + f[(\frac{1}{M}+\frac{1}{m})^2 - \frac{4sin^2qa}{Mm}]^{1/2} \right]^{1/2} \quad (11)$$

$$\omega_- = \left[f\left(\frac{1}{M}+\frac{1}{m}\right) - f[(\frac{1}{M}+\frac{1}{m})^2 - \frac{4sin^2qa}{Mm}]^{1/2} \right]^{1/2} \quad (12)$$

Where M and m are the masses of two different types of atoms with force constant f and wave vector q. The dispersion curves for ω_+ and ω_-(as shown in Figure7)states that ω_+ includes high frequency range of phonon modes categorized as Optical phonons while ω_- includes low frequency range of phonon modes termed as Acoustic phonons[2].

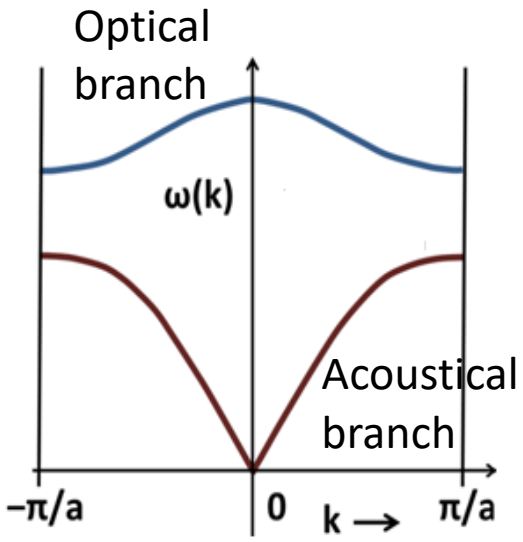

Figure 7: Dispersion Curve of a Diatomic Lattice[8]

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The oscillation of atoms about their equilibrium positions becomes more intensive at high temperatures. This can influence several properties in a solid such as specific heat, thermal conductivity and thermal expansion as discussed below.

Phonons and Thermal Expansion:

A solid undergoes a thermal expansion upon heating which is a direct consequence of anharmonicity of lattice vibrations. For a solid having perfectly harmonic vibrations, the mean position of the oscillator does not get shifted with increasing temperature. But the atomic oscillators in general, have an asymmetric anharmonic potential. In such cases, atoms possess higher energy and consequently greater amplitude of vibration at higher temperatures. The mean position of the atom then shifts towards the right at higher temperatures in order to obtain the symmetric amplitude of vibration. Due to this shifting of the equilibrium position of each atom in the lattice, the mean interatomic separation increases as shown in the Figure No.8. This causes increase in the dimension of the material with a positive coefficient of thermal expansion $(\alpha)^2$.

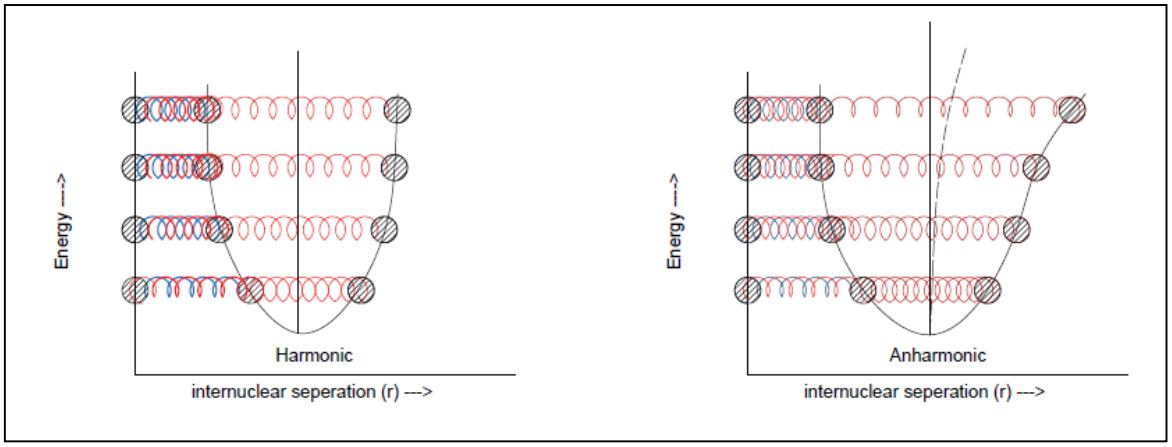

Figure 8: Spring Model for Vibrations of a Solid (Blue: compressed spring, Red: Stretched spring

Researchers have been studying the phonons behavior as a function of temperature over the decades. It is observed that not every material undergoes expansion upon heating but some materials contract when heated. Such materials have been named as Negative Thermal Expansion(NTE) materials. Anharmonicity in phonon mode frequencies plays a vital role for such an unusual thermal behavior in this class of materials. The phonon mode frequency variation with respect to temperature at constant pressure is a combined contribution of two effects: 1. True anharmonicity (also called as explicit anharmonicity) which occurs due to the change in vibration amplitudes at fixed equilibrium positions. 2. Quasi-anharmonicity (also

called as implicit anharmonicity) resulting from volume change with respect to pressure at constant temperature. The total anharmonicity in a solid can be represented mathematically as

$$\frac{1}{\omega_j}\frac{d\omega_j}{dT}\Big|_P = \frac{1}{\omega_j}\frac{d\omega_j}{dT}\Big|_V - \gamma_j\alpha \qquad (13)$$

γ and α (measured in K^{-1}) in the quasi-term is the Grüneisen parameter and coefficient of thermal expansion respectively and can be computed as follows

$$\gamma_j = -\partial \ln \omega_j / \partial \ln V \qquad (14)$$

$$\alpha = V^{-1}(\partial V/\partial T) \qquad (15)$$

The first term in Equation 13, on right hand side is the true anharmonicity and second term is the quasi-anharmonicity. The contribution of these two terms is responsible for the total anharmonicity of the phonon modes expressed on left hand side in the above equation. For a typical positive thermal expansion material (PTE), vibration frequency red shifts with increase in temperature making the left side of the above equation negative. Normally, the first term on the right hand side is also negative and with positive values of γ and α, even the second term on the right side of the equation is negative.

For NTE materials, change in the sign of γ_i in the equation13 may result in the overall sign change of total anharmonicity[9, 10].The average Grüneisen parameter (γ_{AV}) at constant volume is related to α as follows

$$\alpha = \frac{\gamma_{AV} C_V}{3V_m B} \qquad (16)$$

Where V_m is the molar volume, $B$is the Bulk Modulus and $C_V$is the specific molar heat at constant volume given by,

$$C_V = \frac{1}{N}\sum p_i C_i \qquad (17)$$

Where N is the number of formula units per unit cell,p_i is the number of phonons having frequency $\omega_i$andC_i is the single mode specific heat.

One can calculate average Grüneisen parameter (γ_{AV}) by the following expression

$$\gamma_{AV} = \left(\frac{1}{N}\sum p_i C_i \gamma_i\right)/C_V \qquad (18)$$

It can be noticed from above equations that for the material with negativeγ_{AV}, α has to be negative confirming it as NTE material[10].

Major Advancements:

Present article attempts to present various methods often found in literature that can be helpful in understanding the phonon behavior in NTE materials.

1. ***Experimental Methods:***

   Experimentally temperature dependent inelastic neutron scattering experiments and temperature and/or pressure dependent Raman measurements on NTE materials have proven to be very fundamental to assess role of phonons in negative thermal expansion property in these materials.

   In-elastic Neutron scattering technique involves exchange of both energy and momentum of thermal neutrons with moving nuclei, hence giving information about atomic vibrations. This scattered cross-section corresponding to the characteristic of the system provides the information about the phonons of the sample. It gives an idea whether the scattering is due to a one phonon process or multi-phonon process. Moreover, for the case of incoherent approximation this method can give neutral weighted density of states of the powdered sample scattering once the weighting of the total scattering crossection of the constituent atoms is determined[11].From the Inelastic neutron scattering data, one can extract phonon dispersion relation and phonon density of states. This can further be used to determine quantitative thermodynamical response and phase information inmaterials[12].

   The phonon behavior of the very popular NTE material, zirconium tungstate (ZrW_2O_8) has been extensively studied based on this method and below we overview these studiesZrW_2O_8shows isotropic NTE over a wide temperature range from 0.3K to 1050K. The structure contains 3-dimensional network of ZrO_6 and WO_4polyhedra with one non-bridging Oxygen atom present on each WO_4 tetrahedron which undergoes a transverse vibration exhibiting rigid unit mode[13].

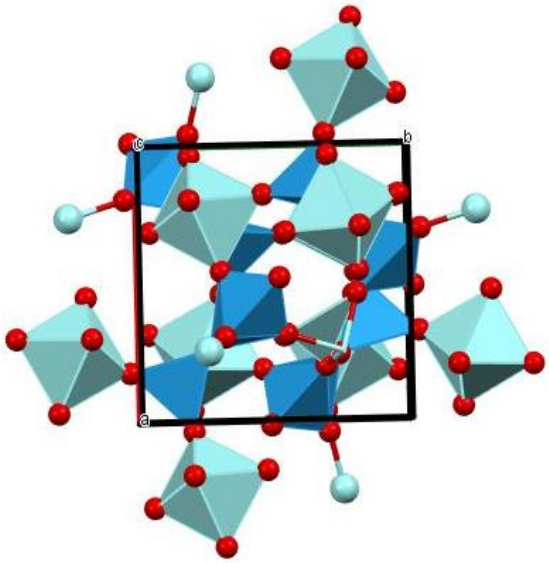

Figure 9: The crystal structure of ZrW_2O_8[13]: (color online). Red: oxygen, Blue: tungsten, Green: zirconium

Inelastic neutron scattering measurements:

Neutron scattering studies by Ernst et al.[14]had traced two groups of phonons: low energy phonons (at 30meV) and high energy phonons (at 110meV). Since there are 4 formula units of ZrW_2O_8 per unit cell, there are total 44 x 3 = 132 vibrational modes, out of which 3are the acoustic modes and 129 are the optical modes. These modes were determined and subjected to investigation of their contribution to NTE. γ_i for low energy phonons were obtained from equation (16) and (17) with negative magnitude as a function of temperature. Moreover, large negative γ_i indicating the frequency red shift as a function of pressure were analyzed for low phonon energies. Inelastic neutron scattering data showed linear decrease in lattice parameter 'a' with increase in temperature, whereas inverse dependence of Grüneisen parameter γ with temperature except some deviation at low temperatures[14]. Considering these aspects, a model was proposed as shown in the inset of Figure10, wherein the low energy phonons lying between E_0(1.5meV) and E_1(8.5meV) were assumed to be responsible for the temperature dependence of theγvalues. Phonons having energies between E_0 and E_1, were assumed to have fixed γ= -14. This model was supported satisfactorily with the help of the density of states g(ω) values. Further g(ω) verses $\hbar\omega$ plot was analyzed for

these set of phonon modes at 50K and 300K. This Low energy spectrum shows hardening for 3.8meV mode with increasing temperature contradicting the assumption that frequency depends only on volume and not on temperature. It is known that the difference in energy increases for every adjacent eigen states with the increasing eigen state index in the case of quartic anharmonic harmonic oscillator. This in turn results into increment of the average eigen states spacing[14].In ZrW_2O_8, the structural orientation of unshared vertex of tetrahedron and large experimental values of $C_V$can lead to the similar variation in the energy of the lattice. Hence it was interpreted that hardening of 3.8meV is the result of dominancy of the quartic potential of the oscillator[14].

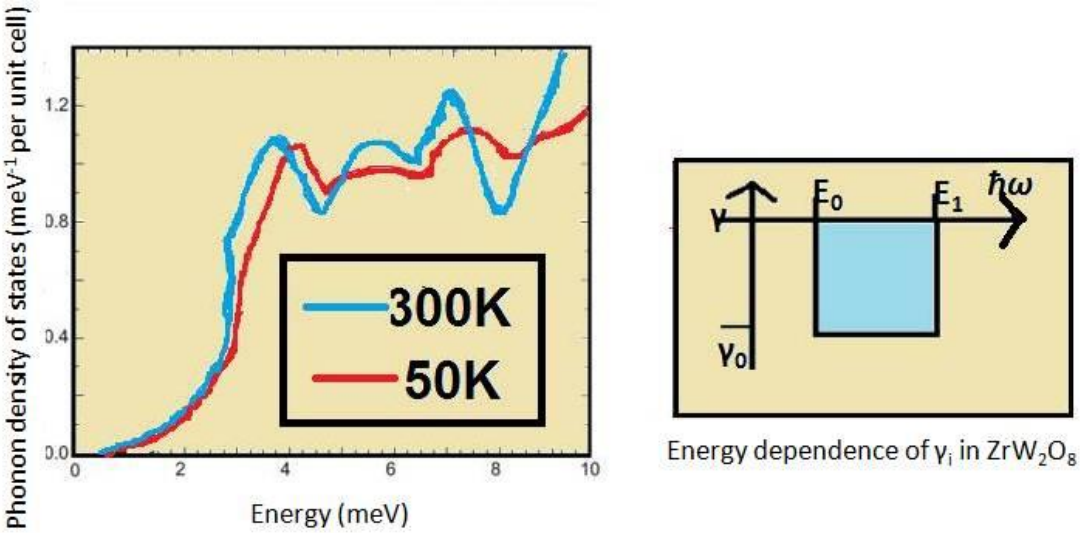

Figure 10: Variation of density of states with low-energy at temperatures 50K, and 300K[14].

Re-drawn from "Ernst, G., Broholm, C., Kowach, G. R., & Ramirez, A. P. (1998). Phonon density of states and negative thermal expansion in ZrW 2 O 8. *Nature*, *396*(6707), 147–149."

Specific heat measurements:

Phonon spectrum and specific heat at low temperature depends upon the atomic masses and bonding forces especially on bonding with neighboring atoms, coordination

number and symmetry of adjacent atoms. The change in the coordination number can result into the structural change of a system. Hence, $C_v(T)/T^3$ vs lnT plot can satisfactorily explain the contributions of $C_v(T)$ for the various different modes in a system[15]. This plot also overlaps approximately with the one dimensional phonon density of states with energy (Ref15) For ZrW_2O_8, $C(T)/T^3$ vs lnT plot was interpreted for spectral weight of low energy phonons using fitting protocols of Einstein and Debye and it was stated that these phonons can be associated to structural transition and liberation of atoms. The former protocol assumes the individual contribution of summation of Einstein phonons while the latter protocol assumes higher Debye temperatures to fit for C_V.After trials of various combinations, it was found that the protocols lead to the ~6.5% fraction of the total degrees of freedom spectral weight for the phonon modes residing at 5meV in ZrW_2O_8 giving out the signatures of order-disorder transition[15].This kind of transition was further understood with an analogy of 'guitar string' as given below.

In ZrW_2O_8, the underconstrained or unshared vertex (non-shared O atom in WO_4) leads to the order-disorder transition. By contrast, ZrO_6 has completely shared oxygen performing a transverse vibrational motion. In addition, the negative sign of γ_i of low energy phonons were also indicating this transverse behavior in analogy to the 'guitar string' wherein a heavy mass suspended between the strings tends to pull in the string support resulting in the shrinkage of the overall structure. So, the transverse vibration of rigid unit modes (RUMs) of low energy phonons plays the key role in ZrW_2O_8 for showing up the unusual NTE property. Low energy phonons show large softening in case of HfW_2O_8 and $ZrMo_2O_8$ consisting of isotropic NTE up to 1050K and 600K respectively. Evidences proved that the guitar string analogy holds true in these two compounds like ZrW_2O_8[15, 16, 17, 18].

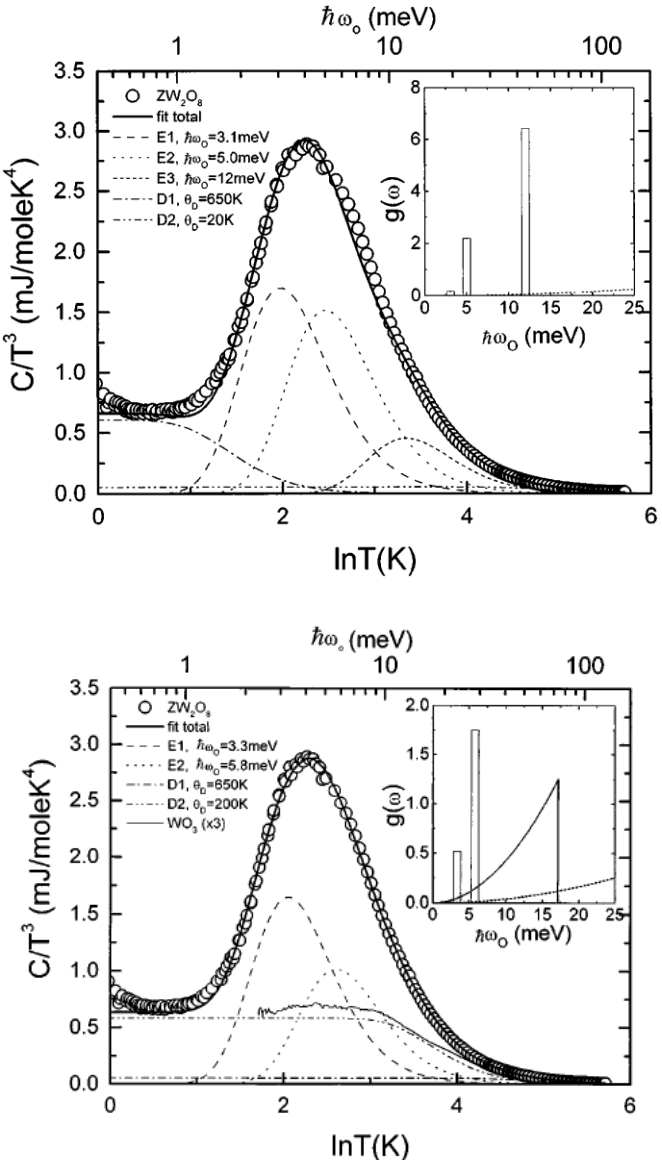

Figure 11: $C_v(T)/T^3$ vs lnT plot of ZrW_2O_8 as per the Einstein and Debye protocols[15].

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Thermal properties of Metal cyanides are of keen interest to the scientists. $Zn(CN)_2$ consists of a pairing of strong C≡N bonds to weak Zn-C/N bonds enabling transverse vibration of Zn-CN-Zn linkages which is the key factor for NTE behavior in this material. It has cubic structure available in two different models namely ordered model

with space group $P\bar{4}3m$ and disordered model with $Pn\bar{3}m$ space group. The former one is having ZnC_4 and ZnN_4tetrahedra around the alternate cations along with CN ions arranged in an orderly fashion residing along the body diagonal of the unit cell. By contrast, the distribution of C and N atoms is oriented randomly in order to meet the site probabilities to be in equal amount. By contrast, disordered model offers equal sites occupancy with the help of randomly distributed C and N atoms[19].

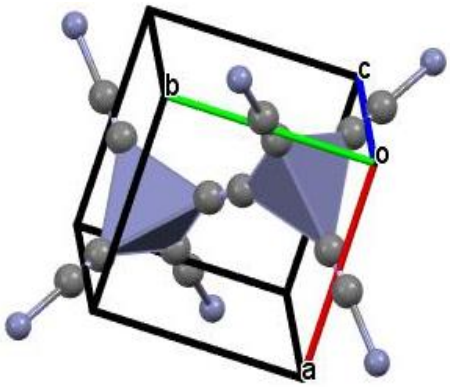


Figure 12: The crystal structure of $Zn(CN)_2$ [20]

High pressure neutron scattering technique reported that the low energy (less than 15meV) phonons cause NTE in $Zn(CN)_2$ by plotting the energy variation of these modes with ratio of calculated γ_i/B; B is Bulk modulus, at an ambient pressure for 165K and 225K temperatures. The γ_i/B ratio obtained from ab-initio calculations were analyzed to observe the anharmonicity of phonons. Using the high pressure neutron scattering data γ_i/B ratio and energy of the low phonon modes, α was determined and it was confirmed that this set low energy of phonons corresponds to NTE. Moreover, temperature and pressure dependency of $Zn(CN)_2$ over atomic displacement parameters indicated the softening of the modes along Zn-CN-Zn transverse linkages which is the key compression mechanism for this material[21,22].

Raman Spectroscopy is a powerful technique when performed on the sample under temperature or pressure constraints as it allows to probe into true and quasi-anharmonic contributions of phonons (in equation13 of total anharmonicity). Further, the contribution of anharmonicity of three phonon process and four phonon process can be determined with true anharmonicity calculations as per Equation No-19 which describes the variation/shift in the frequency of the phonon due to its phonon-phonon anharmonic

contribution $\left(\Delta\omega_j(T)_{anh}\right)$.This equation shows that each phonon frequency (ω) can be characterized into two (ω_m, =1, 2) or three (ω_n, =1,2,3) phonons resulting into three (cubic) and four(quartic) phonon processes. Coefficients A and B describe the strength of three and four phonon processes respectively[23,24]. The frequency variation of phonon modes in a material against temperature and pressure determines the magnitude of α and γ respectively. One can obtain information of α with the help of phonon frequency variation with respect to temperature (refer equation no 15). On the other hand, phonon frequency variation as a function of pressure helps to obtain γ information (refer equation no 14). The calculation of Bulk modulus requires knowledge of γ, which can be deduced from high pressure Raman studies. The study of phonon anharmonicity of certain materials namelyZrW_2O_8, $Ag_3Co(CN)_6$, SnSe, 2H-WS_2 have been discussed below. It has been noticed that major contribution in total anharmonicity is brought by true anharmonicity in the above listed materials.

$$\Delta\omega_j(T)_{anh} = A[1 + \sum_{m=1}^{2} \frac{1}{e^{\hbar\omega_m/K_BT} - 1}] + B[\,1 + \sum_{n=1}^{3} \left(\frac{1}{e^{\hbar\omega_n/K_BT} - 1} + \frac{1}{\left(e^{\hbar\omega_n/K_BT} - 1\right)^2} \right)] \qquad (19)$$

Zirconium tungstate has been reported to have an order-disorder phase transition from $P2_13$(α-phase) to $Pa\bar{3}$ (β- phase) with respect to temperature (at 428K). This phase transition can be the result of anharmonicity in the phonon modes. High pressure Raman spectroscopic study of zirconium tungstate (crystal structure discussed above) was performed from 20K -400K for α-phase. Low frequency modes related to tungsten ion and WO_4tetrahedra and high frequency modes related to only WO_4tetrahedra were traced. In order to examine their behavior closely, phonon frequencies' variation with respect to temperature was analyzed. The slope of each mode reflects the anharmonicity in these modes. The disappearance of certain modes below 400K confirmed the phase transition in the material. Previous reports indicated negative Grüneisen parameters (γ_i) for phonons with energies less than 50meV.Temperature dependent specific heat shows that phonons

much larger than 10meV contributes for NTE apart from low energy phonons (less than 10meV) reported earlier[14,15,16]. Analysis of phonon frequencies variation as a function of temperature and the linewidths were studied to distinguish between true and quasi-anharmonicity. In the literature, $\Delta\omega_j(T)_{anh}$ and FWHM (Γ) are related[25] as follows:

$$\lim_{\delta\to 0} -\frac{1}{K_B T}\sum(kj;\omega \pm i\delta) = \Delta\omega_j(T)_{anh} \mp i\Gamma_j \qquad (20)$$

Where δ, k and j describe the phonon phase, wave vector and j^{th} indexphonon branchrespectively.

Previous reports have given the formalism for cubic and quartic anharmonicities describing three- and four- phonon processes with respect to the FWHM (Γ) as a function of temperature. The cubic and quartic linewidths contributions can be deduced from the equations (21) and (22). A and B define the coefficients of cubic and quartic anharmonicities respectively[23, 24]. For Zirconium tungstate, the quantity called intrinsic linewidth (A+B), bending modes showed large magnitude indicating strong anharmonicity. This corroborated the temperature dependence specific heat results giving out negative γ_i for low frequency modes. Calculated values for true and quasi-anharmonicity using these γ_i confirms true anharmonicity has a larger magnitude corresponding to many lattice modes and some bending modes of tungsten ion in comparison to stretching modes of tungsten ion. Thus, the true anharmonicity of the phonons dominates in the NTE behavior of this material[10]

$$\Gamma_C = A\left\{\left[\exp\left(\frac{\hbar\omega_0}{2k_B T}\right)-1\right]^{-1}+\frac{1}{2}\right\} \qquad (21)$$

$$\Gamma_Q = B\left(\left\{\left[\exp\left(\frac{\hbar\omega_0}{3k_B T}\right)-1\right]^{-1}+\frac{1}{2}\right\}^2+\frac{1}{12}\right) \qquad (22)$$

Mode Frequency(cm^{-1})	**Total Anharmonic (10^{-5} K^{-1})**	**Quasi-anharmonic $\alpha\gamma_j$ (10^{-5} K^{-1})**	**True Anharmonic (10^{-5} K^{-1})**
41	12(5)	15(3)	27(8)
64	-35(1)	-3(2)	-38(3)
84	-29(6)	7.4(2)	-22(6)
144	2.5(9)	3.5(2)	6(1)
236	3(1)	-2(1)	1(2)
308	2.9(7)	1.7(9)	5(2)
333	2.1(3)	0.4(5)	2.4(8)
381	0.6(2)	0.7(8)	1(1)
735	-0.3(1)	-0.2(6)	-0.5(7)
746	-0.8(3)	-1(1)	-2(1)
773	-2.3(2)	-0.1(3)	-2.4(5)
789	-2.5(1)	-1.0(3)	-3.5(4)
861	-1.0(2)	-0.8(7)	-1.8(4)
886	-1.2(2)	0.0(3)	-0.6(2)
903	-1.68(7)	-0.1(3)	-3.2(6)
932	-0.62(4)	-1.4(4)	-0.6(2)
967	-1.8(2)	-0.8(2)	-3.2(6)
1018	-1.1(3)	-0.8(2)	-1.9(5)
1030	-1.3(1)	-0.8(2)	-2.0(3)

Table 1: Anharmonicity offered by various phonon modes of ZrW_2O_8[10].

"Reused (figure 3) with permission from [Ravindran, T. R., Arora, A. K., & Mary, T. A. (2003). Anharmonicity and negative thermalexpansion in zirconium tungstate. *Physical Review B - Condensed Matter and Materials Physics*, *67*(6), 1–4.] Copyright (2003) by the American Physical Society."

Table1 describes the total anharmonicities of the phonon modes of zirconium tungstate offered by their quasi-anharmonic and true anharmonic components as explained in equation11[10]. One can observe that the most of the low frequency modes shows positive

total anharmonicities. It was known that out of 41, 64, 84, 144 and 308cm^{-1}, only 64 cm^{-1}mode was the only one with positive γ but all of these low phonon modes were having large magnitudes of total anharmonicity. Considering the case of 64cm^{-1} mode, having γ to be positive turns the quasi-anharmonic contribution to be negative value as the corresponding thermal coefficient for this material is negative only for all the modes. Further, the calculated true anharmonicity contribution was found to be negative which when combined with the calculated quasi-anharmonic component turns total anharmonicity to be negative. In a similar manner, one can understand the effect of anharmonicity offered by rest of the phonon modes.

Raman Spectroscopy and X-ray Diffraction Measurements:

$Ag_3Co(CN)_6$ exhibits 14 times larger NTE than ZrW_2O_8. This colossal NTE material consists of alternating layers of Ag atoms sitting over a Kagome lattice and $Co(CN)_6$ lies above and below of it forming Co-CN-Ag-NC-Co linkages[26].

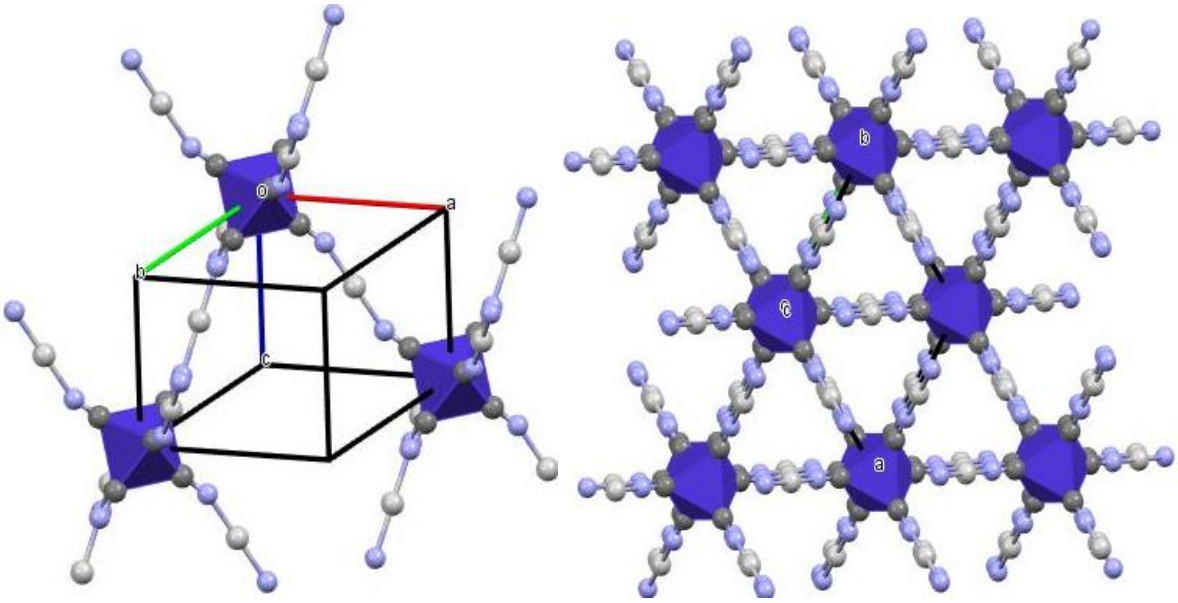
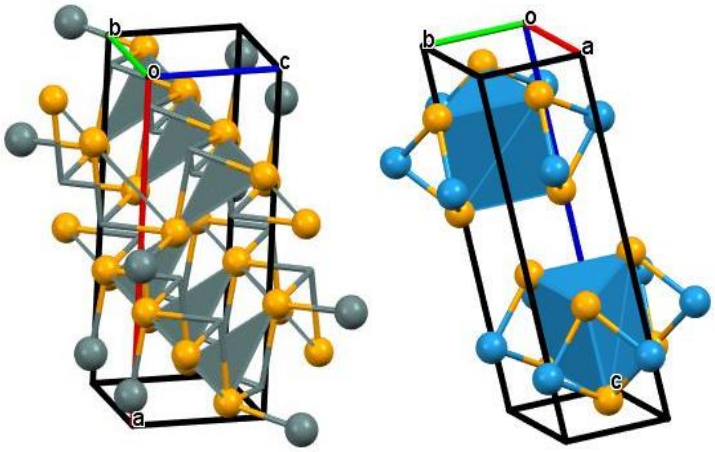


Figure 13: The crystal structure of $Ag_3Co(CN)_6$[27]

High pressure Raman studies of $Ag_3Co(CN)_6$ studies was performed to understand the anharmonic behavior of phonons in this material. Soft phonons were traced by pressure dependence of phonon modes and they possessed negative γ_i. Moreover, quasi-anharmonic contribution of these modes was obtained from frequency variation as a function of

temperature. Consequently, stretching modes related to cobalt and CN were proven to be highly anharmonic out of all other traced modes in the trigonal phase of $Ag_3Co(CN)_6$[26,28].

SnSe crystallizes in orthorhombic layered structure ($Pnma$ space group) at low temperatures.Each layer contains zigzag planes of Sn-Se which is extended into two directions. The network generated from covalent bonds forms the double layer in the material. The Sn atoms orient at the off-center of the rectangle formed by Se atoms. With increasing temperature, Sn atoms drift towards the center of the Se rectangle and eventually at high temperature the crystal undergoes phase transition into $Cmcm$ phase[29].

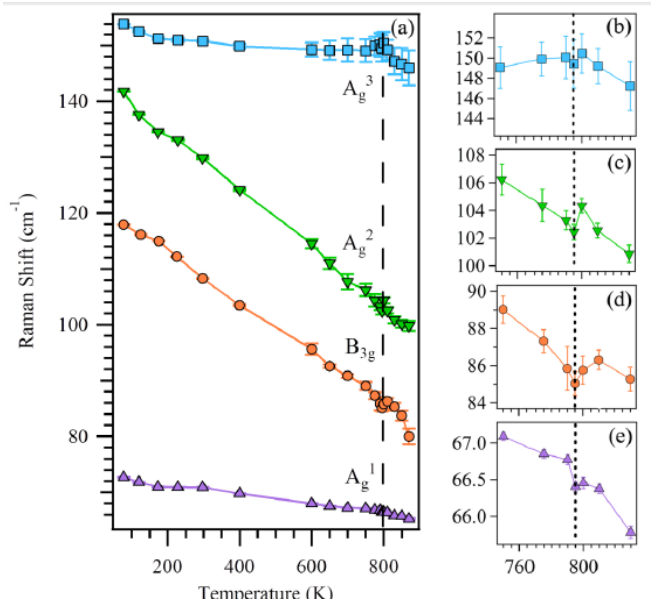


(a) (b)

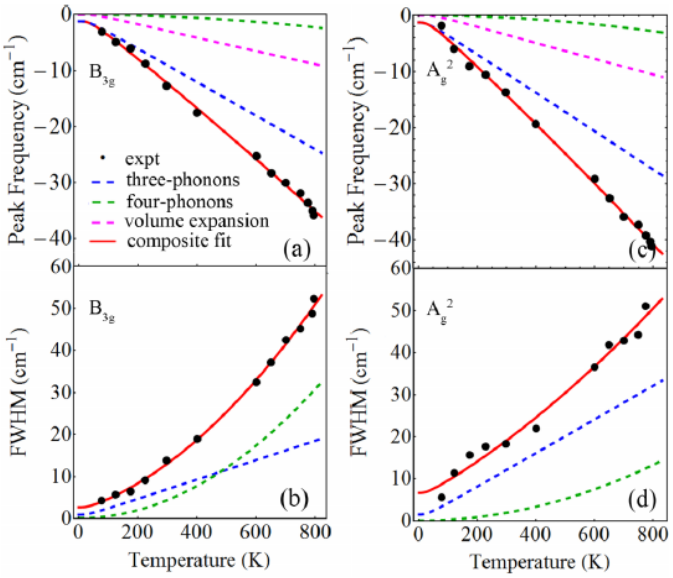
Figure 14: The crystal structure of (a) SnSe[29]and (b) 2H-WS_2[30]

The presence of strong anharmonicity also results in ultralow thermal conductivity observed in single crystalline SnSe. Temperature dependent Raman studies (77K to 800K) exhibited softening of optical phonons (between ~70and150cm^{-1}) six times more along b-c plane in comparison to an axis. The magnitudes of cubic and quartic anharmonicity were calculated and FWHM and peak frequencies of these phonon modes were plotted as a function of temperature which proved that the cubic term of the true anharmonicity is responsible for the phonon decay in this material[23]. Another similar approach was adapted in the study of phonon behavior of Tungsten Disulfide consisting of multiple layer of S-W-S. Each S-W-S layer contains W atom enclosed in a 2D hexagonal lattices formed by six S atoms around it[24,30]. Temperature Dependent Raman Study was performed on Tungsten

Disulfide (2H-WS_2) over a temperature range of 3.6K to 850K. Frequency dependence and FWHM as a function of temperature shows nonlinear red shifts of all the phonons and broadening of linewidths respectively which is a consequence of phonon-phonon interaction (true anharmonicity). Softening of low optical phonons was traced over whole temperature range. At lower temperatures, Softening was found to be dominated by three phonon process while at high temperatures; four phonon processes played the active role in phonon decay in 2H-WS_2. This was in agreement of the results of Density of phonon states[24].



(a)



(b)

Figure 15:Thermal response ofA_g^1, B_{3g}, A_g^2 and A_g^3phonon modes of SnSe (a)Raman spectra of the above mentioned phonon modes in the Left panel and their zoomed view in the right panel (b)Frequency variation and FWHM[23].

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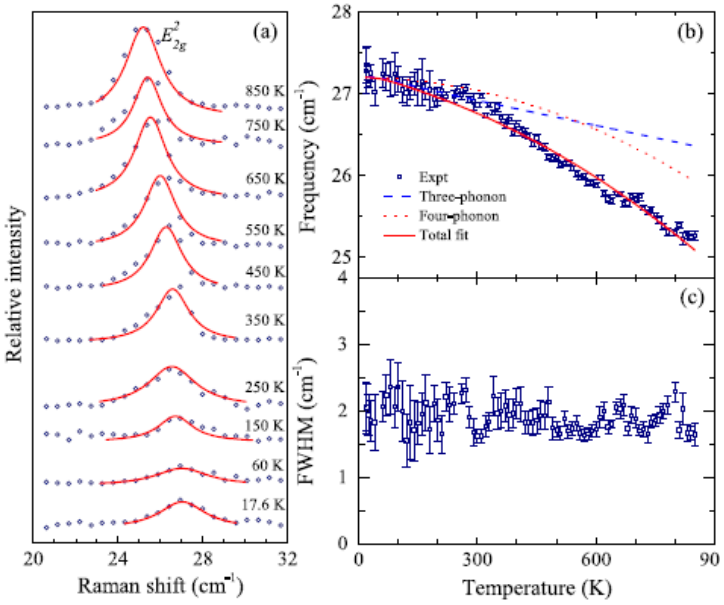

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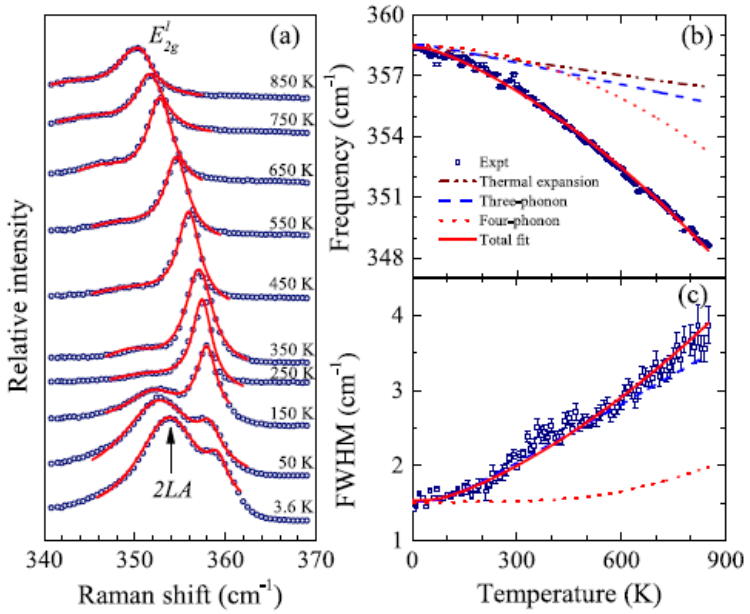

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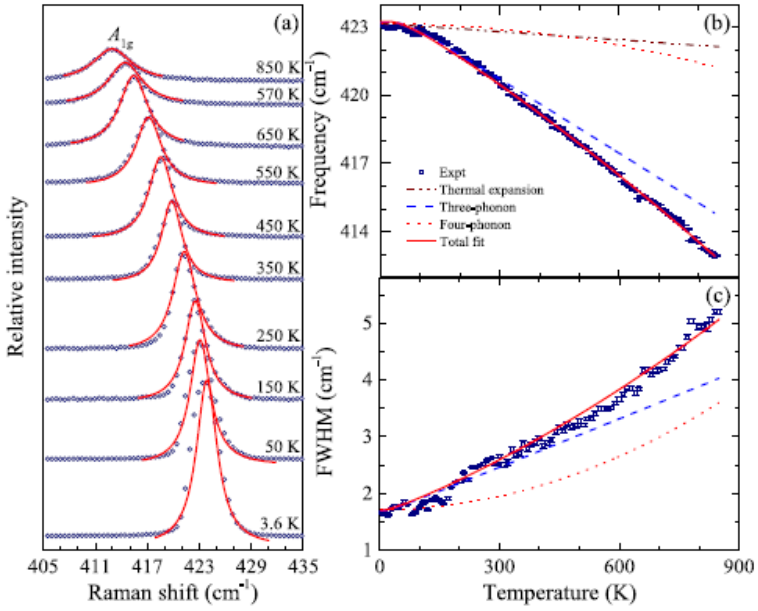

(c)

Figure 16: Thermal response ofE^2_{2g}, E^1_{2g} and A^1_g phonon modes of 2H-WS_2 (a)Raman spectra (b)Frequency variation and (c)FWHM[24].

"Reused (adapted) with permission from {Peng, Y. K., Cao, Z. Y., Chen, L. C., Dai, N., Sun, Y., & Chen, X. J. (2019). Phonon Anharmonicity of Tungsten Disulfide.

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2. *Analytical Method:*

As discussed in the second method, phonon mode frequencies can be interpreted as a function of temperature and pressure. A graphical approach called Zallen and Conwell method is an alternative way to analyze the anharmonicity of phonon modes. The plot of $\partial\omega_j/_{\partial \mathrm{P}}$ vs $d\omega_j/_{\mathrm{dT}}$ for several modes gives out the visualization of anharmonicity. Thus, one can obtain the phonon modes which are strongly anharmonic for a material by plotting their quasi-anharmonic and total temperature dependent components. As described by Zallen and Conwell, an implicit factor (η, dimensionless parameter) can be defined as follows

$$\eta = -\frac{\partial\omega}{\partial P}\left(\frac{d\omega}{dT}\right)^{-1}\left(\frac{\alpha}{\beta}\right) \qquad (23)$$

Where $\beta = -V^{-1}\left(\partial V/_{\partial P}\right)$ defines the isothermic compressibility. For the case where quasi-anharmonic dominates, the temperature and pressure effects resemble each other and $\frac{\partial\omega}{\partial P}\left(\frac{d\omega}{dT}\right)^{-1}$ equals to the$\left(\frac{\beta}{\alpha}\right)$. Hence, in such a case η =1. On the other hand, η =0 describes that the modes have purely true anharmonic contribution. If both (true and quasi contributions) are comparable and possesses same sign then the implicit fraction has a magnitude of 0.5. In a similar manner, one can draw various constant lines of η to realize the specific contributions of anharmonicity[10, 32].

Figure shows the Zallen and Conwell plot for Zirconium Tungstate. The constant lines of various η for the traced modes of zirconium tungstate were examined. For PTE materials modes lies in the fourth quadrant which was found to be shifted in the second quadrant in this material. For most of the modes (41 cm^{-1},144 cm^{-1},308 cm^{-1},381 cm^{-1},333 cm^{-1}) the upwards shift is observed with temperature and for the modes (84 cm^{-1} and 64cm^{-1}) downward shift is observed with pressure indicating NTE behavior in this material. The latter modes were stated to be dominated by true anharmonicity whereas the former one has quasi-anharmonic contribution. The 64cm^{-1} mode and 84cm^{-1}modes (typically) have been marked for exhibiting largest total anharmonicity in this material[10].

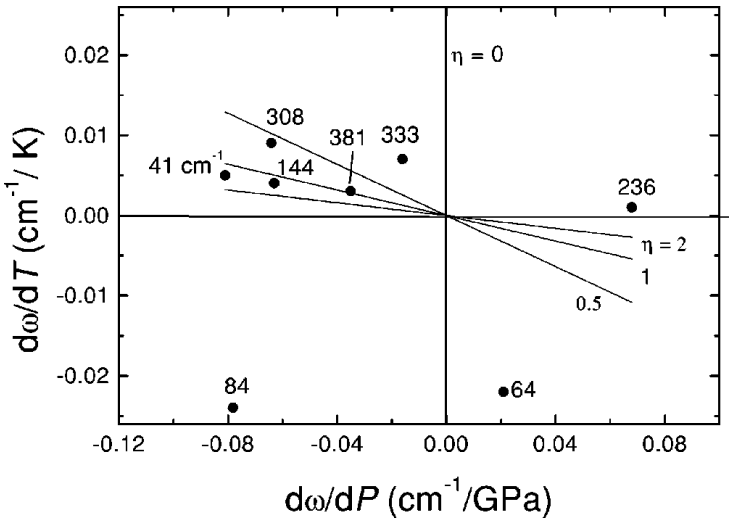

Figure 17: Zallen and Conwell plot ZrW_2O_8 describing Anharmonic contributions of the phonon modes of ZrW_2O_8[10].

"Reused (figure 3) with permission from [Ravindran, T. R., Arora, A. K., & Mary, T. A. (2003). Anharmonicity and negative thermalexpansion in zirconium tungstate. *Physical Review B - Condensed Matter and Materials Physics*, *67*(6), 1–4.] Copyright (2003) by the American Physical Society."

Theoretical Method:

Density Functional theory based ab-initio calculations help to encounter quantities such as band structure, force, pressure etc. Phonons have energy scale ranging from 1-500meV. From Density Functional (DFT) calculations, phonon frequencies and also the phonon dispersion inside the Brillouin zone characteristic of a crystalline solid can be obtained. One can further investigate quasi-anharmonic contribution offered by the lattice dynamics in a material[11,32]. Now, we present some insights into contribution of phonon modes of the two materials (β-eucryptite and ReO_3) with RUMs as a root cause for NTE interpreted by DFT calculations. A variety of materials with source of NTE other than RUMs such as $Ag_3Co(CN)_6$, ScF_3, CuX (X= halides) etc have been extensively studied using DFT calculations.

β-eucryptite ($LiAlSiO_4$) consists of double helices of SiO_4 and AlO_4tetrahedraproviding alternating layers of Al and Si perpendicular to c-axis. Primary channel consists of Li1 atoms while Li2 and Li3 atoms comprise of secondary channel type oriented along different

axes in the unit cell. Li sitting in 1D parallel to c-axis. Single unit cell has six tetrahedra available i.e. three secondary and one primary channel. But only three available sites are occupied in an alternating fashion at room temperature. This material shows strong anisotropic NTE between the temperature range of 300-1400K[11, 33].

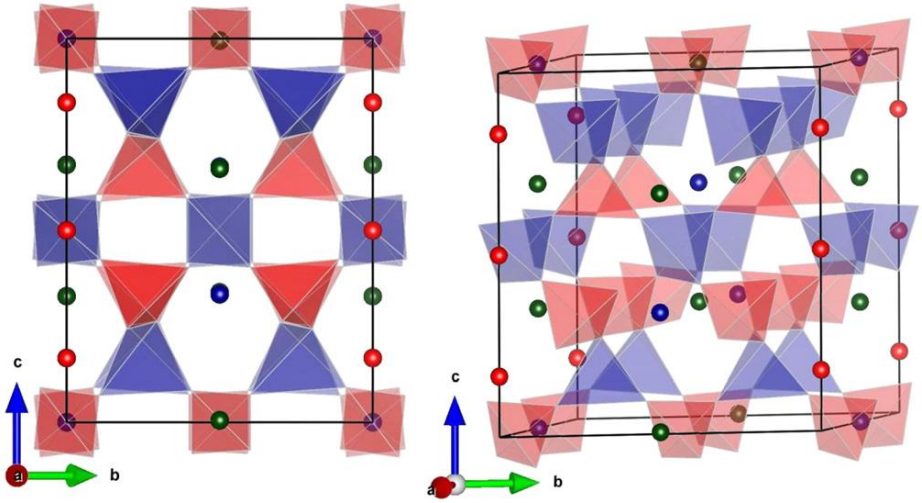

Figure 18: The crystal structure of β-eucryptite[34].

"Reused from [Singh, B., Gupta, M. K., Mittal, R., Zbiri, M., Rols, S., Patwe, S. J., Achary, S. N., Schober, H., Tyagi, A. K., & Chaplot, S. L. (2017). Role of phonons in negative thermal expansion and high pressure phase transitions in β-eucryptite: An ab-initio lattice dynamics and inelastic neutron scattering study. *Journal of Applied Physics*, *121*(8).], with the permission of AIP publishing."

Single crystal X-ray diffraction (SCXRD) and Raman studies have shown pressure induced transition for this material at 0.8 GPa and 300 K. High pressure XRD studies have stated that it involves phase transition from hexagonal to orthorhombic phase between 0.83 GPa and 1.12 GPa, while with higher pressure ~4.5 GPa it becomes amorphous. Experimental inelastic neutron scattering spectra was analyzed with the help of ab-initio DFT in order to understand lattice dynamics, as shown in figure19. It can be noticed that phonon modes can be distinguished in two distinct regimes extended up to 100meV and 110-150meV respectively. The first regime involves vibrations of all the atoms of the unit cell while another high-energy spectrum part involves internal vibrations of the SiO_4 and AlO_4 tetrahedra. The understanding of vibrations of individual atoms in the neutron inelastic spectrum (Figure19) was given by calculating Partial Density of States (PDOS). The calculated mean square amplitude for all the

atoms was then analyzed with the variation of energy and temperature, and it was found that since Li and O are lighter atoms with larger amplitude they can serve in polyhedral motion of this material[11,34].

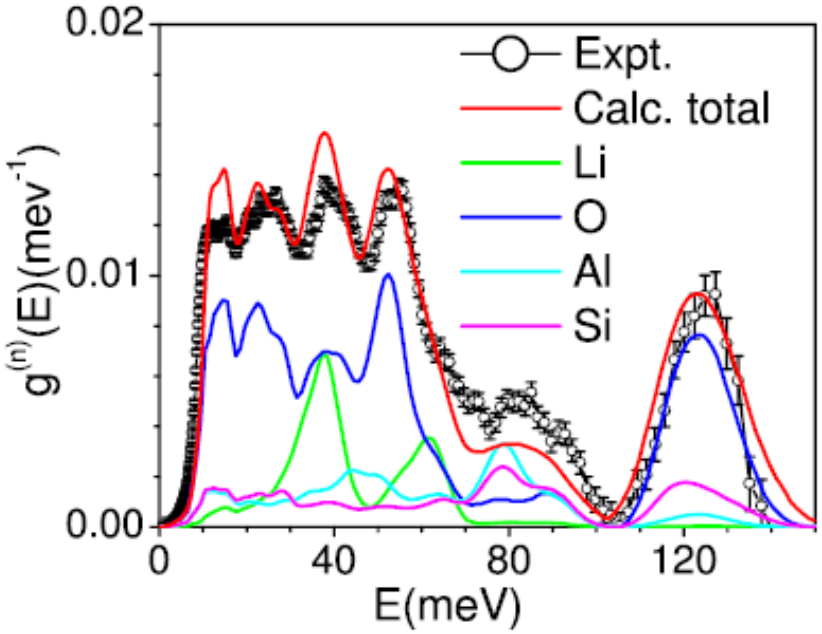

Figure 19: Plot of partial density of states verses energy in β-eucryptite describing individual atomic contribution by comparing experimental (inelastic neutron scattering and calculated (ab- inito) data[34].

"Reproduced from [Singh, B., Gupta, M. K., Mittal, R., Zbiri, M., Rols, S., Patwe, S. J., Achary, S. N., Schober, H., Tyagi, A. K., & Chaplot, S. L. (2017). Role of phonons in negative thermal expansion and high pressure phase transitions in β-eucryptite: An ab-initio lattice dynamics and inelastic neutron scattering study. *Journal of Applied Physics*, *121*(8).], with the permission of AIP publishing."

Anomalous Thermal Expansion in this material required knowledge of Grüneisen parameter $\gamma_l(E_{q,i}) = -\left(\frac{\partial ln E_{q,i}}{\partial ln l}\right)_{T,l'}; l, l' = a, b, c \;\&\; l' \neq l$ obtained for entire Brillouin zone. For hexagonal system, $\gamma_a = \gamma_b$ .Hence, γ_a and γ_c variation as a function $E_{q,i}$ (describing q-point energy of ith phonon mode in Brillouin zone) showed large negative Γ magnitudes for low energy phonons(~10meV) while positive magnitudes for high energy phonons (30-70meV). The observed anisotropy in γ and calculated elastic constants suggested anisotropic NTE in the material. Hence, volume thermal expansion coefficient ($\alpha_v = (2\alpha_a + \alpha_c)$) was then

calculated using calculated values of linear thermal coefficient$\alpha_a$andα_c *as mentioned in Ref*34). $\alpha_v$along a-b plane was found to be negative for low temperatures and positive for high temperature. The deviation of calculated lattice parameters from the experimental data at 600K indicated the presence of anharmonicity. Consequently, this material behaved as NTE(α_v = - 1.7×10^{-6} K^{-1}) below 300K and PTE at high temperatures. To find out the specific mode causing NTE in this material, phonon dispersion at ambient as well as 0.5GPa was constructed. Among all the modes of the Brillouin, $\gamma_a$and $\gamma_c$turned out as negative resulting into NTE along a and c at low temperatures. On the other hand, at high temperatures it showed PTE in a-b plane and NTE in c-axis. The polarization vectors for soft modes were visualized further in order to understand their internal vibrations along the three Cartesian axes. Large negative values for γ_a and γ_c belonged to two modes. 1. M-point involving sliding motion of SiO_4 in a-b plane, AlO_4 polyhedral rotation and movement of Li atoms along b and c axes. 2. A-point: AlO_4ploryhedral rotation about a-axis, SiO_4ploryhedral rotation about b-axis and Li movement in a-b plane. The calculated eigen values for these M and A point phonon modes showed softening in the entire Brillouin zone obtained at 0GPa and 2GPa. This can be the driving point for phase transition in the material. Hence, it is concluded that AlO_4 and SiO_4 polyhedral rotation along a and c axes are responsible for NTE at low temperatures in this material[34]

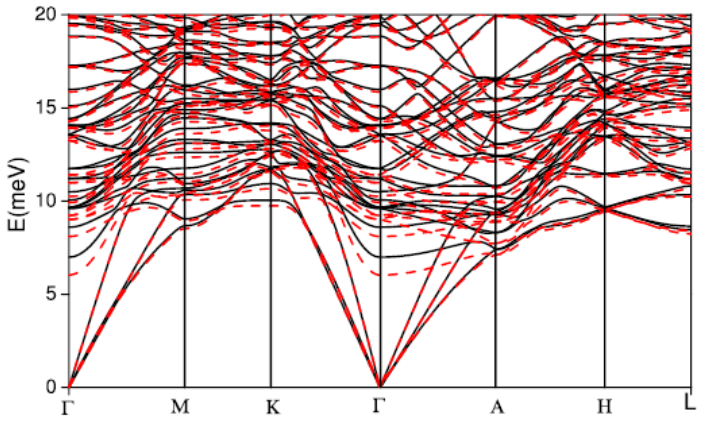

Figure 20: The contribution to phonon dispersion spectra offered by High symmetry directions in Brillouin zone of the unit cell of β-eucryptite at ambient (solid lines) and 0.5GPa (dashed lines) [34].

"Reused from [Singh, B., Gupta, M. K., Mittal, R., Zbiri, M., Rols, S., Patwe, S. J., Achary, S. N., Schober, H., Tyagi, A. K., & Chaplot, S. L. (2017). Role of phonons in negative thermal expansion and high pressure phase transitions in β-eucryptite: An ab-initio lattice dynamics and inelastic neutron scattering study. *Journal of Applied Physics, 121*(8).], with the permission of AIP publishing."

ReO_3 is a simple perovskite like cubic structure of ReO_3 (transition metallic oxide) consists of corner-linked ReO_6 octahedral units having Re at the centers and Re-O-Re linear linkages[11,35].

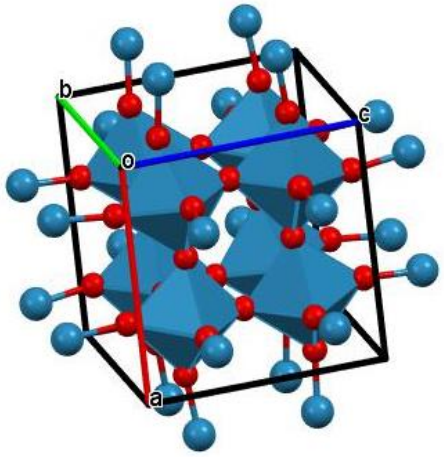

Figure 21: The crystal structure of ReO_3[35]

The structure of $ReO_3$is comprised of linear linkages of Re-O-Re and corner linked ReO_6 octahedra having Re centered in the octahedra[35].It shows phase transition from cubic(I) phase $Pm3m$-monoclinic phase $C2/C$-rhombohedral I phase- rhombohedral II phase as marked through Raman and X-ray diffraction studies over high pressures but there was a large disparity observed between obtained and theoretical phonon frequencies. This variance of the phonon mode frequencies is observed due to electron phonon coupling and anharmonicity. The dissimilarity was tackled using DFT over high symmetry points (Γ, X, M and R) in the Brillouin zone of ReO_3.The phonons along M, R and X points were traced to reveal softening. The M-point belongs to the rotation of ReO_6 octahedron along z-axis and is triply degenerating similar to R_{25} mode involving rotation of ReO_6 octahedron along each of the axes. Instability in either of the above two modes (M_3 and R_{25}) have a tendency for the phase transition occurrence in the material. Among all of the soft optical modes, M_3 and R_{25} only showed strong anomaly as a function of pressure giving out signatures of structural transitions. The transition pressure

between $Pm3m$ and $Im3$ phase was obtained as 0.5 ± 0.1 GPa based upon calculated enthalpies of the modes at different pressures. This was the pressure where M_3 loses its stability. Further it was realized that the transverse (TA) and longitudinal (LA) acoustic modes' coupling to M_3 modes take part in the phase transition.M_3 phonons achieve instability at P>3GPa and phase transition was noticed at lower pressure of 0.5GPa. Previous reports[37, 38]shows that ω^2 is related to phase transition pressure by the relation: $\omega^2 \alpha (P-P_c)$ where P_c is a phase transition pressure and $P< P_c$, following the mean field theory. At the transition pressure, ω^2 corresponding to the soft phonons approaches to a very low value signifying the first order phase transition. Thus, the ω^2 vs P plot for M_3 mode was thereafter analyzed in order to understand the behavior of M_3 soft phonon mode across phase transition. It was observed that there is a discontinuity of slope value for ω^2 for M_3 phonon mode at 0.5GPa and anon-zero magnitude of phonon frequency at 0.5GPa. Moreover, the observed M_3 phonon mode frequency for pressure just lower to transition pressure was found to be 64cm^{-1}. Such a low phonon frequency signified that the transition is of weakly first order.[36].

Neutron diffraction studies of Chatterji et.al.[39]on thermal behavior of ReO_3 found that unusual NTE property is a result of increased anharmonicity in the M_3 mode. It has been witnessed that there is a continuous decrement of lattice parameter with increasing temperature up to 200K. After crossing this temperature, the material again shows normal thermal expansion (PTE) upto the measured temperature of 305K. Further, the atomic displacement parameters of Re and O atoms with change in temperature revealed that vibrations in O atoms are thermally strong. Lattice dynamical analysis suggested that major contribution for NTE in this material comprises of low energy phonons (~14meV), typically belonging to M_3 mode in the Brillouin zone[39].

Significant gaps in the research

Present article focuses on the types of methodologies helpful for understanding the lattice dynamics of NTE materials. Several other techniques such as Inelastic X-ray scattering and Infra-red scattering can also be explored to study the aspect of Anharmonicity in an NTE material. Various families of NTE materials namely metal cyanides, coordinated cyanometalletes polymers, nanostructures, family of halides can also be explored for the detailed investigation in this direction.

Conclusion and Future Directions

In Summary, phonon anharmonicity plays a vital role in understanding the thermal properties of a system. Three methods namely, experimental, analytical and theoretical are discussed in this article to understand the phonon anharmonicity. As discussed, Specific heat dependency with Grüneisen parameter and ab-initio calculations of DFT can be approached to understand the phonon behavior as a function of pressure. Brillouin zone of the phonon spectrum can also be beneficial to the researchers for exploring the phonon anharmonicity. Further contribution of anharmonicity can be studied with Zallen-Conwell plot. Presently discussed examples show that low energy phonons with large negative γ_i cause NTE in the material involving transverse vibrations, liberations and internal distortions of rigid unit modes. In majority of the materials presented in this article, true anharmonicity is the key factor which dominates for strong anharmonicity, typically the quartic or four phonon contribution. Another family of metal cyanides has attracted scientists to inspect their thermal properties. Several compounds such as $HgCN(NO_3)$, CuCN, AgCNetc[40,41,42]have been reported as NTE materials. Investigations of phonon anharmonicity in these compounds can help understand the cause for their NTE behavior. Apart from metal cyanides, family of fluorides and nanostructures NTE materials can be explored in detail[40, 41, 42, 43, 44].

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Glossary:

Bulk Modulus- The property of resisting to compression in a material

Specific molar heat- The total portion of heat energy contributing to increase the temperature by 1K for 1mole of a material

Inelastic neutron scattering- It is an experimental technique to understand atomic and molecular behavior of a material. It determines the variation in kinetic energy achieved due to the inelastic collision between the neutrons and the sample.

Phonon density of states- Total number of phonon energy levels per unit energy per unit volume

Thermal resistance- A property of a material to resist a flow of heat. It is an inverse of thermal conductance.

Harmonic oscillator- It describes a system which dis-orients its equilibrium position when its restoring force is linearly varying to the displacement.

FWHM- The line shape width at the half of its maximum amplitude determines the full width at half maximum (FWHM).

Isothermic compressibility- It is the ratio of partial derivative of change in volume and partial derivative change in pressure at constant temperature.

Lattice- Imaginary grid to place atoms in a crystal

Crystal defects- It describes the state of lattice involving imperfections in the atomic arrangement deceased from regularity.

Secondary Metabolites: A Review of Strategies used in the Synthesis of Secondary Metabolites

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Abstract: Secondary metabolites are the compounds synthesized by plants which are important in providing defense to the plants and also enhance their medicinal value. As the endogenous levels of these metabolites in plants are low, the present day research focusses on strategies for enhancement of these compounds. Biotransformation is a useful method which refers to chemical reactions which are catalyzed by cells or enzymes. This method can be used in plant cell and tissue culture systems in which different explants can be used to produce compounds which have a commercial potential. This method helps in production of secondary metabolites from plant sources. This review focusses on the different strategies which are used for synthesis of secondary metabolites.

Keywords: Biotransformation, secondary metabolites, agar cultures, agitated cultures, hairy roots.

Introduction:

Plants synthesize metabolites by primary metabolism and secondary metabolism. The primary metabolites are carbohydrates, amino acids, lipids etc. These are utilized by the plants for their growth and development. The secondary metabolites are the compounds involved in the protection of plants against various abiotic and biotic stresses[1]. Secondary products are synthesized from

primary metabolites. Secondary metabolites are sources for food additives, flavours, pharmaceuticals and industrially important pharmaceuticals[2,3]. In normal metabolic conditions the synthesis of secondary plant products is often low. The concentrations of various secondary plant products are strongly dependent on the growing conditions and physiology through altering the metabolic pathways responsible for the accumulation of the related natural products[4].

Biotransformation: Biotransformation in plants is the process in which the secondary metabolites are converted into a newly metabolite which is of more use than the former one[5]. The new compounds formed through biotransformation are considered as the modified compounds with improved or advanced molecular structure which consists of high stereo- and region-selectivity[6]. Secondary Metabolites are chemical compounds synthesized by the plants which do not directly aid in the growth and development of plants[7]. Biotransformation can be enzymatic or non-enzymatic conversion from one secondary metabolite to another novel and useful metabolite. The enzymatic reaction is further classified into microsomal and non-microsomal reactions[8].

Enzymatic Reactions

- Microsomal Reactions
- Non-Microsomal Reactions

Non-enzymatic Reactions

The most common enzymatic reactions taking place in biotransformation are Hydroxylation, Oxidation, Glycosylation, Alkylation, *O*-, *N*-dealkylation and Carbon-carbon fission[9]. The biotransformation capacity of the cell culture depends on pH, elicitation, permeabilization and substrate uptake and product release[10]. Any changes in the above factors can cause a change in the whole process so maintaining accurate and appropriate conditions is a must. Biotransformation provides a suitable environment to the *in vitro* cells, which allow the accumulation of secondary metabolites[11].

There are several advantages of biotransformation such as[12]

1. More than one reaction can be used in a single process of cell culturing.
2. The process of biotransformation is simple and efficient.
3. Non-useful compounds can be converted to compounds which are very important and can also be used as precursors.
4. Chemical and natural, both the compounds can be used as substrate.

Biotransformation has applications in the degradation of xenobiotics. The detoxification mechanism is usually done by glycosylation which often leads to the degradation of xenobiotics and the accumulation of different important metabolites and also some water soluble by-products[13].Biotransformation is also used in the transformation of several synthetic and toxic chemicals, some solutes and solvents, organic and inorganic compounds, natural and synthetic chemical compounds, steroids and non-steroidal compounds, sterols, pesticides and herbicides, antibiotics and different kinds of pollutants[14]. Some common substrates for the biotransformation are various phenols, alkaloids, steroids, coumarins, terpenoids and cardenolides[15]. Biotransformation is a very efficient process and is also environment friendly so, it is widely used for the accumulation of secondary metabolites[16]. Biotransformation has also been used to study the bioaccumulation potential and toxicity of the contaminants in aquatic animals[17]. This helps in the biotransformation of harmful toxic contaminants into less toxic compounds which is not lethal to the aquatic organisms. Biotransformation has been successively used in different plant species (Table 1)

Sr. No.	**Plant species**	**Secondary Metabolite**
1.	*Schisandra chinensis* (Turcz.) Baill[18]	Hydroquinone and 4-hydroxybenzoic acid
2.	*Origanum majorana* L.[19]	Hydroquinone
3.	*Astragalus vesicarius* L.[20]	Colchicoside
4.	*Catharanthus roseus* (L.) G. Don[21]	Betulin
6.	*Nicotiana tabacum* L.[22]	Betulin
7.	*Cucurbita pepo* L. Whole pumpkin plants[23]	Tetrabromobisphenol A

8.	*Rhodiola rosea* L. Rose root callus[24]	Cinnamyl alcohol glycosides
9.	*Withania somnifera* (L.) Dunal[25]	Phenol and Flavonoid
10.	*Cannabis sativa* L.[26]	Cannabinoid synthase and Osmoprotective metabolites
11.	*Citrus paradise* Macfad[27]	Citrus Flavonoid aglycones
12.	*Scutellaria lateriflora* L.[28]	Flavonoids and Verbascoside
13.	*Hypericum perforatum* L.[29]	Flavor compounds
14.	*Onobrychis viciifolia* Scop.[30]	Phenolic compounds
15.	*Micrococcus luteus* Cohn[31]	Oleic Acid
16.	*Eryngium borgatii* Gouan var. *borgatii*.[32]	Phenolic Acid and Flavonoids
17.	*Scutellaria baicalensis* Georgi[33]	Flavonoids and Verbascoside
18.	*Scutellaria baicalensis* Georgi[34]	Phenolic Acids, Flavonoids and Phenylethanoid glycosides
19.	*Verbena officinalis* L.[34]	Phenolic Acids and Phenylethanoid glycosides
20.	*Cistusin incanus* L.[34]	Phenolic Acids, Catechins and Flavonoids

Table 1: Secondary metabolites produced by biotransformation

Strategies for Biotransformation: Biotransformation can be carried out by various strategies such as[35]

1. Biotransformation using precursor feeding
2. Biotransformation using co-culturing techniques
3. Biotransformation using Nonspecific/Exogenous molecules

Biotransformation of secondary metabolites can also be done by using various plant cells, tissues and organ cultures. Biotransformation can also be carried out with the help of intact plants. For example, Biotransformation of tetrabromobisphenol-A dimethyl ether was done with the help of

whole pumpkin plants into tetrabromobisphenol-A[36]. Biotransformation can also be carried out by hairy root transformation which has been done by various researchers. Hairy root cultures have several advantages such as low cost and the yield obtained is higher than the conventional methods[37]. For example, sapogenins were produced from hairy root cultures of *Chlorophytum borivilianum* (Safed Musli)[38]. Silymarin flavolignans, phenolics, alkaloids and flavonoids were produced from *Silybum marianum* L. through hairy root culturing[39]. Hairy roots are produced by infecting the plants with *Rhizobium rhizigenes* which is responsible for causing hairy root disease in plants[40]. Hairy roots have been known to produce secondary metabolites in plants since a very long time[41]. The hairy root culture has several advantages due to which its application is high:

1. Biomass accumulation is very high.
2. Hairy roots can be cultured easily with varying mediums so; large number of variations and factors can be tested and studied.
3. Efficiency rate is comparatively higher than other techniques.
4. Effect of various elicitors on the production of secondary metabolites can easily be studied in hairy root cultured plants.
5. The amount of secondary metabolites produced through hairy root plant is higher and can be continuously produced, compared to the natural way.

Other Strategies for secondary metabolite synthesis:

Production of Secondary Metabolites through Hairy Root Culture: Hairy root cultures have been a widely adopted method wherein hairy roots of the selected plant can be cultivated with microbes like *Rhizobium* and the biomass increase is observed. The selected plant can also be subject to hairy root culture which has the potential for enhancement in levels of econdary metabolites(Figure1).

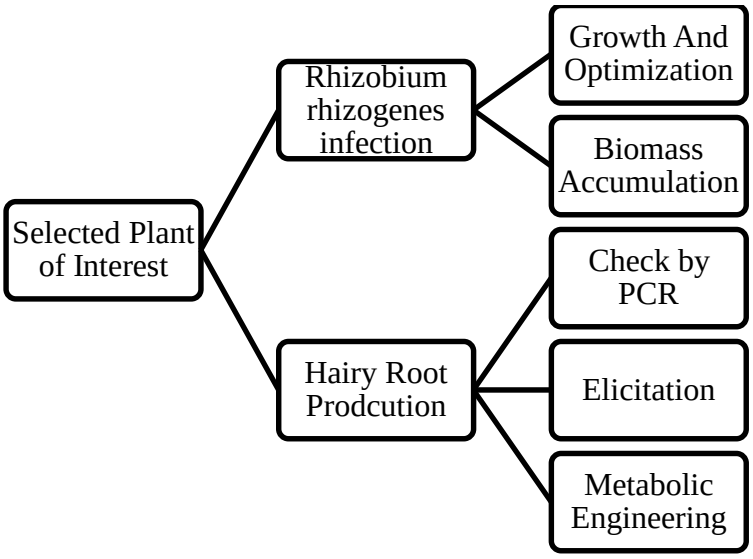

Figure 1: Production of Secondary Metabolites through Hairy Root Culture[42]

Production of Secondary Metabolites through Plant cell suspension cultures: The strategy adopted here includes an approach where the plants are acclimatized on the suspension culture media and using various elicitors, the secondary metabolites are enhanced. This method gives a good yield of industrially important compounds (Figure 2).

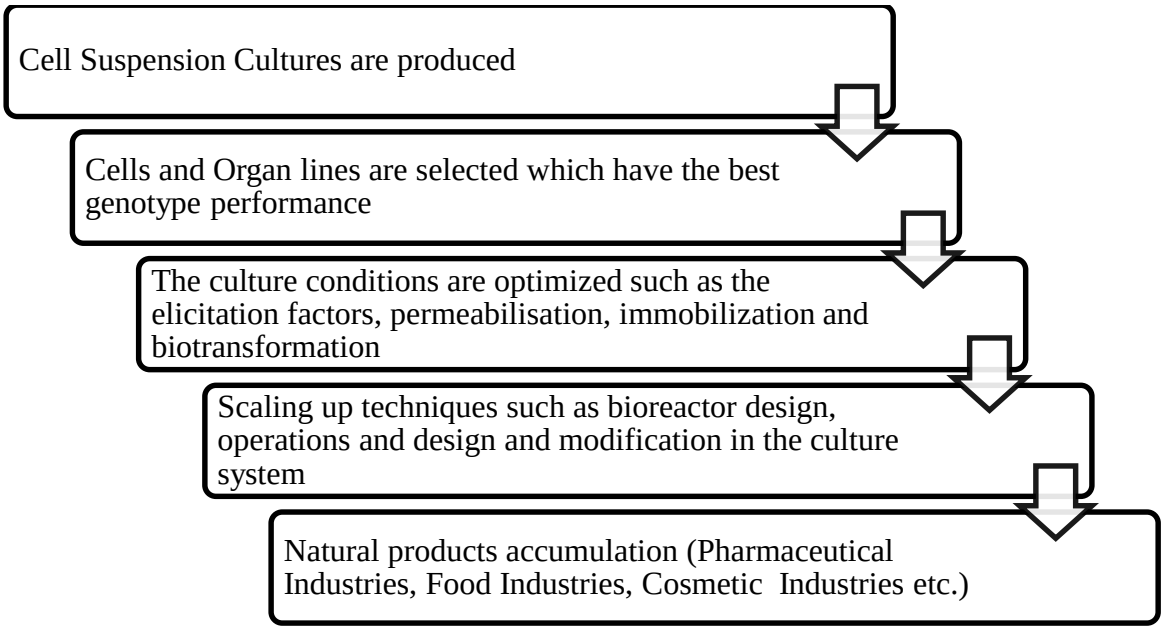

Figure 2: Production of Secondary Metabolites through Plant cell suspension cultures

Biotransformation of secondary metabolites by any of the process can lead to the discovery of various new compounds[43].

CONCLUSION:

The techniques discussed, provide a simple approach towards formation of novel compounds by introducing chemical changes which are normally not a part of their regular pathway of synthesis. Hairy root culture and suspension cultures are also a promising tool for synthesis of these metabolites. By conventional chemical methods, it is difficult to synthesize these compounds and expensive as well. These methods can be a promising tool for enhancement of many important medicinal components in plants.

FUTURE PROSPECTS:

The methods used for production of secondary metabolites can be subject to scale-up for getting good yield of metabolites. This will also help to extract useful metabolites for preparing different drug formulations with good quantities of the metabolites.

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Glossary

Precursor feeding- Addition of chemical substances or enzymes

Co-culturing- Culturing with another organism or two organisms together

Nonspecific/exogenous molecules- Externally supplied molecules

Permeabilization- The process of making a membrane/medium permeable

Xenobiotics- A chemical compound eg: a drug, found in an organism that is foreign to the organisms

Immobilization- Process of encasing the cells in some material to keep cells viable and useful for a longer duration

Microsomes- The components/structures derived from parts of endoplasmic reticulum obtained when the tissue is homogenized

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Cause and Impact of Alteration Along Riverine Landscape

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Abstract

The urban river environment not only consists of natural features but also other physical surroundings within the city that fall under the influence of the river. They include the river system, the built form, and the networks within the city. Due to development pressures, the built form and the networks try to exploit the river systems. On the basis of a literature study, it was found that assessment of the alteration of riverine landscapes due to anthropogenic activities like riverfront development and its impact on the ecological processes in the upstream and downstream of the river system reveals profound methodological gaps. In this review paper, the cause of the alteration of riverine landscapes and how it impacts the ecological processes are discussed. Riverine landscapes with reference to Indian contexts are discussed in detail to understand the seriousness of this problem. Due to riverfront development activities, there is a change in the structure of the land-water median/edge, along which most of the ecological processes thrive. Hence, it becomes important to find and suggest sustainable ways to deal with this issue. Newer habitats and systems get established due to changes in the course of rivers and water, which need to be safeguarded from further alteration for the overall health of the river.

Keywords

Riverine ecosystem; altered landscape; riverfront development; impact evaluation; river health; ecological processes

Introduction

Landscapes around the world express a long-standing, intimate relationship between people and their natural environment. They are manifestations of nature's and humans' collaborative efforts. Land used for traditional agricultural and water harvesting practices, reflect specific techniques of land use that guarantee and sustain biological diversity. Others, associated in the minds of communities with powerful beliefs and traditional customs, embody an exceptional spiritual relationship of people with nature. Riverine landscapes represent specific ecosystems, the existence of which is directly dependent on permanent or at least periodic contact with watercourses. Geographically, riverine landscapes can be defined as the spatial extent of an area along the floodplains[1]. The riverine landscape also hosts some of the most important vegetative communities, which support wildlife species[2]in his article "Riverine landscapes: taking landscape ecology into the water", states that riverine landscapes in their natural state (preferably unaltered) demonstrate high levels of complexity across a range of scales. They can be narrowed down in one (or more) of three ways or scales: i) rivers as elements of a landscape setting/region; ii) rivers linked with their surroundings by boundary dynamics; iii) rivers as internally heterogeneous landscapes. He further adds that there are three main aspects of the riparian landscape which one needs to consider while researching: the water body, riparian vegetation, and river landscape planning. They have significant implications for river ecosystems because they play multiscale functional roles in the geomorphological, physical, chemical, and biological conditions of the river system.

Riverine landscapes in India are subject to extreme developmental activities, starting from the very edge of the river to far-reaching extents. These areas embody a rich cultural imagery versatile species diversity, enable the livelihoods of millions and drive the formation of distinct regional identities. The topographic diversity of the watershed and the boundless productive landscape along major rivers have captured the imagination of the national government to undertake river valley development and riverfront development projects. These activities have transformed riverine landscapes into an interstate infrastructural network of water conveyance and energy generation. Over time, these massive government projects have become widely questioned, sparking heated debates about the need for more environmental protection measures to stem the impact of development on contemporary India[3].In most cases, these developmental/anthropogenic activities adversely affect only a section along the river;

while in some cases they impact the overall river system and its associated processes (such as ecological, socio-cultural, hydrological, geological, geomorphological, etc.). This further leads to extreme changes in the structure of the associated elements (which make up these systems). In contrast to that, sometimes these anthropogenic activities add to the uniqueness of certain places within this landscape, which in turn makes the places important culturally and ecologically. There has been a major shift in the ecosystem and biodiversity along the riparian corridor of such altered landscapes, giving rise to many new established processes. As research in such areas of post-developmental activities is very sparse, one fails to understand the measures that need to be taken for this modified landscape, which will help one intervene in a more sensitive manner and work towards regeneration or enhance the newer relationships that have been built after these infrastructural developments. Hence, it becomes important to observe, record, and understand these changes and take sufficient measures to safeguard them from further alterations.

Indian rivers have a strong physical construct as well as a cultural and religious identity, which gets strengthened by the associations of stories of the land, practices, and beliefs. Eminent researcher Mr. Brij Gopal[4,5] and many others have always highlighted and mentioned how Indian rivers have not been understood as ecosystems but are only treated as conduits of water or wastewater. The flow of rivers in cities has been fundamentally changed, and this can be seen in a variety of ways. Today, the approach towards decision-making on how to deal with altering riverine landscapes is confusing government officials, bureaucrats, and designers into complacency about ecological quality where landscapes look natural, and it is provoking people into objecting to ecological landscape protection or innovation where the resulting landscapes do not look natural. The scales of economic, monetary, and financial gains are usually used to measure concepts of development. The ecological and social costs of such unrestrained pollution and degradation have put a big question mark on the perceived notion of economic development[6]. For this reason, there has to be a greater awareness about the need to protect the environment with effective planning and the ability to strike a fine balance between development and environmental protection. Current trends in research[7]and design approaches for riverine landscapes in India reflect morphological changes, which are governed by expert land-use techniques, which claim to guarantee and sustain biological diversity. This is a change from earlier considerations of human linkages to river flows, which focused heavily on recreational uses of rivers or scenic beauty[7].

Literature Research

A systematic search of doctoral research and dissertations, peer-reviewed research papers, and review articles was performed, which helped identify evidence of the impact of anthropogenic modifications on river landscapes and what has been the trend in research related to writing on Indian riverine landscapes. With the help of the electronic database of Google Scholar, with keywords such as "culture and landscape", "visual character and perception of landscapes", "associative cultural landscape", "Indian riverine landscapes", "altered and unaltered landscapes", "anthropogenic alteration along riverine landscapes", "river health", and later "riparian vegetation", "cultural associations", "socio-cultural practices", "riverfront development", etc., against each type of anthropogenic modification were reviewed (refer Table 1). On the basis of this search, articles were scrutinized on the basis of the following criteria: (1) specific reference to altered and unaltered riverine landscapes and patterns associated with these changes; (2) papers specifying evidence of hydrological, ecological, and geomorphological components of the impact on river landscapes; (3) methods used for assessing the heath of rivers and alteration; and (4) ecological processes, which help sustain river ecology and maintain biodiversity.

Riverine landscapes are demarcated as transitions between terrestrial and freshwater ecosystems and include components of topography, vegetation, and soils. But the planning efforts have destroyed and disfigured the natural landscape, topography, agricultural soil, water catchments, and architectural heritage that give the very character of the place[8,9]. There is a methodological gap in assessing the degree of alteration of riverine landscapes.

A pristine landscape (untouched by humans) or "raw scenery" is amongst the most common responses with regards to an unaltered landscape. As per the definition in Cambridge and Oxford dictionaries, "altered" is defined as "change in appearance, character or structure". This is more in relation to the visual character or appearance (with a focus on vegetation). Some researchers have defined altered landscapes as those with habitat loss or habitat fragmentation. This in turn suggests that the biophysical systems present in such landscapes have an inefficient flow of energy or nutrients among species. Hence, the health of a landscape system can be decided by knowing the "degree of alteration": when the system is resilient to long-term effects

of natural perturbations, or when the landscape system need not be "doctored," or "when the system reaches its capacity for self-renewal"[10].

Ecological Processes

Visible traces of patterns and processes associated with riverine ecology can be witnessed along and across the riverine landscape. If their processes are sustained or revived, there is a probability that river ecology can re-establish itself or provide an environment for newer species and processes to establish themselves. Some of these processes, such as formations of various landforms, transformations in flora species and their associated fauna species, help sustain the river ecology and also help one understand the age of the river. Lateral shifts along the banks of a river are different in this character and also have distinct features across river sections at different locations. These imprints are old traces of the rivers and are similar to cardiographs, which suggest that the river is still "alive". The simultaneous cyclic process of uptake of nutrients from water by biota and subsequent release back to water during downstream transport[11]. But due to development projects like riverfront development, the continuity of water breaks. Also, the seasonal cycle of water retention and movement gets disturbed as a section of the river's water flow is highly regulated for aesthetic reasons.

Instances	**Important actions**	**Prominent researchers**
Helps in reducing soil erosion, and taps nutrients and sediments. This enhances quality of soil. Also because of presence of fertile soil – good for agriculture activities can be carried out	• Taps Nutrients and Sediments • Soil quality improves	
It filters pollutants from surface run off coming from agricultural fields and enhances water quality	Water quality improves	Kileyand Schneider (2005)
Retention of water and recharges aquifers and soil moisture.	• Water Retention • Recharge	

The riparian canopy provides organic matter via litter fall	Organic matter	Amitha (2003)
Regulates water temperature, by reduces solar heating of stream water by shading, especially in low order streams	Controls temperature	Nancy et al. (2004).
Serve as substrates for biological activity by microbial and invertebrate organisms	Supports reproduction and biological activities	Nancy et al. (2004); Gloss et al. (2004)
Single most productive type of wildlife habitat –acts as corridor. It maintains and enriches biodiversity	Maintain and enhance biodiversity	Robert et al. (1997).
Grazing land for cattle	Grazing land	Hannah (1997)

Table 1: Indicate various instances supported by ecological processes.

An initial literature review suggested (refer Table 1) that ecological processes are most vulnerable to anthropogenic activities and that they are the primary contributors to sustaining and maintaining river ecology and biodiversity. These processes include those in rivers that have existed for very long periods of time and range from purely physical to more biologically mediated [12,13]processes. We will focus exclusively on biologically mediated processes, which relate to the most ecologically relevant processes to rivers. Based on readings, five dominant processes were identified, based on different aspects of ecosystem functioning, and they proved to be conceptual and methodological references[14]:

1. Exoenzymatic activities, uptake and degradation of dissolved organic matter

2. Uptake of nutrients, primarily by microbes and plants, at the organism or community scale; Individual processes within the cycle of a particular nutrient (e.g. nitrification, denitrification, N fixation)

3. The balance of energy created (primary production) and used (respiration) within a river reach

4. Pollutant Dynamics: The capacity of the river as well as organisms or communities to take up and bio-accumulate dissolved pollutants.

5. Community Dynamics: Reproduction, Biodiversity, and Habitat Establishment

The morphology of rivers, which is defined as the change in shape and direction of water movement or a river; change in the amount and quality of water; habitat fragmentation due to riverfront development along the riverine landscape. This in turn changes the biophysical attributes along the banks. River morphology (change or lack of water/water retention) and soil quality changes as a result of anthropogenic activities such as riverfront development. This leads to altered landscapes, which in turn change the character and structure of flora-fauna biodiversity (community dynamics), one of the important ecological processes. Habitat and biodiversity in an impact area of 0-10 sq.km from the river edge/land and water mediation are destroyed due to riverfront development, and it's this edge where the river can swale, and biodiversity can thrive. This results in lower habitat heterogeneity, reduced refuge habitat, creates locally intolerable conditions, and shifts aquatic communities.

Anthropogenic Activities: the reason for the change

As discussed above, when the physical, chemical, and biological indicators of a river ecosystem are altered, they lead to significant changes in processes that sustain the riverine ecosystem. Riverine landscapes in India are the preferred landscapes for many anthropogenic activities. These activities or practices can be categorized based on the frequency of performance and nature of their alterations: practices which are conducted on a daily basis; practices which contribute towards livelihood or economic growth and hence are performed either on a daily basis or bi-annually or annually; and religious and cultural activities like festivals; rituals and ceremonies; mass gatherings to invoke rituals or worship; harvest festivals; and respect to water bodies; gatherings/"*mela*"; procession/"*parikrama"*. From a literature review, it was identified that the three main reasons why the river system changes are: technological development factors, natural factors, and socio-cultural practices.

- Technological development factors: initiatives or activities that are carried on as part of developmental activities fall under this category. Political ideologies or preferences, or image building, or responding to urban sprawl or economic growth sometimes governs

these activities. Most of these activities are needed by the hour, and so they get prioritized. These activities cause visible changes to the riverine landscapes. Damming of rivers and siltation due to damming; subsurface alteration due to mining, metro rail, etc.; Infrastructure development-riverfront development; Inter-catchment water transfer and Surface Hydrology-connecting rivers projects; Groundwater absorption as a result of wells and bore wells. Deforestation of natural landscapes to clear land for development activities; on-surface alterations—laying out road network; introduction or discharge of industrial wastes/pollutants into water—causing pollution; waterlogging/drainage during heavy rains due to building in low-line areas; and so on are some of the prominent activities that alter riverine landscapes (particularly the land-water median/edge).

- Natural processes/causes: These processes occur during the geological timeline, as physical transformation in landforms is a time-bound activity mainly influenced by lithological, geological, and earth movements. In most cases, these alterations are irreversible. But due to human involvement or impact, these processes do get accelerated. Shifting of river courses, lithological change, and geographic change—mainly related to soil formation and subsurface water level changes; Climate change; sedimentation and siltation of deposits due to river water movement; floods etc. are some of the important natural processes which alter riverine ecology and landscape.

- Socio-Cultural activities/practices: There is strong linkage between river flow to floodplain agriculture, transportation and social exchange, and as acts of reverence, cultural identity, or sense of place. Change in land-use in the land adjacent to the riverbed, by activities like encroachment and illegal construction, Sand mining, agricultural activities, etc. alter the land-water edges. Daily domestic activities like washing clothes, filling water, bathing animals, fishing, other religious activities during festivals and celebrations mainly pollute the water. Commercial activities like boating as means of transport as well as recreation, cutting of forest wood, and harvesting other forest produce, mainly alter the water quality, and vegetation patterns.

For all the mentioned categories, developmental activities like riverfront development or damming impact and alter ecological processes such biodiversity, habitat heterogeneity, habitat

complexity and riparian cover (refer Table 2). In case of riverfront development, the recent trends have encouraged the idea of concretizing the land-water mediation/edge. It is this edge, which sustains most ecological processes. These processes exit at varied scales along the entire river system: starting for habitat scale (0-5sq.km area), to second order and third order streams (5-10 sq.km) and later first order stream (10-100sq.km); up till watershed and catchment areas (100 -10,000 sq.km and above). It is this edge where the river swales, deposits sediments and keeps the ecological processes going. These are extremely important aspects when it comes to assessing the life and health of river systems.

Anthropogenic modifictions	**Modification type (what it modifies)**	**Response/Impacts**
Damming; Sedimentation	Changes the course of the river; Rise in water level in upstream/catchment; flood plain connectivity	Siltation; Water retention; Water quality; Change in water movement; restricts Species movement; livelihood; increase in tourism; change in character of landscape
Riverfront development	Rise in water level in upstream and downstream; flood plain connectivity; land-water mediation/edge concretized; water logging; structure and composition of riparian vegetation	Siltation; Water retention; Water quality; Change in water movement; restricts Species movement; Species diversity; Habitat fragmentation; increase in tourism; change in character of landscape
Inter-catchment water transfer	Uninterrupted water supply for agriculture; supports navigation and transport	Species diversity; Habitat fragmentation; restricts Species movement

Deforestation of natural landscapes; Timber/Forest (ecosystem service)	Livelihood and income of communities depended on ecosystem services; structure and composition of riparian vegetation	Microclimate regulation is patches; soil formation and quality; species diversity; Habitat fragmentation; lower oxygen concentrations; organic matter; water temperature
Industrial wastes – Pollution; Daily domestic activity; Boating/Tourism and Transportation mode	Physicochemical and biological properties	Bioaccumulation and bio magnification; disturbs the food web; soil quality; water quality
Settlements and built environment; Change in land-use: encroachment, illegal construction, etc.	Change in land use; flood plain connectivity; rise in paved surfaces;	Restricts Species movement; habitat fragmentation; ground water recharge; surface runoff; species diversity
Fishing (ecosystem service)	Livelihood and income of communities depended on ecosystem services	Species diversity
Cultural and religious activates	Change in land use; pollution; biodiversity; natural habitat	soil quality; water quality
Sand mining	Greater availability of construction material; riverbed instability; land-water mediation/edge; widening lake/river section	Bank erosion; soil formation and quality; species diversity; ground water recharge
Agriculture activities	Change in land use; flood plain connectivity;	Soil formation and quality; ground water recharge;

	water quantity; nutrient composition, biodiversity; natural habitat; structure and composition of riparian vegetation	chemical composition of water; species diversity

Table 2: Describes various anthropogenic activities and how they modify natural systems.

To further articulate these practices and activities, one needs to record how frequently and to what extent these activities and practices alter riverine landscapes. The daily activities and those associated with livelihood or income generation happen on a regular basis, which leads to more alteration of the landscape; while those like religious festivals or rituals, which happen on a quarterly or annually, alter less (the scope of revival has time). At this point, one must understand that not all practices alter or affect the riverine landscape to a similar degree. Hence, it becomes important to observe, identify, document, and quantify the "degree of alteration-degree of impact" these activities have on the ecology of the riverine landscape.

Impact due to Altered Riverine Landscapes

Due to the above-mentioned activities, factors and practices associated with river ecology undergo change [15,16,17,18]. This in turn alters and impacts patterns and processes along riverine landscapes. Physical changes mainly include shifts in patterns of sediment movement (change in sediment transport; sediment sequence and composition), change in channel pattern, and alteration of flow regime (which includes change in rate of soil and sediment erosion, degradation in downstream flow, channel narrowing, degrading flood plains), loss of habitat availability, change in quality and flow of surface water quality, alteration of biogeochemical cycles, decreased water temperature, and deepening of river section. Chemical changes include changes in water quality, increased organic contaminants, increases in pollutants, changes in nitrogen and phosphorus levels, etc. While biological changes mainly include a decrease in fish diversity, problems of plant colonization, change in community composition and abundance of

alien/invasive species, increase in sedimentation, change in benthic macro vertebrate species composition, etc.

As defined by Maddock[19], river health, or its ability to sustain or develop resilience, can be measured through visible indicators such as ecological status, water quality, hydrology, geomorphology, and availability of physical habitat. Ecological integrity, resilience, and support of ecosystem structure, functions, and services are the characteristic features of healthy rivers[20]. A healthy river system stabilizes stream banks, regulates the thermal regime of the river, sustains food security of river organisms, enhances groundwater recharge, and provides habitat to wildlife. By knowing/post assessing the health of river, we can predict to what extent the system has been altered and what the scope for it to revert back. The health level of rivers is divided into five grades: very healthy; healthy; sub-healthy; unhealthy; and morbid, according to the comprehensive score. These health conditions are defined as below:

1) A very healthy river is the one that has rich water resources, a good water-ecological environment, satisfies the reasonable needs of human society and supports economic development for the basin resources.

2) A healthy system is one that has a relatively good hydrology and water environment status. It satisfies the reasonable demand of human social and economic development for basin resources.

3) An unhealthy system is the one that has threatened the health status of the basin with scarce water resources, a fragile water ecological environment, maladjusted system structure, and damaged function. In spite of all this, some functions are still maintained.

4) The last condition is defined as morbid, which basically means a system, which is devoid of all functions or most physical, chemical, and biological indicators are extremely low.

Research Gaps

A need has risen to strike a fine balance between development and environmental protection[6]. There has been insufficient research work done in dam-impacted catchment areas, where riparian vegetation has potential for regeneration (altered landscapes). Catchment areas

and tributaries can be considered most appropriate scales to improve hydrologic conditions and to assess the potential of riparian zones that are remnants of altered landscapes. As mentioned by some eminent researchers[4,5], "In India, rivers have not been understood as ecosystems but are treated simply as conduits of water or wastewater." If we specifically discuss about riparian vegetation, then there is a sufficient research done in areas of specific species diversity and conservation (like fishes, planktons, aquatic vegetation and so on). There is a need for researchers to conduct research in areas at specific species and interface levels, along the altered landscapes (specifically along the riparian vegetation and streams interface), as these areas are key for regulating aquatic-terrestrial linkages[21,22,23] and that they provide early indications of environmental change[23,24,25]. Identifying appropriates and role of riparian vegetation in altered landscapes; establishment of newer desired ecosystem systems with response to hydrological and geomorphological changes[26]; development of framework for delineating affected riparian vegetation (especially forest and upland vegetation) are few of the many areas which needs to be studies in detailed (especially from time to time). Basic documentation or recording of this data is also insufficient for Indian rivers.

Conclusion

Due to riverfront development activities, the riparian edge or areas of land and water mediation are altered. It's these points, or areas, which sustain all components that support and sustain river ecology and maintain biodiversity. These activities alter the movement, amount, and quality of water. Due to a break in river water flow, habitat fragmentation also occurs (both longitudinal and lateral). This in turn changes the biophysical attributes along the banks. The overall morphology and soil quality of the river get altered. This impacts flora-fauna biodiversity (community dynamics), which is one of the important ecological processes. When development happens in a small stretch of river, a new ecosystem gets recreated, but it is completely man-made and may or may not be sustained by itself. What this development does is that it impacts the entire river ecology. It changes and creates new patterns upstream as well as downstream. Community dynamics (interrelation between flora, fauna and water) are established in these areas (edges (biodiversity). Hence, it is important to further address and discuss the measures that should be taken to safeguard newly established patterns from further degradation. This paper attempts to inform the importance of land-water mediation/edge to

maintain the health of river ecology and suggests the need to record and document the degree of alteration of riverine landscapes as well as monitor developmental activities to avoid further alteration of riverine landscapes.

Future Prospects

This research will draw attention on the current adapted approaches to designing along riverbanks and its edges, and also develop framework under which assessment of river ecology in areas post and pre riverfront development. This will in turn guide designers, stakeholders, and decision makers to safeguard and deal with land water meditation edge more efficiently. This research will connect the aspect of river ecology and biodiversity with strategic design decisions – the actual agglomeration of research and design.

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Review of Researches on the Right of Children to Free and Compulsory Education Act, 2009

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Abstract

The Right of Children to Free and Compulsory Education Act (RTE Act) 2009 marks a historic moment for the children of India. Every child ages between 6 to 14 years has the right to free and compulsory education. One of the vital objectives of the Act is to bring excellence in education through the medium of reaching unreached section of the society. India became one of the 135 countries in the world to make education as fundamental right of each and every child. Since RTE Act is a new initiative, it is important to develop comprehensive understanding about it from the time it was implemented. The objective of this review article is to map studies across states of India and across the Departments in Universities. The second objective was to analyze the aspects that have been focused in the studies. All the Ph.D. thesis published on the RTE Act 2009 on the Shodhganga were accessed. The literature review indicated that most of the studies have been conducted under Department of Education. The major aspects covered under the studies were: awareness about the Act, perception of stakeholders about the Act, assessment of the Act, socio-legal aspects of the Act, infrastructure facilities under the Act, quality intervention of the Act and social inclusion through the Act. It being the initial years of the implementation of the Act, most of the studies have been about awareness and facilities. With the completion of ten years of implementation of Act, feedback from researches on case studies, longitudinal studies and comparative studies across States of India would prove to be significant. Across all the departments of universities, it had been found that most of the department seem to be focused in input level of the Act. The RTE Act has met with success in achieving some of the goals with which it started in the year 2010. Many of the states have been successful in ensuring effective implementation of RTE. Besides the success of RTE Act, the present study has found gaps in doctoral studies conducted on elementary education after its implementation.

Keywords: RTE Act 2009, Free and Compulsory education

Introduction

The Right of Children to Free and Compulsory Education Act or Right to Education Act (RTE), enacted by the Parliament of India on 4th August 2009, describes 'education' as a fundamental right of every child between the ages of 6 and 14 years and specifies minimum norms in elementary schools[1]. Through Section 12 (1) (c) of the Act, it requires all private schools to reserve 25% of seats to children of weaker and disadvantaged group[2].

Many efforts have been made in India to make elementary education a fundamental right of every child[3]. Not only in India, but in every part of the world various efforts have been made to achieve the goal of universal education[4]. Internationally, the Millennium Development Goals (MDG) have emphasized on Universal Primary Education. It targets that all children should complete a full course of primary schooling by 2015[5]. The enactment of Right to Education Act, 2009 is a timely policy initiative which aims to facilitate achievement of goal of universal primary education in India and thereby also adhere to the MDG[6].

India has made significant progress in universalizing primary education, and is moderately on track to achieve this Millennium Development Goal[7]. The new sets of United Nation Sustainable Development goals (UN SDGs) 2015-2030 to which India has committed universalization of education up to secondary level needs extension of RTE to secondary level.[8]

Several national legal systems across the world have attempted to give effect to the rights of primary education through constitutional arrangements as well as through legislative enactments[9]. The period for providing free primary education varies from 9 years to a maximum of 14 years. The age cohorts of children who can avail of this free education usually are 6-14 or 7-16 and on very odd occasions extend up to 18 years[10]. In India, 'compulsory education' casts an obligation on the appropriate Government and local authorities to provide and ensure admission, attendance and completion of elementary education by all children in the 6-14 age group. With this, India has moved forward to a rights-based framework that casts a legal obligation on the Central and State Governments to implement this fundamental child right as enshrined in the Article 21A of the Constitution, in accordance with the provisions of the RTE Act 2009[11]. Though the Act was passed by Parliament in 2010, it was implemented in different states and Union Territories in different years. The year of implementation of RTE Act 2009 in different States and Union Territories is mentioned in Table 1.

Year of Implementation of RTE Act 2009	Name of the States	Name of the Union Territories
2010	Arunachal Pradesh, Sikkim, Manipur, Odisha and Chhattisgarh	Andaman & Nicobar Islands, Dadra & Nagar Haveli, Daman &Diu, Lakshadweep and Chandigarh
2011	Andhra Pradesh, Assam, Bihar, Haryana, Himachal Pradesh, Jharkhand, Kerala, Madhya Pradesh, Maharashtra, Meghalaya, Mizoram, Nagaland, Punjab, Rajasthan, Uttarakhand, Uttar Pradesh, Tripura and Tamil Nadu	Delhi, Pondicherry
2012	Goa, Gujarat, Karnataka and West Bengal	
2019	Jammu & Kashmir	

Table 1: The year of implementation of RTE Act in States / Union Territories (UTs) of India

The data in Table 1 indicates that though the RTE Act 2009 is enacted in 29 States and six Union Territories in India, the year of implementation differs across the nation. In most states, the Act has been implemented in 2011 whereas in Jammu & Kashmir, the Act is implemented almost after a decade in 2019 of its enactment.

After a little more than a decade of implementation of RTE Act, it is important to have a comprehensive understanding of various aspects of implementation of RTE Act. The present review is conducted to understand what aspects of RTE Act and its implementation have been studied. Though many organizations and independent researchers may have conducted research on RTE Act, the present review considers only doctoral studies conducted under auspice of a University. A university is a multidisciplinary academic institution which might have led to researchers from different domains of discipline to conduct research on RTE Act. Such multidisciplinary understanding would strengthen and broaden understanding about RTE Act and its implementation. The objectives and methodology of the present review have been presented here below.

Objectives

The objectives of this review are:

1. To map the doctoral studies conducted on RTE Act 2009 in various universities of India
2. To analyze the understanding gained from the doctoral studies conducted on RTE Act 2009 at universities of India

Methodology

This review of literature has considered Ph.D. thesis on RTE Act 2009 available on Shodhganga. Shodhganga is a digital repository of theses and dissertations submitted to universities of India. It provides a platform for research scholars to deposit their Ph.D. theses and provide open access to it for the entire scholarly community. It is mandatory to submit doctoral study report on Shodhganga. Hence, all the doctoral studies conducted in universities of India could be accessed on this platform. A total of 49 thesis related to RTE Act 2009 were accessed on the Shodhganga. Out of 49 theses, one thesis is published in Urdu language, one in Hindi language and one in Gujarati language. These three theses were not included. The rest of 46 theses were published in English. The authors of the paper have good proficiency in English language hence only 46 theses published in English language were considered for the present review. However, to understand the spread of the thesis across departments and year of submission, all 49 theses were considered.

Data Analysis

In order to map the studies on RTE Act 2009, the analysis was undertaken in four phases. The first three phases dealt with mapping the doctoral studies. Phase one was about state wise analysis of 49 studies on RTE Act 2009. Phase two was about segregating studies as per the discipline based Departments of University in which it was conducted. Phase three dealt with trying to understand the period in which the studies were conducted. Hence, the studies were listed as per year wise submission of 49 studies on the Shodhganga. Phase four was about understanding the aspects of RTE Act 2009 focused in each study. In order to arrive at the understanding gained from the studies, the objectives of the studies and the findings of the studies were considered. Based on this the following seven aspects have been arrived at: awareness about the Act, perception of stakeholders about the Act, assessment of the Act, socio-legal aspects of the Act, infrastructure facilities under the Act, quality intervention of the Act and social inclusion through the Act. The specific understanding arrived under each aspect is presented. It is also observed that studies were not exclusively for a particular aspect but addressed more than one aspect. Thus, the same study is also referred under different groups mentioned here. A detailed description under each phase is presented next.

Mapping of doctoral Studies on RTE Act 2009

State wise analysis of doctoral studies conducted on RTE Act 2009

All the states are responsible to enforce the RTE Act 2009. The dates of implementation of RTE Act in each state varies as indicated in Table 1. The implementation of RTE Act can be strengthened if it is supported with feedback from researches. To proceed further with the analysis from the number of doctoral studies, the below Table 2 indicates number of doctoral researches in different States.

Sr. Number	States in which research study on RTE Act had been conducted	Number of doctoral studies
1	Gujarat	08
2	Punjab	08
3	Rajasthan	06
4	Uttar Pradesh	04
5	Andhra Pradesh	03
6	New Delhi	03
7	Odisha	03
8	Tamil Nadu	03
9	Haryana	02
10	Mizoram	02
11	West Bengal	02
12	Assam	01
13	Bihar	01
14	Madhya Pradesh	01
15	Maharashtra	01
16	Jharkhand	01
Total number of studies		49

Table 2: States in which research study on RTE Act had been conducted and number of doctoral studies in each state

The data in Table 2 indicates that across India, 49 studies have been conducted in 16 states out of 29 states. More studies were conducted in Gujarat, Punjab and Rajasthan. The other studies were spread across 13 other states of India. None of the studies were conducted in five Union Territories except New Delhi where three doctoral studies had been conducted.

Year wise submission of doctoral studies on the Shodhganga

The Act has been implemented more than a decade ago. It is important to know in which year the doctoral studies on RTE Act have been done. The Table 3 presented below focussed on the year wise submission of doctoral studies on the Shodhganga.

Year of Submission of doctoral studies	Number of thesis submitted on RTE Act 2009
2014	6
2015	1
2016	1

2017	2
2018	9
2019	3
2020	10
2021	13
2022	4
Total	49

Table 3: Year wise submission of doctoral studies on the Shodhganga

It can be seen from the data presented in the above Table 3 that more studies were submitted in the year 2021 and least number of thesis were submitted in the year 2015, 2016 and 2017.

Disciplinary domains of the Departments and the specific aspects covered by the departments

Disciplinary domains of the Departments and the specific aspects covered by the departments are presented in Table 4. These aspects are derived from the findings of the theses reviewed. These aspects are: awareness about the Act, perception of stakeholders about the Act, assessment of the Act, socio-legal aspects of the Act, infrastructure facilities under the Act, quality intervention of the Act and social inclusion through the Act.

Sr. No.	1	2	3	4	5	6	7	8	9	
Department of	Education	Law/ Legal studies	Sociology	School of Social Science	Political science	Human Rights	Humanities and Social Science	Public Administration	Politics & Public Administration	
Awareness about the Act	9	3		1	1	1	1	1	1	
Perception of stakeholders about the Act	5	1								Total
Assessment of the Act	2	9	1							
Socio-legal aspect	3									
Infrastructure facilities	2									
Quality intervention	2									
Social inclusion			1	1	1					
Total	23	13	2	2	2	1	1	1	1	46

Table 4: Domain discipline of Departments and the specific aspect covered in the doctoral studies

The data in Table 4 indicates that out of total 49 doctoral studies, 23 and 13 studies were conducted by Department of Education and Department of Law respectively. Out of 23 studies conducted by Department of Education, nine studies focussed on awareness about the Act, five studies focussed on perception of stakeholders about the Act, two studies on assessment of the Act, three studies on socio legal aspect, two studies on infrastructure facilities and two studies on quality intervention. In Department of Law/ Legal Studies, out of total 13 studies, most of the studies, that is, nine studies focussed on assessment of the Act, three studies focussed on the awareness about the Act and one study focussed on the perception of stakeholders about the Act. School of social science and political science studied awareness along with social inclusion. In addition to this, one study from each department: human rights, humanities & social science, public administration and politics & public administration has focused only on awareness about the Act. There is only one study from Department of Sociology focused on assessment of the Act and social inclusion respectively. There are few studies which focused on multiple aspects to have multi-dimensional view of the Act. On the basis of the focus of studies presented above, it can be inferred that this Act is unique and new, awareness seems to have captured the attention of the researchers across all the streams to study the extent of awareness people have about this Act. Assessment of the Act has been studied more by the researchers of law and legal studies as this Act is in Indian history the very first law made for education. This might have captured the attention of researchers of law. Across all the departments of universities found during this review, researchers seem to be interested in input level of the Act that is awareness about the Act. Assessment of the Act studies were in focus mostly by the Department of Law/Legal Studies as RTE Act, 2009 being a recent new law for education might have interested the researcher to explore more on this Act.

The mapping of the researches thus can be described on the basis of preceding analysis. It is observed that though the Act was implemented in states in 2011, studies were undertaken only in 16 states. This restricts the understanding required about implementation of RTE Act to 13 states. On the basis of the preceding analysis, the researches on the RTE can be mapped as - most of the studies have been conducted in Gujarat and Punjab followed by Rajasthan and Uttar Pradesh. Least number of studies have been conducted in Assam, Bihar, Madhya Pradesh, Maharashtra and Jharkhand. Most of these studies were submitted in the year 2021 and least number of thesis were submitted in the year 2015. Though the RTE Act primarily addresses the domain of education, the influence of other disciplines on it cannot be ignored. The spread of studies in various disciplines facilitates a comprehensive understanding of the issue.

The next part of the review is based on the aspects about RTE Act that have been covered in the identified researches. These aspects are awareness about the Act, perception of stakeholders about the Act, assessment of the Act, socio-legal aspects of the Act, infrastructure facilities under the Act, quality intervention of the Act and social inclusion through the Act. Detailed analysis of each aspect coved in the researches is presented below.

Awareness about the RTE Act 2009

Awareness about the RTE Act is one of the most studied aspect of implementation of RTE Act 2009 going by the fact that 18 out of 46 studies are focusing on it[12-30]. Most of these studies adopted normative survey method. These studies revealed that awareness of RTE Act 2009 is satisfactory among the teachers but most of the Economically Weaker Sections (EWS) families were not aware about the availability of the EWS Quota under RTE Act 2009. Study by Sharma (2015) revealed that not only the society in general, but principals and teachers also, who have a very significant role to play for the effective implementation of RTE Act, had lack of awareness about the same. One group of studies: Ranchhod (2018), Vinayak (2017), Mondal (2015) & Nagaraj (2017) focused on measures adopted to create awareness among the stakeholders about the various provision of the Act through the national awareness campaign to drive home the shades of this law, whose provisions vibrate with the aspirations of the poorest. Mondal (2015) & Nagaraj (2017) recommended that for the successful implementation of the Act, all the stakeholders are required to know their responsibilities and the provisions of the Act. And further suggested that the awareness programmes on RTE Act/rules should be taken up for Teachers/Parents/ Guardians for sending their children/wards to schools. Community based NGOs may be involved to take up such programmes. Workshops should be held regularly with various officials and officials at district and block level as well as government and private school officials on rules awareness, implementation and monitoring of the RTE Act. As substantiated in the study by Ghumaan (2016) that the very first challenge to implement any policy or law in our country is awareness[56].

The group of studies on awareness have indicated that despite a general level of awareness, specific awareness about EWS quota was lacking. This is a significant point as RTE Act is aimed at largely this group of people in society. The foundation of an effective implementation is awareness. Many studies have made recommendation for creating awareness about the Act among stakeholders through awareness programmes on RTE Act. Perception of stakeholders about the RTE Act is other important aspect for the effective implementation of the Act. Therefore, the studies conducted on RTE Act 2009 are presented herein below.

Perception of the stakeholders about the RTE Act 2009

Studies about perceptions of stakeholders namely heads, school management committees, teachers, parents and students etc., in implementing the procedure of RTE Act, 2009 are very few. It is substantiated by the fact that only six out of total 46 studies were conducted on it [28, 31-35 & 53]. Most of the studies adopted descriptive survey method. These studies explicitly highlighted the opinions of stakeholders on various dimensions in terms of community related issues, curricular issues, evaluation processes, infrastructural facilities, school related issues, School Management Committee (SMC) related issues, student learning aspects, student related issues and teacher related issues towards Status and Implementation of Right to Education Act 2009 at Elementary Level. A step ahead, Kaur (2021) and Zorinsangi (2018) explored that teachers thought that the provision of the Right to Education Act was difficult to fully implement it because education could not be provided completely free of

charge as parents had to contribute/spend money on stationery mainly due to the introduction of Continuous Comprehensive Assessment (CCA) and the amount allocated for textbooks and workbooks exercises for each child was less than the actual price of the books. The study further concluded that stakeholders face many issues and challenges.

The group of studies on the perceptions of the stakeholders clearly revealed stakeholders' dissatisfaction with some of the provisions of RTE 2009. Very few studies highlighted issues and challenges stakeholder face. Few studies suggested that the government at both Center as well as the State should value the perception of the stakeholders for having highlighted the positive improvement in the field of education to improve the quality of education.

Assessment of implementation of RTE Act 2009

Assessment of the implementation of RTE Act 2009 is another dimension covered under the implementation of the Act and are studied by 12 out of 48 studies. Studies conducted by Singh (2021), Gurbaksh (2021),Pagaria (2021),Kumar (2018), Arora (2018), Kumar (2018), Ranchhod (2018), Anbarasi (2018), Banerjee (2018), Mehta. (2018), Khan & Khan (2017), Verma (2017), Udayakumar (2017), Sharma (2016) and Pandey (2014) focused on the assessment and evaluation of RTE Act 2009. Most of the studies adopted descriptive study. Most of these studies revealed that the RTE Act was framed to eradicate all the problems related to elementary education system of India [21,28,36-45]. These studies further added that the provisions of RTE Act cover all the actions necessary for improving the quality standards of the elementary education in India. Mehta (2018) aims to look at the development of school education, literacy and alternative schooling After completion of primary level education 25 percent of the student were not able to read standard I text or standard II text [54]. But, still it is quite depressing to find out that even after six years of the implementation of RTE Act, people lack awareness about it. Thus, it can be said that if the Government and society made their earnest efforts towards the implementation of RTE Act, only then we can achieve the goal of Universalisation of the elementary education.

Most of the studies focused on the assessment and evaluation of RTE Act. These studies indicated general level of problems related to elementary education system of India and specific efforts of government and society towards the implementation of RTE Act. Socio-legal aspect is another aspect studied by and presented below.

Socio-legal aspect of RTE Act 2009

Socio-legal aspect of the RTE Act 2009 is aspect covered by very few studies. Substantiated by the fact that only three out of 46 studies are focusing on socio-legal aspect. These studies explored the constitutional guarantee of Right to Education and role of Ministry of Human Resource Development in India and Centre-State relationship for Allotments of Fund aspec[31, 52]. Tiwari (2019) focussed on the adjudication and enforcement of socio-economic rights under the Indian Constitution[46]. The Constitution of India as well as international human rights law conferred a host of special rights to minorities. The study explored the major issues such as minority status and its proof, the right to establish and

administer educational institutions, the problem of recognition and affiliation, state aid, the medium of instruction, admission, governing bodies and the extent of the state's regulatory power have been comprehensively covered. Udayakumar (2017) revealed that simply using the law as a legal instrument to take action against institutions and/or individuals who are perceived to be responsible for not enforcing the provisions of the law will not really solve the problems of illiteracy and lack of educational opportunities[44]. At best, a coercive approach could bring out-of-school children into the school system.

The analysis of the studies leads that very few studies focussed on the judicial intervention in the realm of socio-economic rights which has paved the way for the eventual enactment of the legislations for the realisation of different rights. However, it cannot really address the central problem of the lack of meaningful learning in current forms of schooling across the country.

Infrastructure facilities under RTE Act 2009

Very few studies focused on the availability of infrastructure facilities. Studies by Sahoo (2016) and Kumar (2018) examined its availability and usage[47, 27]. The Act suggests barrier free entries for all the schools whereas presently, only about 40% of the schools have ramps. The studies further revealed that schools in tribal areas had poor infrastructure, non-availability of appropriate furniture for children with disabilities, non-availability of special aids and appliances, poor quality of aids and appliances for children with locomotors disabilities are major challenges in fulfilment of RTE to these children. The essential amenities like access to drinking water are also missing in numerous schools. The Act stipulates a playground for every school. The studies further highlighted the major challenge will be to establish a balance between Centre and State. Several regulatory measures can only be taken after individual inputs from state governments. There are no clear demarcations between the responsibilities of the centre and state and it would be a challenge to work out the details. All elementary schools must have minimum infrastructure facilities, teachers, teaching learning materials, playground etc. for better teaching learning. These studies reveals that majority of schools do not have minimum facilities which is one of the major cause of poor quality education in elementary school and therefore, the administration must take appropriate step to provide minimum facilities in all elementary schools so that better educational experience can be provided to learners.

The above studies have shown that infrastructure availability is important for the quality dimension of education under RTE Act. Its availability and appropriate usage can be achieved by appropriate involvement of all the stakeholders. Another important aspect highlighted is the quality intervention of the RTE Act.

Quality intervention of RTE Act 2009

Another dimension covered under the implementation of the RTE Act 2009 is the quality intervention of the Act. Very few researches, that is, two out of 46 focused on it. One of the researcher, Ila (2018) monitored the progress of "Quality Interventions of RTE Act – 2009" and studied the factors affecting the effective implementation of RTE Act-2009 at upper

primary level in Delhi[48]. The study concluded that the RTE act-2009 was implemented with an excellent intention of providing free and compulsory education to the children of 6-14 years of age and the Government is still putting efforts to make it successful and it can be seen and observed easily in the field but the results show that it still needs a bit more attention and hard work to accomplish its objectives. The schools are found to be in a much better condition than before its implementation. The teachers are found to be more dedicated despite of the fact that they are being overloaded by the work given to them. The teaching learning process has been improved comparatively but one thing which it is actually lacking is the attention given to students with special needs. On the other side Majhi (2022) focussed on the quality with reference to teachers and School Management committee (SMC) in schools[49]. The findings of the study indicated that onsite academic support as and when required by them; training needs of the teachers are identified before organizing training programs for them; teachers transact their curriculum by following activity-based approach with getting the availability of variety of teaching-learning materials used in the classrooms. And for SMC's capacity building programs are organized for the SMC members with facilitating them to visit the schools for monitoring purpose; parent teacher meetings are organized by the schools to discuss the academic issues. It further added that the schools can organize campaigns with the help of School Management Committee showing various benefits of the policy. Provisions for Students with Special Needs (SWSN) are not getting enough attention by the schools. It is also observed by the researcher that "there were no Braille books, no assistive devices, no educational materials and no fulltime special teachers in so many schools, which is making it extremely difficult to ensure that Right to Education (RTE ACT-2009) is helpful to children with various types of impairments to adjust and study in the classrooms.

It is concluded by the above mentioned study that the Right to Education Act has already been implemented, but what it needs is a continued action at all levels of society. The above mentioned studies focused on the status of implementation of Quality Interventions of RTE Act-2009 and also the factors affecting the implementation of the RTE Act-2009. There is a need to explore the status of implementation of the Act with the help of the Quality interventions undertaken in the study and also would suggest improvements to address them. The researcher would discuss the supporting mechanisms, administrative imperatives and implementation challenges that need to be addressed.

Studies focussing on social inclusion through RTE Act 2009 and its impact on these students

There are only three doctoral studies conducted on social inclusion through RTE Act 2009 and its impact on the lives of children living on the street, children belonging to weaker and disadvantaged section and girl child. These studies were descriptive survey. Gulgani (2020) aimed to bring issues one of street children, a hidden invisible vulnerable population[50]. It had been found that the medium of instruction in the school is English, these children face problem in understanding the content taught. As there is no one to help them with their work at home and the parents are also clueless about the curriculum, these children are not motivated

to study. It was also pointed out that these children are not able to cope up with the home assignments given which restricts their understanding and participation in the class. Another study conducted by Devi (2014) focussed that students of many classes are studying in the same over-crowded classroom[51]. There can be many reasons and consequences for this. One reason is that there is a huge shortage of teachers along with the classroom, and the result is that children do not get qualitative education properly. Due to the large number of children and the number of children belonging to many classes in the same class room, it was found to be run outside the classroom, which adversely affects the way of teaching and learning. Lack of sports arrangements and lack of sports equipment were seen in almost all schools. There is very less emphasis on learning outputs. Some teachers believe that parents get their children admitted to school, but most of the children never come to school, even they do not give the exam, they have to pass without examination. This makes the literacy rate increase quantitatively but not qualitatively. If there is a qualitative increase in the resources and education of schools, then the number and attendance of children can also be increased. The study by Banerjee (2018) focussed on the implementation of the RTE Act with special reference to girl child. It states that the RTE Act 2009 categorically aims at the 'Compulsory' education of children aged 6 to 14 years[41]. Yet, the issue of children dropping out or remaining absent from schools for the reasons of accompanying their parents who migrate for work is nothing new in India. This process of migration has severe implications for the aim of universalization of elementary education. Girls fall the victim of migration and are compelled to discontinue education either to work along with their parents or to look after younger siblings while their parents are migrating. The empirical research revealed that migrating children are not treated as 'Drop-out' children.

Research Gaps

An analysis of the findings of the studies reviewed above have indicated research gaps. As per the studies reviewed, studies on RTE Act are conducted only in 16 states out of 29 states in which it is implemented. The studies reviewed are from the states of Gujarat, Punjab, Rajasthan, Uttar Pradesh, Andhra Pradesh, New Delhi, Odisha, Tamil Nadu, Haryana, Mizoram, West Bengal, Assam, Bihar, Madhya Pradesh, Maharashtra and Jharkhand. The field reality in 13 states is not studied. As the studies are from only 16 states, the understanding gained about the implementation of the Act is partial. If studies from all the states indicate similar findings, then it will provide an input for the policy makers. The population of the study can be taken from 29 states. Comparative studies among different states of India in which RTE Act has been effective and the states in which it is not effective can be conducted to study the challenges and effective implementation of RTE Act. Continuing this further, studies on best practices adopted for effective implementation of RTE Act can be undertaken as now it is almost a decade after its implementation.

An important factor in effective implementation of the RTE Act is the role played by the stakeholders involved. There are six studies on role of stakeholders which in some ways also

studies the challenges faced by them. More studies on role of stakeholders: heads, school management committees, teachers, parents and students and their perception of RTE Act in various states of India will inform a stronger understanding.

The findings of the studies reviewed on awareness among stakeholders about RTE Act 2009 has indicated that parents have low awareness and teachers have satisfactory awareness. In this connection, researches on different aspects of awareness such as measures and initiatives taken by government and organizations for creating awareness of RTE Act can be taken. At the same time, how have those the parents who have admitted their children under RTE Act become aware about it can be studied. This will add to the best practices for creating awareness and implementation of RTE Act.

One important aspect of implementation of RTE Act is that students learn and benefit by schooling. The academic achievement of RTE students, the challenges in learning and coping mechanism adopted have not been studied in the studies reviewed.

There is only one study on Section 12 (1) (c) of RTE Act under which private schools are mandated to have 25% reservation for students under EWS Quota. This study is also mainly about awareness and infrastructure support. The condition of students in classrooms with wide disparity of socio-economic background and the challenges that it can throw up have not been studied.

Methodologically, almost all the studies have adopted survey as the research design. While survey design has offered a basic understanding of the status of implementation of RTE Act in schools, an in-depth understanding of the RTE students schooling experience is not studied. Longitudinal studies on RTE studies can be conducted to understand how the weaker sections of society have coped with the school and classroom processes. Case study of RTE students who have excelled and benefitted and those who have not been able to take advantage of the Act can be conducted.

Conclusion

The above analysis of the studies leads that very few studies were conducted on the weaker section; the findings indicate that this is an important area which will help in effective implementation of the RTE Act. More researches in this area will provide appropriate understanding and input to policy makers and implementers. Most of the studies on RTE Act, 2009 are concerned with implementation status, awareness about the RTE Act and impact of RTE Act. A point for deliberation here is, has the RTE Act been implemented effectively? What are the factors which facilitate the implementation of this Act? What are challenges and problems faced by stakeholders (parents, school management committees, teachers, principals/Headmasters, local bodies etc.).

As far as studies on Right of Children to Free and Compulsory Education Act 2009 are concerned, there have been numerous studies that have discussed the extent to which the Act

has reached the masses. In India, RTE Act 2009 is implemented in all the states and union territories. The researches based on RTE ACT 2009 have indicated an inclination towards implementation and assessment. The attention to processes and the output are the areas which need attention as a decade has passed by after the enactment of the Act. Based on the present review further studies can be planned.

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A Survey on Deep Learning Methodologies for Neurological Disorders- Alzheimer's, Autism, Epilepsy

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Abstract

Deep learning has frequently been utilized for detection of neurological disorders Generally two types of data i.e. Neurophysiological signals such as Electroencephalogram (EEG), Electrocorticography (ECoG) and Neuroimages, such as Positron Emission Tomography (PET) structural Magnetic Resonance Imaging (MRI) and functional MRI are taken into consideration for diagnosis of neurological diseases. Deep learning has achieved substantial performance developments over handcrafted feature extraction followed by machine learning techniques in computer-aided diagnosis (CAD) of neurological ailment. This study presents a broad assessment of the deep learning methodologies for neurophysiological and neuroimaging-based neurological disorders i.e., epilepsy, Alzheimer's, and autism.

Keywords: Alzheimer's disease, autism disorder, deep learning, EEG, epilepsy, MRI

Introduction

Medical data (signals and images) encompasses a variety of technologies that offer visual illustrations of the internal part of the human body to help clinicians discover, diagnose, and treat diseases more quickly and effectively[1]. Medical imaging, which includes computed tomography(CT), mammography, RI, PET, X-ray, and ultrasound has fast become a

dominating and effective technology over the last few decades[2]. Neurophysiological signals which include EEG is widely used for the detection of epilepsy. For diagnosis and research, the data gathered by these technologies provides numerous information about the various human organs. Human professionals, such as radiologists and doctors, must undertake detailed interpretations of medical data in taking decisions. However, due to the large amount of medical data, elucidation is time-consuming and simply affected by human specialist's prejudices and exhaustion. As a result, clinicians have been using CAD systems to understand neural signals and brain images to increase their effectiveness.

Handcrafted feature extraction followed by classical machine learning techniques is capable of extracting informative features that explain the immanent patterns from data in CAD systems, and it renders an important part in medical data analysis. The structures of medical data, on the other hand, are extremely complicated, and feature selection is still done by humans using their domain knowledge. This makes machine learning approaches in medical image and signal analysis and difficult for non-experts to use.

As a result, handmade feature selection isn't appropriate for medical signals and images. Although the efficacy of sparse learning and dictionary learning for impetuously identifying inequitable features from training samples has been shown, these algorithms' shallow designs limit their representational power.

Deep learning, in contrast to typical handcrafted feature extraction techniques, automatically extracts useful information without the need for domain experts' knowledge, allowing non-experts to effectively apply deep learning approaches. As a result, deep learning has quickly become the preferred procedure for medical data analysis in recent times. Deep learning has perceived unparalleled accomplishment in numerous artificial intelligence applications, such as speech recognition, autonomous vehicles, and computer vision, thanks to increased computation facilities and, the availability of enormous data. The use of deep learning in medical data analysis was driven by the simultaneous progress and successes of computer vision.

Deep learning is currently driving significant progress in medical image analysis. Classification, detection/localization, registration, and segmentation are the four major categories of medical image analysis tasks[3]. The initial job in which deep learning makes a significant involvement to medical image processing is categorization. The goal of this job is to divide medical images into two or more categories. To identify Alzheimer's disease or

moderate cognitive impairment, the stacked auto-encoder model was utilized by merging medical imaging and biological[4]. The detection/localization challenge entails locating and identifying features or lesions in a whole medical image. Deep convolutional neural networks, for example, were utilized to locate lymph nodes in CT scans. The objective of segmentation is to divide a medical image into distinct segments, such as tissue classes, organs, diseases, etc. The U-net, is the widely utilized deep learning architecture for segmentation is composed of convolutional network. Medical image registration technique corrects the alignment of images. In an unsupervised approach[5]used convolutional layers to extract characteristics from input patches. The acquired feature vectors were then employed in the HAMMER registration process to substitute the handcrafted features. Other important tasks in medical image analysis include content-based picture retrieval and image synthesis and augmentation in conjunction with image data and reports.

Alzheimer's Disease Analysis using Deep Learning Techniques

Alzheimer's disease (AD) is the supreme prevalent basis of dementia and is a neurological, irreversible, growing brain illness. Although the causes of Alzheimer's disease are unknown at this time, correct diagnosis of the disease is critical in-patient management, particularly in the early stages. The Alzheimer's Disease Neuroimaging Initiative (ADNI), a research study is targeted to progress clinical studies for the precaution and therapeutics of AD, has the prominent public neuroimaging dataset for AD diagnosis. The ADNI study began in 2004 and is currently in its third phase. The ADNI dataset currently covers over 1,000 patients and includes ADNI-1, ADNI-GO, ADNI-2, and ADNI-3.These individuals were in three phases of disease which are normal control (NC), mild cognitive impairment (MCI), and Alzheimer's disease (AD).

A slew of articles on deep learning algorithms for Alzheimer's diagnosis have just been released. These methods can be loosely separated into two types based on various architectures: DGM-based and Convolutional Neural Network based methods. The Deep Belief Networks (DBN), Stacked Auto-Encoders (SAE), and Auto-Encoders (AE) variants were included in the DGM-based approaches. Authors in[6]built a sturdy deep learning structure by stacking multiple restricted Boltzmann machines (RBMs) and using the reliability selection and multi-task learning technique. In[7], authors suggested a number of deep learning approaches, including the Deep Boltzmann Machine (DBM) and SAE[4–8].To merge longitudinal and cross-sectional characteristics calculated from MR brain images, Authors used multi-modality stacked

denoising sparse AE (SDAE)[9].Multiscale patch-wise metabolic attributes as input on multiscale deep learning network is also used[10]. Authors employed a deep convolution AE (DCAE) model to extract features that have strong relationships with clinical variables including cognitive exams, age, and tau protein deposits[11]. Authors in [12]efficiently fuse and learn feature representation using a multimode-stacked deep polynomial network (DPN) from a short multimodal neuroimaging dataset due to tiny labelled samples in neuroimaging dataset. Authors in [13]used a sparse AE on random patches of natural images to pre-train a 2D-CNN based on sMRI data. The use of cross-domain characteristics to show MRI data was an important strategy. On ImageNet, Liu and Shen utilized an analogous method and trained a pre-trained deep CNN[14]. The fMRI data was originally used in deep learning applications by authors in [15].In the preprocessing step, the 4D resting state-fMRI and 3D MRI data were fragmented into 2D format images, which were then fed into the CNN-based architecture's input layer.

Billones et al. adapted VGGNet structure and proposed a DemNet model where the coronal image slices were chosen for classification task[16]. By reducing 3D PET scans into 2D slices, introduced a unique classification methodology which learns characteristics from a succession of 2D slices[17]. The intra-slice features were captured using hierarchical 2D-CNN, while the inter-slice features were extracted using GRU.

The 3D brain images must be split into 2D slices in the preprocessing step, resulting in 2D-CNN approaches removing the spatial information. As a result, many 3D-CNN algorithms have been presented, all of which can straightforwardly input 3D brain images. A sparse AE to train a 3D-CNN on tiny 3D patches from sMRI data was proposed [18]. To encapsulate anatomical structure fluctuations in sMRI data, Authors suggested a deep 3D-CNN based on a 3D CAE (Convolutional AE)[19].Extracted features from PET and MRI images-using several deep 3D-CNN on various local image patches[20]. The learnt local features were then ensembled and latent multi-modal features for AD classification were identified using a set of higher high-level CNN. To increase performance, authors in [21]presented a 39-layer 3D-CNN architecture which works on a residual learning network (ResNet).

The scientists initially identified parametric anatomical landmarks from MR images using a data-driven approach, and then developed a 3D-CNN to learn patch-based features. This technique avoids the high-dimensional voxel-level difficulty and manual ROI-level definition. Following that, A deep multi-instance CNN methodology is presented, in which several image

patches were employed as a bag of illustrations to characterize individual subject, with the whole-image-level class label determining the label of each bag[22]. In[23], authors predicted missing PET images from sMRI using a 3D-CNN and authors has achieved classification accuracy similar to the genuine PET images. In[24] authors proposed Cycle-GAN to study sMRI and PET mapping in order to create missing PET scans created on their associated sMRI scans. Authors in [25]presented a CNN architecture based on T1-weighted MRI.

MCI had a transformation frequency of 10–15 percent per year in 5 years as an early stage of AD, but it was also the ideal time for treatment. As a result, developing an accurate prediction model for early MCI diagnosis has become an important subject. MCI prediction has recently been the subject of some Graph Convolutional Networks (GCN) based studies. In [26]and [27], combines neuroimaging data with the demographic relationship on GCN for MCI prediction. In[28], authors used a multi-class GCN classifier to divide people on the Alzheimer's spectrum into four groups. PETNET, a model based on the GCN, was proposed by authors in [29]to analyze PET signals.

Autism Spectrum Disorder (ASD) Analysis using Deep Learning Techniques

ASD is a prevalent neurodevelopmental disease that impacts approximately 62.2 million people worldwide. The Autism Imaging Data Exchange (ABIDE) project gathered fMRI brain scans from laboratories all over the world. Two large-scale collections were released as part of the ABIDE initiative: ABIDE I and ABIDE II. The ABIDE I study encompassed 17 international sites and included 1,112 people, 539 of whom were autistic sufferers and 573 of whom were not. The ABIDE II compilation, which included 19 worldwide sites and 1,114 subjects from 521 people with ASD and 593 people without ASD, aimed to increase the number of specimens with enhanced depicted genotypes.

Many approaches using deep learning techniques for Autism detection have been proposed. To minimize data dimension and discover highly inequitable representations, AE-based approaches exploited several AE variations or layered numerous AE. The basic SAE was developed by Hazlett et al., who primarily extracted surface area information from brain MRI to diagnose autism in children in [30]. In [31]employed a stacked multiple sparse AE (SSAE) to develop whole-brain functional connectivity patterns, whereas in [32]only used the top 3,000 F-score ordered connectivity features from SSAE in descending order.

In[33], authors employed 34 sparse AE for 34 spatial activation zones to create an automated autism diagnosis method. Each sparse AE lowered the dimensionality of feature vectors. In

[34]employed VAE to extract two-dimensional features from functional connection networks. One feature was discovered through a high level of discriminating between ASD and NC, and it was found to be narrowly linked to ASD-related brain regions. In[35] authors employed DAE to increase generalization and lessen the effect of multi-site heterogeneous data. In[36], authors used transfer learning to build a deep neural network architecture for ASD classification due to a lack of training samples. First, an SSAE was used to train this framework to discover functional connectivity patterns. After then, it was moved to a new categorization with fewer target subjects.

In[37], authors devised a technique which augment the data to generate artificial datasets for the ASD-DiagNet model's training. To enhance the condition of retrieved attributes, this model included a single-layer perceptron and an AE. The aforementioned techniques ignored the spatial shape of the brain networks since the resting state-fMRI data were flattened into a feature vector. Authors in [38]presented a CNN architecture on ABIDE dataset to classify ASD patients and control subjects. In [39]used pretrained models VGG-19 and NASNETMobile to detect ASD on facial dataset publicly available on kaggle.

Epileptic Seizure Detection using Deep Learning Techniques

Around 65 million people are suffering from epileptic seizures worldwide out of which mostly are developing countries. To detect seizures EEG reports are used by neurologists which is captured by 10-20 system. Various publicly datasets are available for researchers to implement their CAD system. One of the most widely used EEG dataset is developed by University of Bonn, Germany. Temple University and CHB-MIT EEG datasets are also publicly available used by various researchers. First CAD system to detect seizures using deep learning model was done byauthors[40]. They proposed a 13-layer 1D-CNN architecture. Authors proposed a pyramidal 1D-CNN model which has less training parameters and gives good accuracy[41]. In[42], authors proposed a 1D-CNN model to extract features followed by machine learning classifiers. In [43]proposed a CNN model which classifies the seizures only in 20 epochs. Authors in [44]presented a 2D- deep convolution autoencoder followed by Bi-LSTM model to detect seizures in children.

Future Directions

It can be observed from this review, research on neurological disorders applying deep learning has been examined across three diseases. Furthermore, in PubMed, the number of papers on

neurological disorders is increasing at an almost exponential rate. Unfortunately, no uniform deep learning architecture exists that could be used for all disease studies. There is no single model which is optimal for all problems. As a result, to detect a specific disease, several deep learning approaches are constructed employing various modalities.

Despite the fact that deep learning models have an unprecedented success in analyzing neurological diseases, there are still certain issues that need to be addressed. The following is a list of probable challenges and possible solutions-

(1) Deep learning methodologies are very dependent on hyper-parameter setting i.e., batch sizes, learning rate, activation function, number of hidden layers etc., which can substantially affect performance. Hyper-parameter optimization approaches such grid search and Bayesian Optimization etc., are proposed to achieve the best configuration. The process for creating the architecture of deep neural networks, is still in the hands of experienced specialists.

(2) Deep neural networks use complex structures to extract features from training data before making predictions for diverse tasks. These technologies have potential to outperform human specialists and give accurate results. However, trusting predictions is tough as we don't have sufficient knowledge of extracted features. As a result, the deep learning algorithms' black-box nature has limited their therapeutic application. Some studies are beginning to explore the explain ability of deep learning architectures in neurological disorders, with the goal of demonstrating the features that have the biggest impact on the predictions.

(3) Deep learning approaches necessitate a high number of samples to train their models, despite the fact that obtaining training samples in various real-world circumstances, particularly for neurological diseases, is sometimes difficult. In neuroimaging analysis, a lack of appropriate training data has been often noted as a barrier to applying deep learning architectures. A data augmentation approach has been presented to overcome this problem, and it is extensively utilized to increase the amount of training samples.

(4) The data having lack of information is unavoidable in multimodal neuroimaging research due to patient withdrawals and substandard data quality, therefore participants may be missing some modalities. Traditionally, data-missing individuals are discarded, resulting in a considerable reduction in the number of training samples and a decrease in diagnosis performance. Most of the data-computing approaches impute the missing hand-crafted feature values set by professionals for describing neuroimages.

Conclusion

In this study, we focused on three common illnesses and examined the deep learning algorithms presented by several researchers. Alzheimer's is a neurodegenerative disease while ASD is a psychiatric disorder. Using brain images and signals, deep learning models have achieved trailblazing achievement for the three brain illnesses. Finally, we address various research avenues and outline these potential obstacles. CAD systems for disease identification and treatment will become a companion in upcoming days as the etiology of human brain illnesses becomes clearer, deep learning techniques get more advanced, and open-source datasets grow in size.

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Glossary:

Neuroimages- these are the images of brain.

Positron Emission Tomography-an imaging test that can help reveal the metabolic or biochemical function of your tissues and organs.

Magnetic Resonance Imaging - a medical imaging technique that uses a magnetic field and computer-generated radio waves to create detailed images of the organs and tissues in body.

Autism-refers to abroad range of conditions characterized by challenges with social skills, repetitive behaviors, speech and nonverbal communication.

Convolutional Neural Network- deep Learning algorithm which assign importance (learnable weights and biases) to various objects in the image and be able to differentiate one from the other.

Auto-Encoders-an unsupervised artificial neural network that learns how to efficiently compress and encode data then learns how to reconstruct the data back from the reduced encoded representation to a representation that is as close to the original input as possible.

Deep Boltzmann machine-a model with more hidden layers with directionless connections between the nodes.

Long short-term memory- is an artificial neural network used in the fields of artificial intelligence and deep learning. Unlike standard feedforward neural networks, LSTM has feedback connections.

Grid Forming Inverters to Strengthen Frequency Stability of a Very Low Inertia System: A State of the Art

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Abstract

As renewable power from DC sources is constantly increasing their power generation share compared to the high inertia generators that provide robustness to the grid, the overall stability of the grid decreases. A grid-forming converter could be the solution to this problem. Grid-forming inverters act as voltage source converter (VSC) and it has important characteristics of synchronous generators (SG). These also include the provision of inertia and voltage source behaviour. These properties are required to interconnect synchronous generator and inverter-based sources. However, grid-forming VSC cannot replace an important feature of SG: overcurrent capability. This property of SG contributes to power system stability. In the case of severe disturbances, SG may initially be overloaded before the load is gradually shared with other IBRs. Due to the risk of damage, VSC has overcurrent protection. The main mission of a grid-forming converter is to replicate the behaviour of the synchronous machine via different control strategies. Additionally, they can contribute to grid stability by providing voltage and frequency support. This paper includes a systematic review of recent advancements in grid-forming converters with BESS (GFM BESS), its modelling and different control techniques to enhance the frequency stability of large-scale power system networks. Inertia in the power system is the energy stored in a large rotation part of a conventional synchronous generator which helps during any contingency like load imbalance or generator outage. The inertia of rotating parts under such conditions will help to stabilize the frequency. With an increasing

share of IBRs, the lack of inertia by grid-forming converters is provided with a pulse width modulation controller linked with conventional inverters. This concept of virtual inertia by emulating the behaviour of GFM as a synchronous generator has been discussed with different virtual inertia-based control techniques with their comparative study. Also, challenges and open issues related to the high penetration of GFM BESS and the transition from islanded to a grid-connected mode of grid-forming converters are discussed.

Keywords

Grid forming converters, Battery energy storage system, frequency stability, Power electronics based sources.

Indices

GFC= Grid forming converters

GFL= Grid following inverters

GFM=Grid-forming inverter

PBS= Power electronics-based sources

SG= Synchronous generators

BESS= Battery energy storage system

SO= System operator

IBR= Inverter based resources

BSD= Battery storage device

Parameters

P_{elec} =Electrical power output

P_{mech} = Mechanical power input

$\boldsymbol{\omega_e}$ = Grid frequency

$\boldsymbol{\omega_m}$ = Reference Frequency

J= Inertia constant

De = Damping constant

K_D and K_V = Droop co-efficient

L_g= Grid side inductance

R_g= Grid side resistance

L_c= Converter side inductance

R_c =Converter side resistance

C_f= Filter capacitance

V_g= Grid voltage

V_c = Voltage at point of common coupling

V_t= Converter terminal voltage

Introduction

The traditional electrical grid is required to rethink over a new era of increasing per cent shares of power electronics-based sources (PBS), its new control algorithm, load flow analysis for active and reactive power flow, protection system for any symmetrical and unsymmetrical fault, transient, small signal, frequency and voltage stability analysis is a challenging part. Traditional generators producing electricity for the grid have spinning parts They rotate at the right frequency to balance supply and demand and can spin faster or slower if needed. The kinetic energy 'stored' in these spinning parts is our system inertia. The renewable sources used nowadays for power generation doesn't have similar rotating part and thus grid is referred to as a low inertia grid. These required paradigms to establish stable and dependable operation of electrical power systems with high shares of non-conventional energy sources like solar, wind or any other storage devices. When more inverter-based sources like solar, wind and BESS are integrated with such a grid having no or less inertia, grid synchronization is the most challenging part. It will create large voltage and frequency fluctuations and unstable operation of the grid. This may lead to trip IBRs or load. Also, it may arise reliability issues for the power system. Recently system operators (SO) in Europe, Texas, Denmark and Ireland are experiencing issues with a higher penetration level of IBRs. The issues are more challenging when penetration of IBRs goes above 50-60 % with very few traditional synchronous generators. The challenges that occur are specific to the system, their location and no. of SGs in operation, level of load unbalance, and interconnection between other IBRs. SO of Ireland and Great Britain faces such issues when more than 65% of the load

has to be supplied by IBRs. System operators (SO) in Germany and Denmark are recently facing issues when supplying a major portion of load (nearly 100%) through IBPS. They are getting support from the rest of the synchronous area which helps to avoid total collapse. In contrast, a higher percentage of SGs slow down the overall system dynamic response, while currently used grid following inverters (GFL) have fast controllers to accurately track the angle and frequency. However, these fast-responding IBRs fail to synchronize with the system. Which requires robust controllers with high penetration of IBRs. Recently the SO of South Australia, Ireland and Texas are working by frequently limiting the output of IBRs and running with sufficient SGs. They have installed synchronous condensers to provide necessary reliable operations. Still, it is difficult to maintain a minimum number of SGs. Having operations constraints and extra investments, SOs of these countries face the common major challenges of reduction in mechanical inertia due to rotating part of SG to inverter-based static sources. The drastic decrease in stored kinetic energy (inertia) of rotating parts results in drastic frequency oscillations during load unbalanced. It may also give malfunctioning of IBRs and strikethrough non-reliable power supply.

As a solution to these challenges recently the concept of Grid forming converter with battery energy storage system (GFBESS) technology has been investigated by researchers. It offers recent advancements in control techniques, fault right-through capabilities and stability strengthening of a weak grid. Recently Australia, UK and USA have taken up projects to underline trends in power industries by adding GFBESS to address the issues of frequency stability in weak grids.

This paper includes a systematic survey on micro-grid concept and control strategies, low inertia issues with high penetration of IBRs, operation characteristics of grid backing and grid setting up converters and its control strategies to support the grid, challenges faced by the implementation of the mixed system including grid supporting, grid forming and traditional alternator on a massive scale. Also, it needs an assessment of the future scope in the era of grid-forming inverters.

The micro-grid concept and its control strategies are divided into centralized and decentralized control. Micro-grid control strategies must fulfil the required study for power management, power quality coordination control and stability studies[1,2,3]. For this study hierarchical control architecture has been discussed which is classified as: (i) primary control

provides primary current and voltage control, power contribution, frequency and voltage stability in the islanding approach. (ii) secondary control includes dynamic and responsive power control, grid synchronization and capability of restoring electrical power management (iii) tertiary control provides coordination of no. of micro-grids, fault supervision and optimization of variables like cost, efficiency, etc. With increasing shares of IBRs in the power system, issues with low inertia and its solution have been reviewed by Tamarakar in 2017[4]. The virtual inertia concept has been introduced by the author in 2008 by J. Driesen[5]. The behaviour of IBR has been emulated as a conventional synchronous generator by providing virtual inertia support for improving grid stability and reliability under contingency conditions. Virtual inertia control techniques are required to be developed for the successful operation of IBRs. Which have been investigated by J. Driesen, 2008, and H. Bevrani, 2014 and in 2017 J. Liu[5,6,7]. The virtual synchronous generator currently works as a current source inverter that controls the grid's frequency and voltage under the grid-supporting mode of operation.

Operation of a micro-grid with solar and wind integrated with the power grid through the inverter is considered as grid following mode of operation. This concept has been introduced by L.Liu [8]. This grid-following inverter has a low over-current rating due to power electronics devices. Also, solar and wind farms are located at a far distance with high impedance which creates voltage variation issues at the point of common connection through conventional control of the grid resulting in a fragile grid. Looking at the above issues with increasing shares of PBS the researcher D. Pattabiraman has proposed a concept of grid forming inverter with a battery storage device (GFM BSD) capable of supporting grid operation under grid-associated mode and isolated mode under normal and contingency action without depending on service of synchronous generator and synchronous condenser to completely work on 100% IBR[9]. In the era of 2019-20 authors Matevosyan, Rosso, and P. Unruh have worked on the grid forming converters control approach and its successful grid synchronization[10,11,12,13]. They have also discussed the overview of GFM, and their basic operation in grid-connected and islanded modes. Control techniques for voltage and frequency regulation, grid synchronization of GFM. The advanced control techniques of GFM have been investigated by W. Du and N. Pogaku[14,15]. Both papers have discussed basic governing methods like sink control, synchronization with the power controller, effective synchronous mechanism control, synchronverter, identical control, and computer-generated oscillator controller. These control techniques determine to control frequency and voltage for the large

imbalance in load. Researcher W.Du has given a detailed comparative analysis of different GFM control techniques, which is not considered in papers by Rosso[13,14]. Comparison parameters are virtual tunable inertia, PLL synchronization, and overcurrent protection[15]. After reviewing papers by Rosso, W. Du, and R. Majumder on Grid forming converters control approaches, grid-synchronization and future trends, a comparison between various techniques has been shown in table-II[13,14,16]. Challenges with existing control techniques of GFM and a wide perspective of research opportunities have been discussed by W. Du, N. Pogaku, and J. Hu. The challenges are about GFM stability analysis with a low inertia system, weak grid, the optimal location of GFM with the smallest short circuit ratio (SCR), and frequency stability as the high penetration of GFM BESS drastically changes grid dynamics and give impact on system frequency and re-occurrence of frequency[14,15,17,18]. This will impact security strategies and load-detaching schemes to rethink. Transient stability analysis of GFM BESS has been studied through equal-area criteria. Capabilities of GFM BESS in grid-connected mode have been investigated by S.D'Arco. The GFM is capable of providing synchronization stability without the need for PLL, Generating Units and Power Park Modules to ride through fault, and smooth transition from isolated mode to grid-associated mode[19].

Major challenges with GFM and the future scope for further research in the area of GFM BESS have been covered by Ndreko in 2018, Tayyebi in 2020 and Rathnayake in 2021. The authors of these papers have come up with some open research questions like how the system will function and what will be the solution of network reshaping sources with backup energy storage provided for very low inertia of synchronous generation. How much reserve capacity is available to keep frequency within the limits mentioned by the IEC standard? What are the new limits provided by the IEC standard for a strong inverter-based grid?[20,21,22]

The answer to this question has been presented in this paper. Major topics covered in this paper are (I) modelling of synchronous generators, operational structure of grid following and grid forming inverters with battery storage (II) Control techniques of GFM for a system without rotating parts with high percentage shares of power electronics-based sources (III) Challenges with GFM converters control to enhance frequency stability (IV) future scope in the area of grid-forming control techniques.

(I) Modelling structure of Synchronous generator and Grid integrated inverters

(a) Synchronous generator

A typical synchronous generator behaves as a voltage source with small internal sub-transient reactance. When there is a sudden load change, it supplies the required current, but its internal voltage remains the same. At the same time, prime mover action takes place slowly. This will create an imbalance between electrically generated energy (P_{elec}) and mechanically generated energy (P_{mech}) and it strengthens the rotor to rotate at its new speed. The primary control action of the generator is to regulate voltage and frequency which is achieved by exciter and governor control. The swing equation (1) provides the required inertia constant to be varied as per the imbalance between P_{mehc} and P_{elec}. The inertia constant H is significant for a synchronous generator to maintain frequency firmness during any inequality of load, also it is having high fault current handling capability. Active power flow and frequency can be easily controlled using P-f droop control characteristics represented by equation (2).

$$\boldsymbol{P_{mech} - P_{elec}} = 2\mathrm{H}\frac{d\omega}{dt} \quad \text{.....(1)}$$

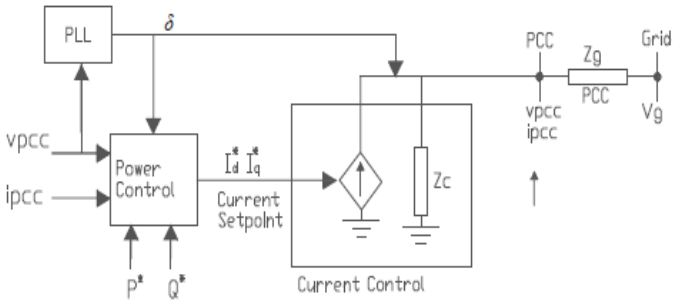
$$\boldsymbol{P_{in} - P_{out} = J\omega\frac{d\omega}{dt} + D\mathrm{e}\Delta\omega} \quad \text{..... (2)}$$

Where, $\boldsymbol{\Delta\omega = \omega_m - \omega_e}$

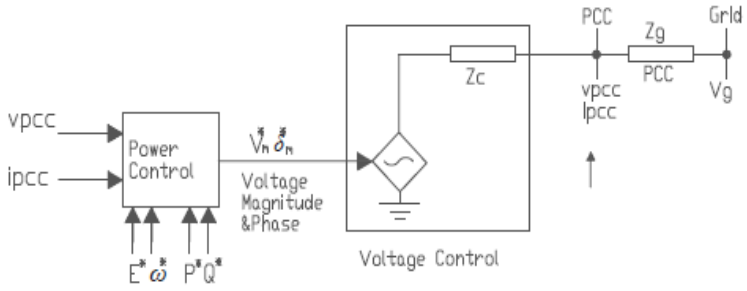
Where D_e is the damping constant, $\boldsymbol{\omega_e}$ is the grid frequency and $\boldsymbol{\omega_m}$ is the reference frequency. With the increasing demand for renewable energy sources like solar, wind, and battery storage due to their intermittent behaviour, the overall control of a mixed power system needs to be rethought and re-designed.

(b) Modelling of the grid-following inverter

Recently most of the grid-connected renewable sources work in grid-following mode. It means that all the time it gets synchronized with the grid using phase lock loop (PLL) control. Grid following inverter (GFL) behaves exactly as a current source. They follow the network voltage and frequency but do not have the ability to control frequency output. They don't have intrinsic voltage source behaviour. Also, these GFLs are not considered with sufficient storage to provide inertia response. Power electronics-based inverter sources have very low fault current level capability compared to conventional synchronous generators. The major challenges with increasing levels of IBRs with GFL behavior are voltage and frequency stability. Figure 1 (a) and (b) show control diagram of GFL and GFM. (Rathnayake D., 2021)



(a)



(b)

Figure 1: Approximate control diagram (a) GFL inverters and (b) GFM inverters[22]

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(c) Modelling of grid-forming inverters with battery storage

From the latest research study, it has been noticed that as the percentage shares of the grid following inverters increases, by eventually decreasing synchronous generators, the system stability is greatly affected. Micro-grid can function as a grid synchronization mode or isolated mode. When it is in a grid synchronized mode its function is to control voltage and frequency as per grid code i.e. it follows the grid. In an island mode, one or many inverters regulate voltage and frequency and form the local power grid. This instigates the concept of grid-forming converters. GFM BESS act as a voltage source converter to provide the local voltage and frequency support to the grid as shown in fig.1 (b). Thus GFM has a self-

synchronization capability in absence of grid signals. This makes the power system completely work on 100% IBRs.

The desired functionality of GFM are as follows:

i) Under normal operating conditions it should work as an AC voltage source with a small internal impedance.

ii) It should work satisfactorily when there is a transition from grid synchronization mode to isolated mode.

iii) It should provide black start service with sufficient energy storage capacity (like battery storage, and super capacitor.

iv) It should be capable of arresting frequency dip and increase the frequency nadir under sudden load imbalance or contingency of SGs.

v) It should be capable of providing optimum inertia support to maintain the system's safety.

With the above-required features, GFM is required to emulate the behaviour of SGs in the concept of a microgrid. Initially, this concept was developed for islanded operations but now the same is adopted for large-scale distribution systems especially when wind and solar are integrated into large power systems [19]. A comparison of operational functionality between GFL and GFM has been summarized in Table-I[20,21,22].

(II) Control strategies of GFM for low inertia system

Currently, all Grid following inverters (GFLI) is operating on current control, while grid-forming inverters (GFMI) can form voltage vectors at their common point of connection. To coordinate with the grid this voltage vector is dynamically controlled. In a grid-connected mode of GFM, the reactance to resistance ratio (X/R) plays an important role in deciding the relation between active power and reactive power. The power stages of GFM have been shown in figure 2. In this Lg and R_g are responsible for the X/R ratio of a line connecting GFM with the grid. If this ratio is very high, then active power is used to control frequency called power-frequency droop control. The Responsive power controls the magnitude of the voltage at the PCC called reactive power-voltage droop control. On the contrary, if X/R is less then it follows Q-f droop and P-V droop characteristics. In general, the approach for all control techniques is to enhance the strength of the system.

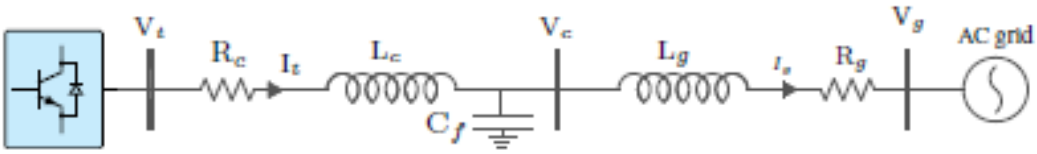

Figure 2: Power stages of Grid forming inverter[22]

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(a) Droop control technique

The Droop regulator method was being used for operating many SGs in parallel to share the dynamic and responsive power and accordingly common frequency and voltage at the PCC. This method has been successfully used for two decades and it requires no communication with other operating power grid centers. That is the reason these control techniques fall in a decentralized mode of control over major load imbalances. The control equations are shown in equations (3) and (4).

$$\omega = \omega_{ref} + K_D(P_{ref} . - P).....(3)$$

$$\upsilon = \upsilon_{ref} + K_v(Q_{ref} . - Q).....(4)$$

Where, ω_{ref} is the standard grid frequency, K_D and K_v-are the droop coefficient. To eliminate high-frequency harmonics normally droop controllers are used with low pass filters. Researcher Tayyebi A. has explained the droop control method to improve the transitory response of the conventional droop control method where droop control is applied with derivative and integral control. This overcomes the issues of transient current and power-sharing accuracy. Sometimes this droop control technique is used to regulate the angle and magnitude of the voltage at the grid connection point. The advantage of phase angle droop control is no internal inverter communication is required and values of droop co-efficient are selected based on load distribution and voltage variation[21].

(b) Virtual synchronous machine-based control

The droop control technique does not provide inertia and damping support. Thus it persists with stability issues. To overcome this virtual inertia-based control was proposed by S.F.Zaveri, and Lopes in the last decade. In this control technique, a virtual machine is modelled exactly like a synchronous generator, with armature winding, excitation winding and

damper winding[23]. The virtual machine voltage is calculated based on the measured current then it has been fed to the grid. The latest virtual inertia control offers the measurement of grid current, generating reference voltage signal for active and reactive power control. It is controlled in a similar way to SGs i.e. dynamic power is controlled by torque and responsive power is controlled by the voltage at the excitation. A virtual synchronous generator (VSG) has a minor frequency concavity due to virtual inertia and damping which reduces the transient peak and it is provided by virtual impedance. The author in paper ref [24] has proposed tunable inertia constant (J) and damping constant (D), according to load imbalance and required active and reactive power sharing. Also, this will help to provide a stability margin for the rating of the power grid, no. of GFC and SGs connected in the power system. These variable values of J and D are related to the D.C. link capacitance value which is connected between the inverter and filter. From the results of the paper [24], it has been observed that if the DC link capacitance value increases the settling time of frequency response decreases. Also the other parameters like DC link inductor, AC-side inductor and capacitor and moment of inertia constant help to decrease the frequency dip and provide faster settling time[24]. The overall effect on frequency dip by adding virtual inertia can be seen in figure 3. Classification of different virtual inertia control techniques is shown in figure 4. After reviewing control techniques of GFM proposed by Rathnayake and S.F. Zaveri, one can easily compare their operational functionality in terms of virtual inertia tuning, grid synchronization, fault-ride through capabilities which have been summarized in table-II[22,23].

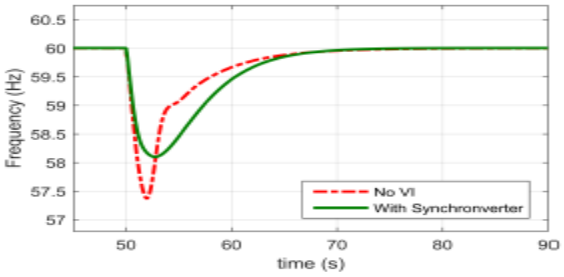

Figure 3: Effect of inertia on frequency response[4]

Retrieved from [Tamarakar, U. (2017), *Applied science, 7*, 654]. This paper is published under open access journal. Link which gives permission to reuse figure is https://www.mdpi.com/openaccess.

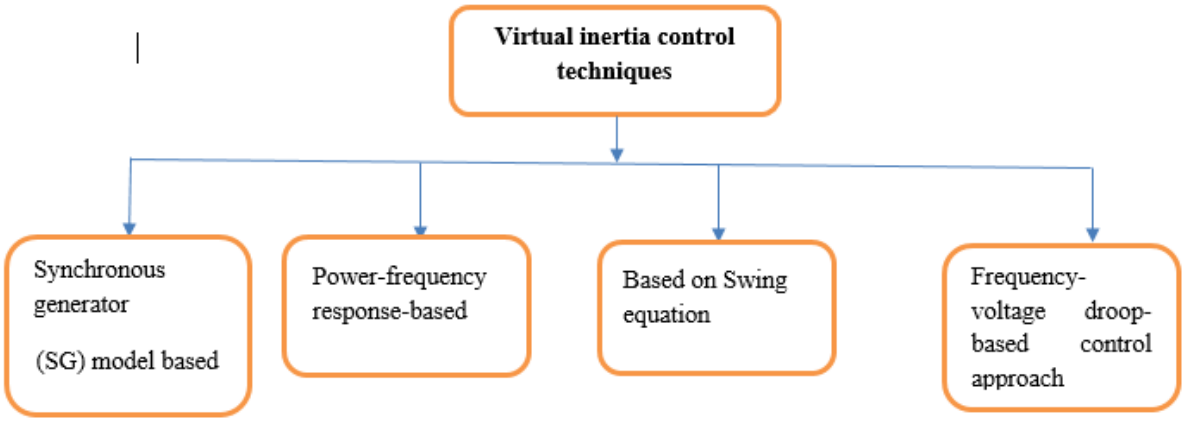

Figure 4: Classification of virtual inertia techniques

(III) Challenges with grid forming inverter control

The ultimate function of GFM is to work as a voltage source inverter not as a current source inverter, which creates some limitations. The inverter current is not strongly controlled in a basic GFM control method. As a consequence of this, when load changes or any contingency condition occurs such as a fault or grid transient it becomes a difficult task to limit the overcurrent of GFM. Thus advanced regulatory control methods like current limiting using virtual impedance is required to achieve overcurrent limitation.

Normally GFC acts as a voltage source in isolated mode, so implementing its operation in grid synchronization mode is a crucial task. Existing grid-tied inverters are working in the grid-following mode, in future, if they are replaced with grid forming mode of operation then it is important to study the dynamic behaviour of the power system with a combination of GFL-GFM-SG. Major difficulties with GFM operation have been resolved for the microgrid. But a more detailed research is required for the application of GFM to a larger power system.

Major challenges with GFM and the future scope for further research in the area of GFM BESS have been covered in this paper like how the system will function and what will be the solution of network reshaping sources with backup energy storage provided for very low inertia of synchronous generation. How much reserve capacity is available to keep frequency within the limits mentioned by the IEC standard? What are the new limits provided by the IEC standard for a strong inverter-based grid? What percentage shares of GFM can be optimal for

power system stability and security? The optimal location of GFM is also a challenging task for the overall system loss reduction[11].

(IV) Research gap analysis and future scope

Non-isolating for distributed inverters is one of the biggest difficulties. In case of sudden disconnection of SM, the GFM is required to supply the total load with the given power limit. But at that time DC source current exceeds the limit and saturates the DC source for a prolonged period. At the same time due to the slow response of SM with fast responding GFM for large load disturbances up to several seconds, the SM doesn't reach its stable power injection. During this time, the reaction of droop control results in a power inoculation which exceeds the DC source limit and collapses the DC voltage. Also results in exhausting the DC link if the alternating current of the converter is not limited. In the GFM converter, AC side measurement is used to drive the angle dynamics with active power measurement and improves the frequency performance of GFC. DC voltage measurement using matching control gives direct current limits. Review analysis shows that combined AC side and DC side control for complementary benefits by GFCs is yet not taken for study[21]. Further research can be carried out on combined AC and DC control along with frequency stability constraints with GFM.

Also, these research papers have not included how reactive power load demand could be supplied by Power electronics-based resources. For supplying sufficient active and reactive power demand, how much battery energy storage is required in contingency conditions is not considered in an existing grid forming inverter control techniques. Along with frequency stability how the voltage stability gets affected due to insufficient reactive power supply from PEB sources is still an open challenge.

Some significant research can be done in this sector for the advancement of this concept in the future. For example, the combination of multiple grid-forming concepts (e.g., a hybrid model of a virtual oscillator and matching control) can be conducted by highlighting the strengths and neglecting the drawbacks of specific methods.

	GFL inverters	GFM inverters
1.	Behaves like a current source.	Behaves like a voltage source.
2.	Can be operated only in grid-connected mode by following grid voltage and frequency.	Can be operated in both modes by giving stable operation of the grid.
3.	The primary objective is to supply dynamic power with a maximum power point tracker therefore responsive power supply is the least. The secondary objective is to support the grid	The primary objective is to vary grid frequency and voltage by changing the active and reactive power reference of the grid.
4.	Need PLL for synchronization with the grid.	It may use PLL to change the mode of operation from grid connected to isolated and vice versa.
5.	Measurement in delay makes its response slow for a sudden change in load.	Depending upon a change in grid voltage angle it gives an instantaneous response.
6.	The strong dependency on active and reactive power control.	Slight coupling between active and reactive power
7.	Requires reference voltage at the point of common connection to supply necessary active and reactive power.	Can back-start a power system.
8.	The stability margin reduces for a weak grid.	Having self-synchronization property under weak grid operation with concern on current limitation.
9.	Cannot operate at 100% IBRs: instability threshold exists.	Can be operated at 100% IBRs penetration: can co-exist with grid following inverters.
10.	It gives a more oscillatory and under-damped response which increases the frequency peak.	It gives a better-damped response and decreases frequency peak.

Table 1: Comparison of operational functionality between GFL and GFM inverters

Control Techniques	Advantages	Limitation
Synchronous generator (SG) model-based	• Perform the same as SG dynamic characteristics. • Derivation of frequency term is not required.	• The absence of frequency derivative terms creates noise in the System • The absence of a current-control mode, cannot protect the system against over-current faults.
Swing equation-based approach	• The Mathematical model is very simple compared to SG based model. • Derivation of frequency term is not required.	• The absence of a current-control mode, cannot protect the system against over-current faults. • False tuning of the damping factor and moment of inertia system gives fluctuating reactance.
Power-frequency response-based topology	• Implementation of a control strategy is very easy. • It applies current source operation. • It has in-built over-current Protection.	• ROCOF gets affected with inertia constant tuned as per demand. • only suited for a grid-synchronized mode of operation where the system works as a grid-following inverter. • Problem is to deal with the uncertainty of the PLL, and the sensitivity related to the frequency derivative.
A frequency-voltage droop-based control approach	• No communication is required. • Basic control is very much similar to conventional droop control in a synchronous generator.	• sluggish transitory response • Compromise between power-sharing and voltage oscillation precision. • Harmonic current sharing is unstable. • Control of voltage and frequency is highly dependent on the output impedance of the inverter.

Table 2: Comparative analysis of GFM control techniques

Conclusion

This paper discusses the conceptual difference between grid forming and grid following inverters for the large interconnected system. From the critical review of the literature, it has been proposed that with increased sharing of IBRs, the GFM with sufficient storage capacity is capable of supporting power system dynamics by using appropriate control techniques. The purpose of GFM control is to provide the required voltage and frequency at PCC in grid-connected mode and isolated mode, i.e., acting as a voltage source inverter. This is achieved by using a suitable control technique. Various GFC control methods have been reviewed in this article. Concept of virtual inertia by emulating the behaviour of GFM as a synchronous

generator has been discussed with different virtual inertia-based control techniques with their comparative study. Looking at the potential of GFM, it is capable of providing ancillary services like fault ride-through capability, system strength for the weak grid, contribution to system inertia, fast frequency response to any load variation or other contingencies like disconnection of any generating unit, power restoration capabilities on the occurrence of larger black-out with the high percentage shares of power electronics based sources. The areas which require the next step toward research and development are also discussed.

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Glossary:

Electric Grid- The electric grid is a network which connects the electric power generation with the consumer through transmission and distribution lines controlled through one or more control centers.

Inverter- The inverter converts DC energy to AC energy, which is the standard form of electricity used by utilities and most of the home appliances.

Battery energy storage system- Battery storage, or battery energy storage systems (BESS), are devices that enable energy from renewables, like solar and wind, to be stored and then released when customers need power most.

System Operator (SO)- A system operator is responsible for ensuring sustainable energy distribution to customers, businesses, and industry.

Inertia- Inertia is the property of a body due to which it opposes or resists any change in its state of rest or uniform motion.

Virtual inertia- Virtual inertia is the short-term stored energy in the DC link of the renewable energy sources power converters, which should be injected to the AC side for the virtual inertia control under load imbalance.

Droop- Droop is a method of controlling the reactive power of an alternator as the load increases. This is used in synchronizing applications, where multiple generators are in parallel.

Damping- Damping is a reduction in the amplitude of an oscillation as a result of energy being drained from the system to overcome frictional or other resistive forces.

Negative Refractive Index Metamaterials- Introduction and Methods to produce Achiral and Chiral Metamaterials

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Abstract

J.K. Rowling's fantasy series book "Harry Potter" talks about an invisibility cloak. It's not just the author's imagination; it can be practically realized in the real world. Anyone who learns about this magical world in real life will undoubtedly want to read about it. The present article focuses on such materials that don't exist in nature and need to be prepared artificially, termed negative refractive index metamaterials. Negative refractive index metamaterials (NIMs) theoretically predicted by Veselago in 1968 came into practical realization by J.B. Pendry. NIMs essential requirements in the material are to have simultaneous negative permittivity(ε) and negative permeability (μ). Negative permittivity occurs in many natural materials, and it is easy to achieve. On the other hand, it is a tedious task to achieve negative permeability, as natural materials do not possess this property, and such materials need to be fabricated artificially. Hence, NIMs are completely artificially generated materials. An invisibility cloak is just one application of NIMs. It has many more applications. In this paper, we will discuss an alternate chiral path to achieve NIMs with no requirement of negative permittivity and negative permeability. These chiral NIM materials are capable of showing optical rotation and circular dichroism along with the negative refractive index.

Keywords

Permittivity, Permeability, Negative refractive index metamaterials (NIMs), Chirality.

Introduction

When electromagnetic radiation travels from one medium to another, it bends rays due to the variation in optical densities. In different media, the speed of light is different, and this difference is measured in terms of refractive index (n), a dimensionless quantity referred to as Eq. (1). All naturally occurring materials have a positive refractive index, and thus they bend light in one particular direction and thus follow Snell's law.

$$n = \frac{n_2}{n_1} \tag{1}$$

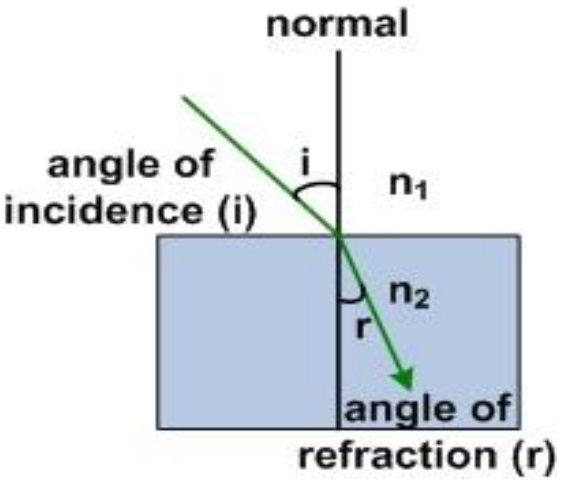


Figure 1: Ray traveling through two different media, showing refraction

Snell's law shows how incident angle (i) and refracted angle (r) relate to each other, as shown in Figure 1 The refractive index of the material can be calculated with the formula in terms of permittivity (ε) and permeability (μ), refer to Eq. (2)

$$n = \pm\sqrt{\varepsilon\mu} \tag{2}$$

Permittivity (ε) and permeability (μ) of the material are important parameters as they directly affect the refractive index of the material and decide how the electric and magnetic fields will respond when electromagnetic radiation falls on it. As a result, materials are classified on the basis of ε and μ values. In nature, the permittivity (ε) of most materials is positive, but for some materials, it is negative as well, but permeability (μ) is always positive and has to be achieved negatively artificially.[1]

The materials that have positive permittivity (ε) and positive permeability (μ) are known as double-positive materials (DPM), and follow Snell's law. In addition, DPMs show normal positive refraction. The materials with negative permittivity (ε) are epsilon negative materials (εNG), and materials with negative permeability are Mu negative materials (μNG).[2]. The question arises whether double negative materials (DNMs) with both negative ε and μ exist in nature? If **yes**, how are they different from DPMs? If not, how can such materials be fabricated artificially?

The term "metamaterial" is a Greek word in which "meta" means something that is beyond the real'. Theoretically, DNMs, also known as negative index metamaterials (NIMs), were first anticipated by V.G. Veselago in 1968. Veselago et al. proposed that if such materials exist, their electrodynamics will be completely different from DPMs.[3] With mathematical calculations, Pafomov et al. showed that if ε and μ both negative, then the phase velocity and group velocity will be antiparallel to each other,[4] directly affecting Snell's law, as shown in Figure 2. The bifurcation of materials based on ε and μ values is shown in Table 1.

ϵ	**μ**	**Material**
+	+	Double positive materials (DPM)
-	+	Epsilon negative materials (εNG)
+	-	Mu negative materials (μNG)
-	-	Negative refractive index metamaterial (NIMs)

Table 1: Materials classification chart having different ε and μ values

According to Veselago et al., negative permeability and permittivity do not result in a mathematical conflict with the expression for the refractive index (Eq. 2). The electrodynamics of materials when both microscopic parameters (ε, μ) are negative, is completely different from the materials that have both microscopic parameters positive (Refer to equations 3 and 4).He proved the behaviour of an electromagnetic wave when it travels through a medium that has permittivity (ε) and permeability (μ) simultaneously negative, through Maxwell's curl equations, Eq. (3) and Eq. (4).

$$\nabla \times \vec{E} = -\frac{1}{c}\frac{\partial \vec{B}}{\partial t} \quad (3)$$

$$\nabla \times \vec{H} = \frac{1}{c}\frac{\partial \vec{D}}{\partial t} \quad (4)$$

s lies in the direction of phase velocity and a Poynting vector lies in the direction of group velocity. The phase velocity and group velocity are antiparallel when permittivity (ε) and permeability (μ) are simultaneously negative.[5] DNM (-ε,-μ) will refract light in the mirror reflection direction as in case of DPM (+ε,+μ). As a result, the material's permittivity and permeability influence its refractive index, refer Eq. (2). When ε and μ are positive, n is the positive quantity, and when they are negative, n is the negative quantity.[5]

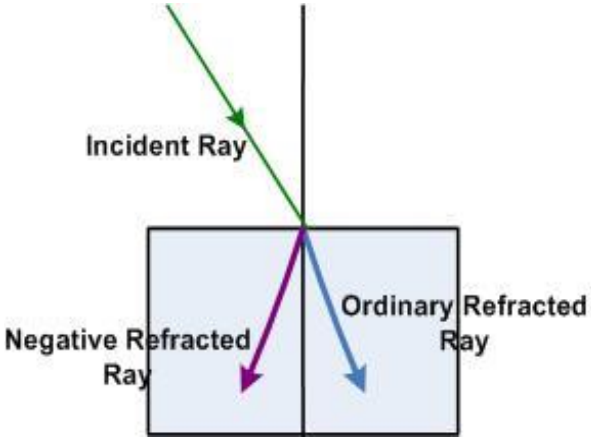


Figure 2: A ray diagram represents two different bending directions of light. Blue refracted ray is for refraction through DPM and purple is for NIM.

Major Advancements

Although the prediction of NIMs was made by Veselago in 1968, no such materials were practically realized until three decades. As achieving negative permeability was really difficult.[1]Theproperties of NIMs are independent of the material from which they are made, but their properties are solely dependent on their structures,[6] which must be very small in comparison to the incident wavelengths.[2] By designing microstructures appropriately, specific features (-ε, -μ) can be achieved for a certain frequency range. In the initial years, microstructures were designed only to work in the microwave region (GHz), but now microstructures are prepared that can work in the radio frequency region (MHz), far IR range (1 THz), mid IR range (100THz), and even the near IR range (200THz).

In 1998, Pendry et al. prepared thin structures of metallic wires that were able to produce negative ε[7] and in 1999 proposed different cylindrical structures that were able to produce

different low μ values and gave the theoretical idea of split ring resonators that can generate negative μ when certain frequency range electromagnetic radiation falls on them.[8]

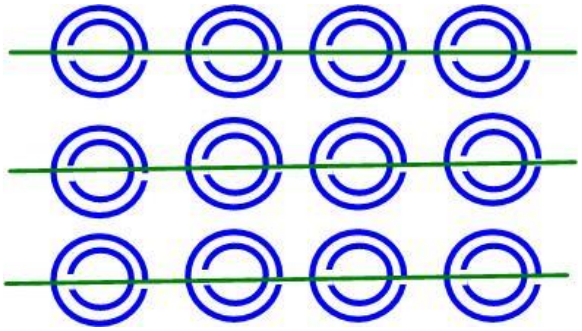


Figure 3: An array of Split ring resonators (SRRs) and continuous wires. SRR has splits in opposite ends and produces negative permeability and wires produce negative permittivity in negative refractive index metamaterial.[14]

Re-drawn from "Aydin, K., Guven, K., Kafesaki, M., Zhang, L., Soukoulis, C.M. & Ozbay, E. (2004). Experimental observation of true left-handed transmission peaks in metamaterials. *Opt. Lett., 29*(22), 2623–2625."

In 2000, Smith et al. practically realized such a metamaterial. It consists of an array of split ring resonators (a pair of concentric loops) (Figure 3) on a substrate with splits at opposite ends and arrays of continuous thin wires. Proper combination of SRR and periodically arranged continuous thin wires make μ and ε negative for a certain frequency range to form NIMs.[9] SRRs act as an LC oscillator. They can be circular, square, or U-shaped. Such artificial structures work on resonance formed by repeated elements, and their properties are completely different from those of individual components. These engineered structures have the potential to function as negative refractive index metamaterials for a specific frequency range.[10]The working of continuous thin wires depends upon plasma model with a frequency limit below which ϵ is negative.

Before going deeper into the negative refractive index metamaterial world, let's understand the workings of the LC oscillator. Electromagnetic oscillations in an LC circuit take place between the capacitor's electric field and the inductor's magnetic field and charge where, current and potential difference vary sinusoidally. The schematic of an LC oscillator is shown in Figure 4 Electric field energy stored in the capacitor is $E_E = \frac{q^2}{2C}$, where C is the capacitance and q is the

electric charge in the capacitor. The magnetic field energy stored in the inductor is $E_B=\frac{Li^2}{2}$, where L is the inductance and i is the current through the inductor. At the initial stage, charge stored in the capacitor is maximum (electric field E_E is maximum) and energy stored in the inductor is zero (magnetic field E_B energy is minimum) and no current is present in the circuit. When the LC circuit oscillates, energy starts alternating from electric field energy to magnetic field energy and vice versa by following the law of conservation.

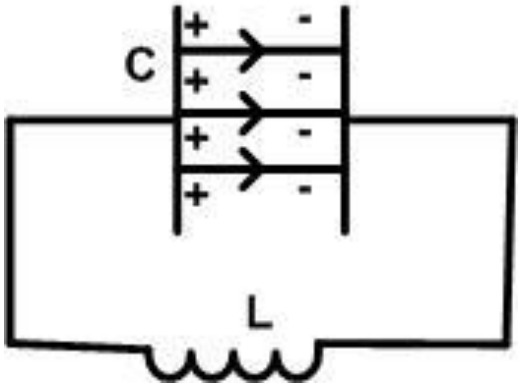


Figure 4: The schematic of an LC oscillator. Electromagnetic oscillations in LC circuit take place between capacitor's electric field and inductor's magnetic field

Negative refractive index metamaterials are made up of repeated combinations of inductor and capacitor elements, forming LC oscillators. When electromagnetic radiation falls on these LC oscillators, they resonate at a maximum frequency, termed the resonant frequency. At the resonant frequency, Eq. (5), the system oscillates with maximum amplitude, and this condition is termed resonance. Electrical resonance occurs when the inductive reactance and the capacitive reactance are equal in magnitude in an electrical circuit.

$$\omega = \frac{1}{\sqrt{LC}} \qquad (5)$$

ω is angular frequency of oscillations, L is inductance and C is the capacitance. At the resonance circuit, impedance is minimum and current is maximum.[11]

How does the combination of SRR and wires generate negative refractive index?

Electromagnetic radiation consists of electric and magnetic components vibrating in perpendicular planes. When electromagnetic radiation falls on the material, it is controlled by two microscopic parameters: first, the permittivity (ε) and second, the permeability (μ) of the

material. Permittivity (ε) describes the response of a material to the electric component of an electromagnetic wave, and permeability (μ) describes the response of a material to the magnetic component of an electromagnetic wave.[12] Both are crucial microscopic frequency dependent parameters (Refer Eq. (7) and Eq. (9) that affect the interaction of electromagnetic radiation with the material. These microscopic parameters depend up on the refractive index (n) of the material, which is referred in Eq. (2). It is significant to know refractive index specific value, as it signifies in which direction the incident light will bend. Artificially engineered metamaterials' electrodynamics is completely different from initial materials. Let's review how unique metamaterial shape and geometry manipulate electromagnetic waves to provide them with desired properties.

a) Magnetic response:

The split ring resonator (SRR) consists of two concentric rings with a split on each ring. It is planer and fabricated by lithographic technique to give a desired response to the magnetic component of the electromagnetic field. Two rings of a split ring resonator are near to one another and acts as an LC oscillator. When electromagnetic radiation falls on the SRR, a magnetic field that is polarized perpendicular to the SRR plane induces circulating current due to Faraday's law. These circulating currents induce charge across the split gap of SRR and energy is stored as capacitance as shown in Figure 5. The current path of SRR acts as an inductor. Hence, the SRR resonator acts as a simple LC resonator, oscillating with a resonance frequency refer to Eq. (6).

$$f = \frac{1}{2\pi\sqrt{LC}} \tag{6}$$

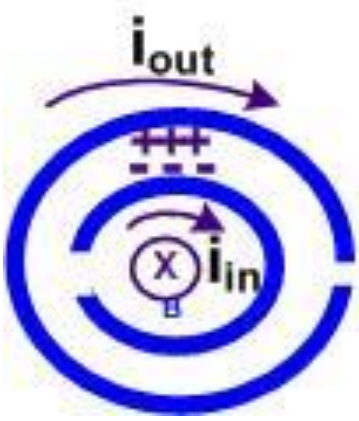


Figure 5: Split ring resonator acting as LC resonator. Circulating currents induce charge across the split gap of SRR and energy is stored as a capacitance and current path of SRR acts as an inductor.[8]

Re-drawn from "Pendry, J. B., Holden, A. J., Robbins, D. J. & Stewart, W. J. (1999). Magnetism from conductors and enhanced nonlinear phenomena. *IEEE Transactions on Microwave Theory and Techniques*, *47*(11), 2075–2084."

The current in the rings produces magnetic field lines. Current flows through SRR, which can either strengthen or weaken the incident magnetic field. A split ring resonator behaving as an LC circuit resonates with a resonance frequency (ω_0). When magnetic field is incident on the resonator effective permeability (μ_{eff}) exists in the medium and its value can be varied by making the constituting unit resonate. Refer to Eq. (7).

$$\mu_{eff} = 1 - \frac{F\omega^2}{\omega^2 - \omega_0^2 + i\omega\Gamma} \qquad (7)$$

Where effective permeability (μ_{eff}) depends upon incident frequency(ω), resonant frequency of the resonator (ω_0), fractional area of the unit cell (F) occupied by the split ring and dissipation factor (Γ).[9]

When frequencies of the external magnetic field(ω) are less than the resonant frequency(ω_0), current in the split ring resonator leads due to force produced by the external varying magnetic field, EM interaction is in phase and it strengthens he incident magnetic field, effective permeability (μ_{eff}) is enhanced and normal (positive) refraction takes place. If the external magnetic field's frequencies (ω) are more than resonant frequency (ω_0), the split ring resonator's current lags and is out of phase, and it weakens the incident magnetic field. Its effective permeability (μ_{eff}) is reduced, and negative refraction occurs.[10]Every split ring resonator has its own tuned frequency. Its negative permeability can be adjusted to the range of frequencies by changing the split ring resonator's dimensions. An array of split ring resonators is arranged to get an efficient magnetic response. Different modifications and changes in metamaterial designs were able to operate over a wide range of frequencies, from the radio frequency range to near IR. [10]

b) Electric response:

Metallic wires arranged periodically behave as low-density plasma. Analytical theory, computer simulation, and experiments prove that the thin wires are able to achieve negative permittivity for a certain frequency range.[7]

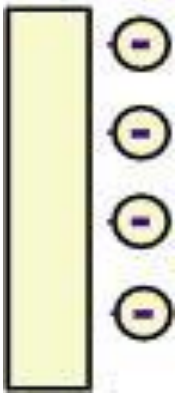


Figure 6: In solids positive charge is fixed in core and free negatively charged electrons are present around it

Plasmons are quasiparticles with an equal concentration of positive and negative charges. In solids, positive charge is fixed in the core and free negatively charged electrons are present around it (Figure 6), balancing the equal concentration of positive and negative charges. As electrons are displaced, a force acts on them and brings them back to equilibrium. As a reaction to this displacement, electrons start to oscillate with (ω_p)plasma frequency.

$$\omega_p{}^2 = \frac{4\pi n e^2}{m} \tag{8}$$

Where plasma frequency (ω_p) is directly proportional to n (carrier density), e (charge of an electron), and inversely proportional to m (effective mass of the electron) refer to Eq.(8). The dielectric function permittivity (ε) is related to the plasma frequency with the following relation. Refer to Eq.(9).

$$\varepsilon = 1 - \frac{\omega_p{}^2}{\omega^2} \tag{9}$$

By making sufficiently thin wires, effective density (n) is reduced and effective mass of electrons is increased. As a mesh of thin wires is spaced a few millimeters apart, these spaced structures reduce the density of electrons but increase the concentration of electrons. Sufficiently thin wires (less radius) increase the inductance of thin wires, and any current that

is present in wires works against inductance and makes electrons much heavier than they are. Hence, effective mass is increased. [1] Due to the variation in these parameters, the plasma frequency (ω_p) is reduced. Hence, such thin wires, when resonated below their plasma frequency, achieve negative permittivity values. As plasma frequency can be tuned by geometry, different negative values of permittivity (ε) can be obtained for a wide frequency range. Thin silver, gold and aluminum wires can be fabricated on the substrate to get negative permittivity (ε) at optical frequencies.[7,10]Combinations of these structures can provide negative permittivity and negative permeability and are used to make NIMs.[13]Refer Eq. (2)

Details of NIMs reported in Literature

The combination of structures that are capable of generating negative values of permittivity (ε) and permeability (μ) for a certain frequency range, called NIMs, are also termed as left-handed materials (LHM). Padilla et al. have shown different metamaterials working from radio frequency to the near IR range.[10]Pendry et al. (1998)[7]proposed the first feasible structure that exhibited negative permittivity, and Pendry et al. (1999)[8]proposed models that exhibited negative permeability. They proposed magnetic microstructures and named them models A, B, and Swiss roll structure (C) to achieve different imaginary magnetic permeabilities. Each magnetic microstructure discussed was made with a size less than the wavelength of the incident radiation. All structures discussed were made from nonmagnetic conducting sheets of very low density and are extremely light-weighted. Each structure is fabricated in a way that resonates due to internal capacitance and inductance.

In model A, Pendry et al. arranged square arrays of conducting metallic cylinders, and an external magnetic field was applied parallel to the cylinders as in Figure 7. It induces currents that flow around the cylinders and produce a magnetic field. In this model, they achieved a permeability (μ) more than 0 and less than 1. Although the artificially achieved μ value was very low, it was still positive ,hence model A was further modified.

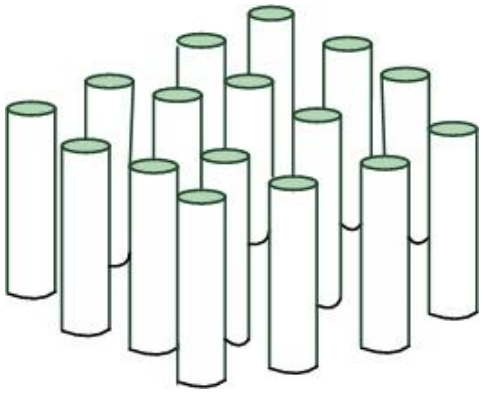


Figure 7: Model proposed to produce negative permeability by Pendry et al.[8] made up of conducting metallic cylinders

Re-drawn from "Pendry, J. B., Holden, A. J., Robbins, D. J. & Stewart, W. J. (1999). Magnetism from conductors and enhanced nonlinear phenomena. *IEEE Transactions on Microwave Theory and Techniques*, *47*(11), 2075–2084."

Pendry et al. modified model A due to its limited range. In model B, sheets were divided into split ring structures (Figure 8), separated by a certain distance, and a magnetic field was applied parallel to the cylinders. It induces a current in the split rings and makes it a resonant structure due to the capacitance between the sheets and the inductance of the cylinders. When the frequency was kept lower than the resonant frequency, the value of μ was calculated more, but when the frequency was more than the resonant frequency, μ was calculated less than unity. Thus, around the resonant frequency μ was found to be negative.

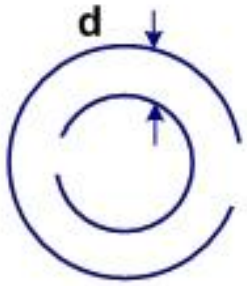


Figure 8: In model B conducting cylinders consists of split ring structures separated by distance d to produce negative permeability. (Top view).[8]

Re-drawn from "Pendry, J. B., Holden, A. J., Robbins, D. J. & Stewart, W. J. (1999). Magnetism from conductors and enhanced nonlinear phenomena. *IEEE Transactions on Microwave Theory and Techniques*, *47*(11), 2075–2084."

To achieve more capacitance, Pendry et al. modified model B and named it the Swiss roll structure (model C). In model C, metallic sheet was wound around each cylinder in a coil and each coil spacing was kept d from the earlier sheet (Figure 9). When a magnetic field is applied parallel to the cylinder, it reduces current in coiled sheets, and capacitance between the first and last turns of the coils enables the current flow. In it, the resistivity of the material and capacitive structures variates the μ. These capacitive structures were capable of adjusting magnetic permeabilities.

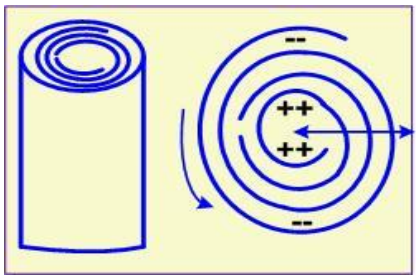


Figure 9: In model C magnetic field is applied parallel to the coil having N turns. Current is reduced in coiled sheets and capacitance is developed between first and last turns of the coil, due to its current flows in the circuit.[8]

Re-drawn from "Pendry, J. B., Holden, A. J., Robbins, D. J. & Stewart, W. J. (1999). Magnetism from conductors and enhanced nonlinear phenomena. *IEEE Transactions on Microwave Theory and Techniques*, *47*(11), 2075–2084."

All the structures discussed by Pendry worked well in microwave radiation, and by changing the structure's design, different values of magnetic permeability were achieved. All the structures discussed above vary their magnetic properties when the magnetic field is applied along the cylinder axes, but zero magnetic response is observed in other directions. To overcome this insufficiency, Pendry's further plan was to replace split ring cylinders with flat disk split rings to achieve negative permeability.[8]Pendry et al. (1999) work was focused on achieving negative permeability by using cylindrical structures. Smith and Padilla (2000)[9]fabricated the first NIMs by replacing cylindrical structures with split ring resonators.

They combined continuous wires (negative permittivity) with copper split ring resonators (SRRs) (negative permeability) on board to construct negative refractive index metamaterials.

A unit cell consists of a wire paired with SRR. Thin continuous wires provide negative permittivity. SRR are two split rings facing opposite to each other. Smith et al. fabricated a split ring resonator with the following dimensions: the thickness of each ring was kept at d = 0.8mm, with a gap of g = 0.2mm, and the radius of the inner ring was r = 1.5mm, as shown in Figure 10 The gap between the rings acts as a capacitor, and the rings act as an inductor. Due to the presence of splits in rings, SRR can resonate.

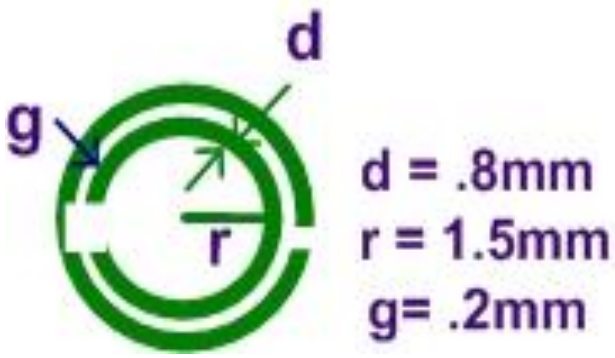


Figure 10: Parameters of Split ring resonator prepared by Smith et.al.[9]

Re-drawn from "Smith, D. R., Padilla, W. J., Vier, D. C. & Schultz, S. (2000). Composite medium with simultaneously negative permeability and permittivity. *Phys. Rev. Lett.*, *84*(18), 4184–4187."

Aydin et al. prepared a negative refractive index metamaterial on FR4 circuit board with a copper layer deposited of 30µm thickness. They prepared two structures, one combining SRRs with wires and other combining closed SRRs (CSRRs) with wires. On one side, SRRs were arranged and wires on the other side of dielectric board as shown in Figure 11. SRR details: d = t = .2mm, w = .9mm, r = 1.6mm. 5, 15 and 18 SRRs unit cells were arranged periodically along the x, y, and z directions. Wire details: The thickness, length and width of wire 30µm, 13.5cm and 0.9mm. With the same parameters, CSRRs were fabricated on one side of board and wires on the other side of the dielectric board. Through experiment, they showed transmission band that coincides with the region where both µ & ε are negative. The plasma frequency of this combination is less than the plasma frequency of wire. Combining SRRs and CSRRs with wires exhibits negative refractive index properties.[14]

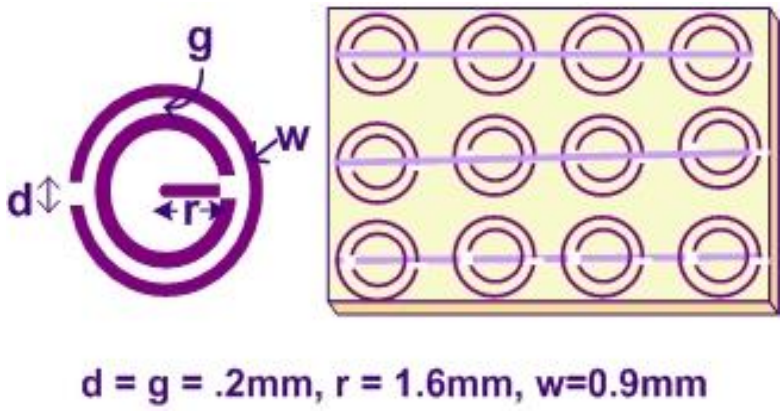


Figure 11: Parameters of metamaterial prepared by Aydin et al. Transmission curves of these structures show Negative refractive index region where both permittivity and permeability is negative.[14]

Re-drawn from "Aydin, K., Guven, K., Kafesaki, M., Zhang, L., Soukoulis, C.M. & Ozbay, E. (2004). Experimental observation of true left-handed transmission peaks in metamaterials. *Opt. Lett., 29*(22), 2623–2625."

Ozbay et al. observed a negative refractive index by different techniques. By combining a split ring resonator with wire patterns fabricated on an FR4 circuit board. The length of continuous thin wire was 19cm and width 0.9mm. They were able to observe negative refraction through three different methods, beam shift method, the phase shift method and the wedge shaped method.[15]

The split ring resonators built by[15] consist of two concentric metal rings on a dielectric printed circuit board (thickness 1.6mm and permittivity (ε) 3.85 of the board). The width of the metal is kept .9mm and the gap between the inner and outer rings is .2mm. This SRR structure helps to attain magnetic resonance in the microwave frequency region. The copper of a thickness of 30 μm is deposited to make SRR. They arranged an array of these SRR's to achieve negative permeability (μ). The array consists of a number of unit cells along the x, y and z axis 10, 15 and 25, respectively, with lattice spacings of $a_x = a_y = 8.8$mm and $a_z = 6.5$mm. Through experiments, they found the resonance frequency of such SRR is in the GHz range.

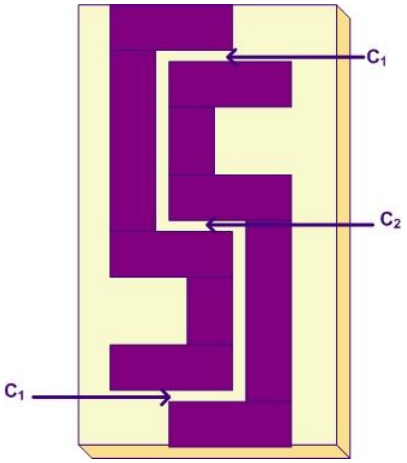


Figure 12: S shaped metamaterial prepared by printing only on one side on F4 board.[16]

Re-drawn from "Wang, D., Ran, L., Chen, H., Mu, M., Kong, J. A. & Mu, B. I. (2007). Experimental validation of negative refraction of metamaterial composed of single side paired S-ring resonators. *Appl. Phys. Lett. 90*(25), 254103(1–3)."

Wang et al. introduced a unique and easy technique to fabricate controllable negative refractive index metamaterials. They printed a one-dimensional S-shaped metallic strip on one side of the dielectric board that was easy to fabricate, as shown in Figure 12. Inductance is introduced by the two metallic strips, and the capacitances is introduced by the gaps between the strips. Numerical simulations and experimental results show negative permittivity and negative permeability can be achieved simultaneously by this basic structure that is printed only on one side of the 1 mm thick F4 board.[16]

Later, much simpler negative refractive index structures were fabricated[17]**.** Short wires were paired with continuous wires separated with dielectric spacers to form negative refractive index metamaterials through microfabrication as shown in Figure 13(b). Unit cell of wire pair structure is shown in Figure 13(a). The short wire shows inductive behavior along the wire and capacitive behavior between adjacent ends of short wires. Simulations and microwave experiments for transmission and reflectance show that fabricated material shows negative refractive index properties. The calculated frequency (f_m) of magnetic resonance.

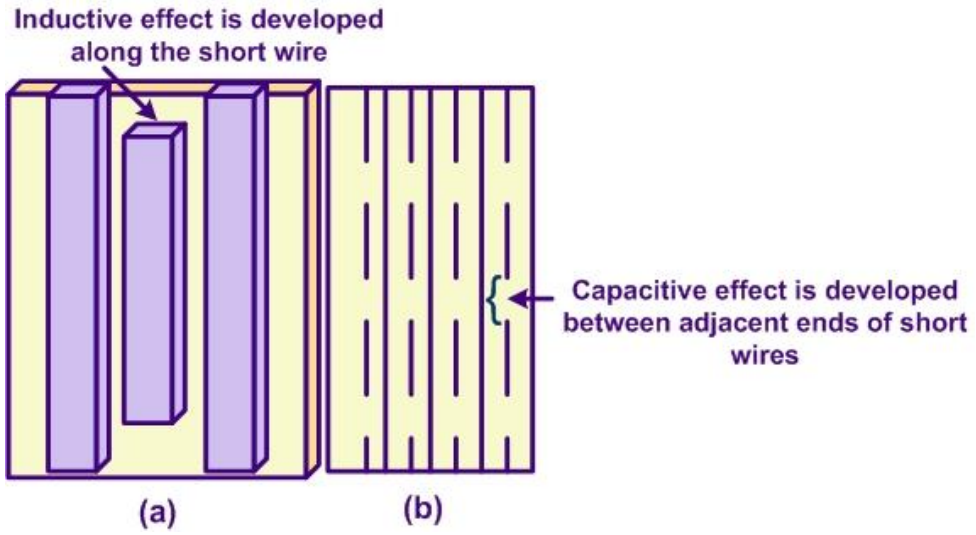


Figure 13: a) Unit cell of wire pair structure. b) Wire pair structure fabricated on FR4 Board.[17]

Re-drawn from "Zhou, J., Zhang, L., Tuttle, G., Koschny, T. & Soukoulis, C. M. (2006). Negative index materials using simple short wire pairs. *Physics review B. 73*(4), 041101(1-4)."

$$f_m = \frac{c}{\pi l \sqrt{\varepsilon_r}} \qquad (10)$$

where c is the speed of light in a vacuum, *l* is the length of the short wire, and ε_r is the relative dielectric constant between the wires. The magnetic resonance frequency is inversely proportional to *l* refer to Eq.(10). The unit cell dimensions of metamaterial are kept much smaller than the wavelength of incident radiation.

Applications of Negative refractive index metamaterials:

The development of negative refractive index metamaterials has opened the world to multiple unusual phenomena that were never observed in past with conventional resources. Their specific designs help them manipulate optical frequencies.[18] Here I am going to discuss some of the applications of these (NIM) wonder metamaterials.

a) Perfect lens:

Ordinary lenses are made up of glass and are used for image formation. They work because of their specific shapes, but their work has certain limitations as their optical resolution is limited

to the wavelength of light. So today, NIMs are used to make perfect lenses as they go beyond the diffraction limit and enhance resolution to form sharp and perfect images.

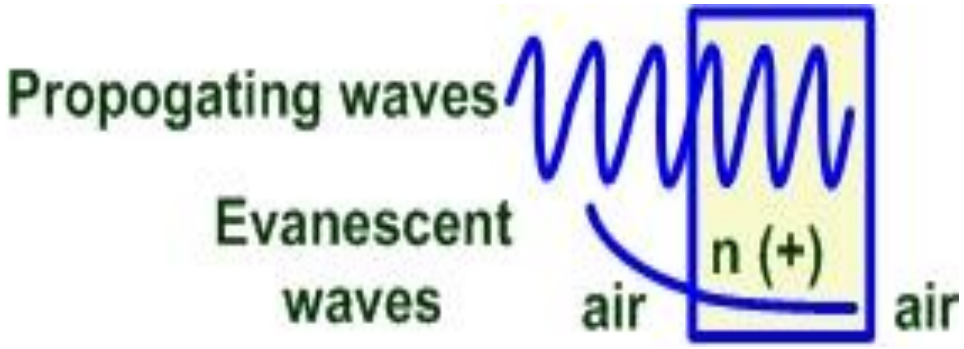
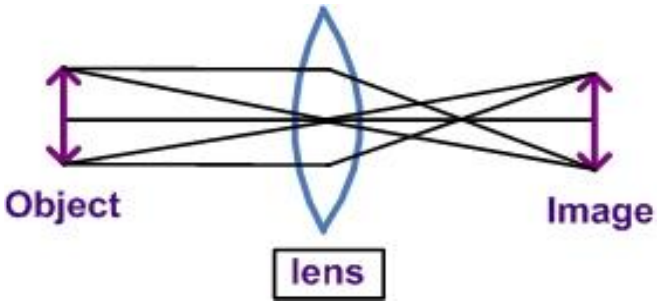


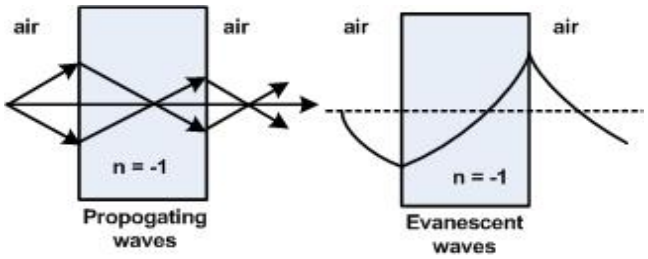
Figure 14: Propagating and evanescent waves travelling through the normal lens. Evanescent waves decay exponentially in normal lenses and make less or no Contribution to form images.[19]

Re-drawn from "Goudus, S. K., (2017*). Microwave Systems and Applications (edition).* InTechOpen. https://doi.org/10.5772/62931"

As the field coming out of an object is a superposition of plane waves that consists of propagating waves and evanescent waves, as shown in Figure 14.[19] In normal lenses, an image is formed due to propagating waves as evanescent waves carry subwavelength information about an object and decay exponentially in normal lenses (positive refractive index). One more limitation of normal lenses is that, due to their aperture, they diffract and form blurred images (Figure 15(a). A lot of information is lost due to these losses. If lenses are made up of NIMs and placed close to the object, the near-field evanescent waves are enhanced across the lens. Lenses made up of NIMs focus both propagating waves (Figure 15(b)) as well as enhanced evanescent waves (Figure 15(c)) in phase and amplitude to form high resolution perfect images. Images formed with NIMs are ultra-sharp as they do not have to go through the diffraction limit.



(a)



(b) (c)

Figure 15: (a) Image formed through normal lens. Its aperture diffracts light and limit it to make sharp images
(b) Lenses made up of negative refractive index metamaterial (NIMs) first diverge propagating waves from point source and then converge to form images.
(c) Evanescent waves are enhanced in negative refractive index metamaterial and give good contribution to form images. Images formed through NIMs are not limited to diffraction limit and images from through it are very sharp.[20,21]

Re-drawn from "Pendry, J. B. (2000). Negative refraction makes a perfect lens. *Phys. Review Letters*, *85*(18), 3966–3969." & "Pendry, J. B. & Ramakrishna, S. A. (2003). Refining the perfect lens. *Phys. B.*, *338*(1-4), 329–332."

NIMs bend light to a negative angle with the normal, first diverge, and then converge to form images by restoring the phase of propagating waves and amplitude of evanescent waves.[20] Today, perfect lenses are also made by combining a series of thin slices of the negative refractive index metamaterial, as this combination enhances absorption and resolution to form low loss images (Figure 16).[21]

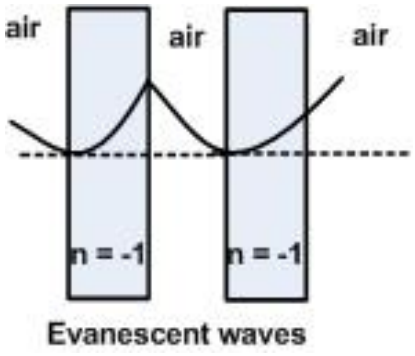


Figure 16: A perfect lens made up of combining slices of NIMs to get lossless image due to good absorption and enhanced resolution.[21]

Re-drawn from "Pendry, J. B. & Ramakrishna, S. A. (2003). Refining the perfect lens. *Phys. B., 338*(1-4), 329–332."

b) Invisibility Cloak:

John Pendry of Imperial College in 2006 created a small device that can redirect microwave radiation around an object and can hide the object, making it invisible. Cloaking means hiding objects from view. This property was derived from the structural geometry of the metamaterial. In these structures, the electromagnetic field is controlled by the material's specific design so that the displacement field, magnetic induction and Poynting vector are displaced in line. Variation in these values affects electromagnetic waves and this distortion in the field is represented by coordinate transformations. These structures are capable of manipulating electromagnetic radiation by either amplifying, bending or absorbing it (Figure 17). Especially designed metamaterials can redirect electromagnetic waves and adjust it to the desired configuration for a particular frequency. [22]

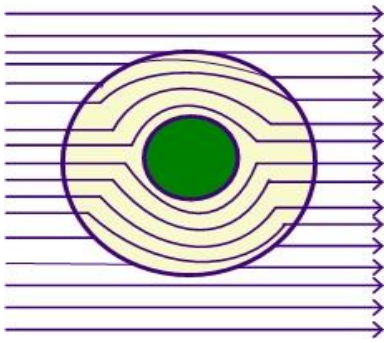


Figure 17: Invisibility cloak, to hide objects from the view.[22]

Re-drawn from "Pendry, J. B., Schurig, D. & Smith, D. R. (2006). Controlling electromagnetic fields. *Science, 312*(5781), 1780–1782."

Schruing et al. prepared an invisibility cloak with a NIM for a narrow band of microwave frequencies. The cloak that is formed around an object decreases the scattering of the hidden object and parallelly reduces its shadow. The metamaterial structure prepared by Schruing et al. consists of equally spaced 10 concentric cylinders, and the height of each cylinder was 3unit cells tall (Figure 18). In each successive cylinder, the number of unit cells is increased.[23]

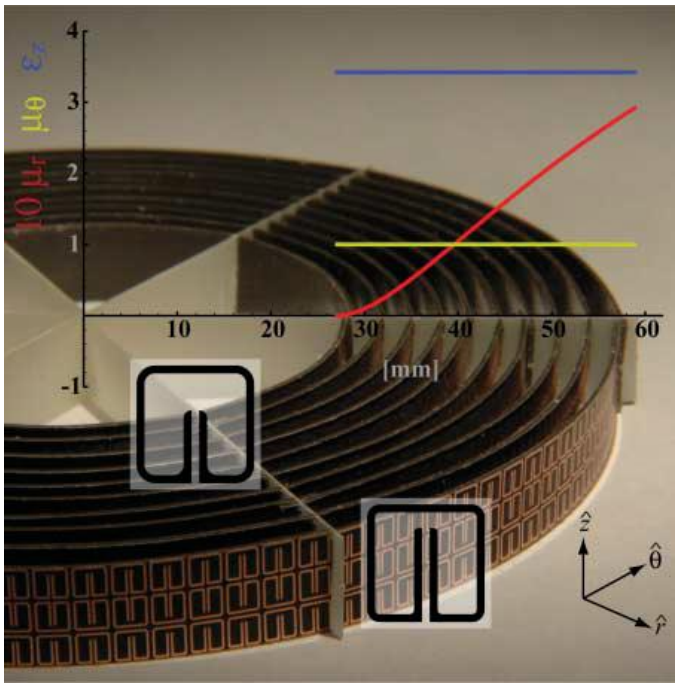


Figure 18: Schruing et al.[23] consists of equally spaced 10 concentric cylinders and height of each cylinder was 3-unit cells tall.

Adapted with permission from permission from "[Schurig, D., Mock, J. J., Justice, B. J., Cummer, S. A., Pendry, J. B., Starr, A. F. & Smith , D. R. (2006). Metamaterial electromagnetic cloak at microwave frequencies. *Science, 314* (5801), 977–980.] Copyright 2006, The American Association for the Advancement of Science"

c) Nonlinear Optics:

J. Pendry and coworkers predicted nonlinear optical properties could be achieved from metamaterials. Klein et al. observed second harmonic generation from metamaterial that was made up of split ring resonators. [24, 25]

d) Antenna:

Another important application of negative refractive index metamaterial is to make antennas. One of the examples is the beam tilting antenna, where the NIM array is fixed between two

dielectric resonator antennas (DRAs). When an electromagnetic wave enters the medium, the direction of propagation changes by deflecting the direction of the beam. The beam tilting angle depends upon l and d (parameters shown in Figure19a and is independent of the number of NIM layers while the gain of the antenna is dependent on the number of NIM layers, and gap between them. The NIM unit cell (Figure 19b) array is kept above the DRA, tilts the beam in the opposite direction due to its negative refractive index property, and redirects the DRA beam. Experimental and simulation data show that by variating d, l and gap parameters of the structure, beam tilting direction and antenna gain can be changed.[26]

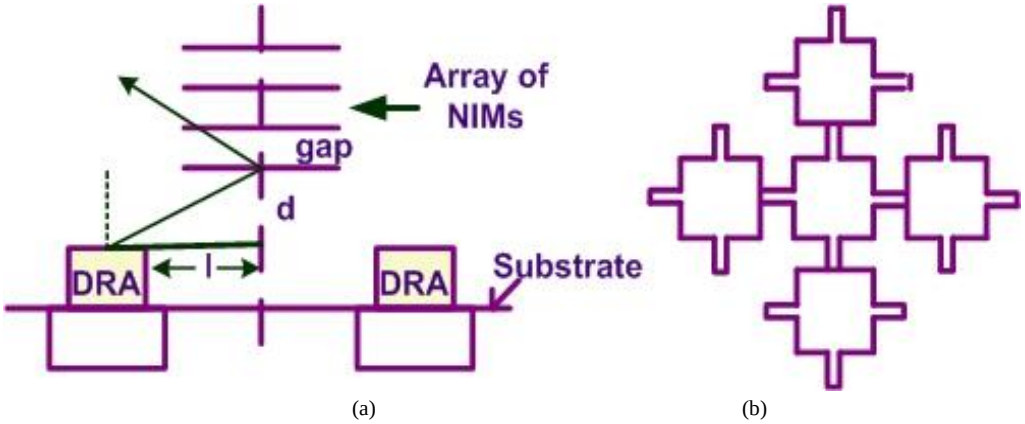


Figure 19: (a) A beam tilting antenna made up of NIM, fixed between two dielectrics resonator antennas. (b) NIM unit cell.[26]

Re-drawn from "Li, J., Zeng, Q., Liu, R. &Denidni, T. A. (2017). Beam-tilting antenna with negative refractive index metamaterial loading. *IEEE Antennas Wirel. Propag. Lett. 16,* 2030–2033."

NIMs are also used to make dynamic beam tilting terahertz antennas. In this type of antenna, the pattern structure is designed on a p-type Si substrate (dielectric constant 11.7) and covered with SiO_2 (dielectric constant 4) to make an antenna. The dynamic beam tilt antenna consists of the antenna (above mentioned) and the NIM (Figure 20a).

Graphene is embedded in a metallic resonant structure to variate the refractive index of NIM (Figure 20b). By varying the chemical potential of graphene values of negative refractive index values can be varied. Graphene can tune its surface conductivity at a THz frequency range. If direct current (DC) is applied to graphene, it changes its chemical potential and variate refractive index of the NIM. The variation in refractive index of the negative refractive index

metamaterial variate the steering angle of the antenna. Hence, graphene is able to control the negative refractive index and opens the path to fabricating dynamic beam tilting antennas.[27]

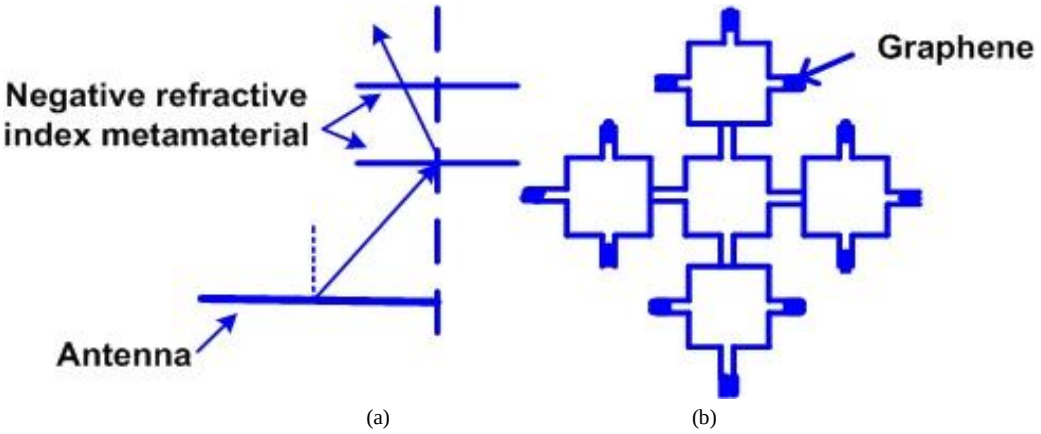


Figure 20: (a) Antenna with NIM. (b) Graphene embedded in NIM, by modulating chemical potential of graphene negative refractive index values is changed and an effective way to make beam tilting antenna.[27]

Re-drawn from "Luo, Y., Zeng, Q., Yan, X., Jiang, T., Yang, R., Wang, J.,Wu, Y., Lu, Q. & Zhang. X. (2019). A graphene-based tunable negative refractive index metamaterial and its application in dynamic beam-tilting terahertz antenna. *Microw. Opt. Technol. Lett.*, *61*(12), 2766–2772."

Chiral metamaterials, a unique way to achieve negative refractive index:

The above discussion summarizes two essential conditions for negative refractive index metamaterials: first negative permittivity and second negative permeability. Some alternate paths do not need these conditions to be completely filled, and such alternatives are chiral metamaterials and photonic crystals. Chiral metamaterials are asymmetric unit cells that lack mirror symmetry, while photonic crystals are order of wavelength and show diffractive phenomena. Their phase velocity and group velocity are in opposite directions, which are very similar characteristics to NIMs.[28]

Here, our primary focus is on chiral metamaterials that are artificially fabricated in labs and consist of unit cells that are asymmetric, lack mirror symmetry, inversion symmetry, and improper axis of symmetry. Benfeng et al. studied optical activity in planar chiral metamaterials (manufactured artificially) made up of dielectric and metal. Through numerical analysis, they proved a thickness of only hundreds of nanometers of chiral metamaterial can achieve optical activity, an essential condition of chiral materials.[29]

The idea that chiral structures can exhibit negative refraction was first theoretically proposed by Tretykov[30]. In his work he talked about chiral nihility materials (ε=0, μ=0) and (κ) chiral parameter is non-zero for a certain frequency and explained the properties of such materials through Maxwell's equations.

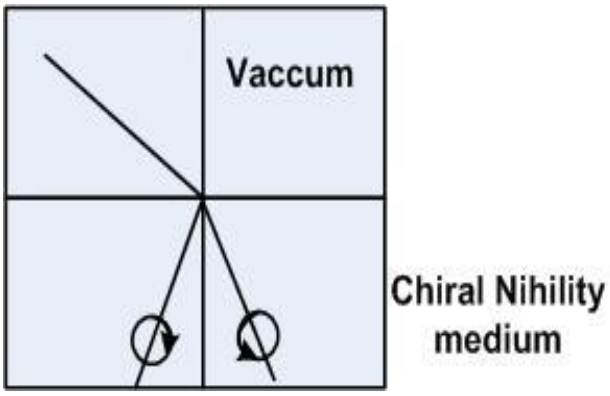


Figure 21: Double refraction taking place through chiral nihility material (ε=0, μ=0). Both refracted rays are circularly polarized (CP), one CP refracted ray is refracted positively and other is refracted negatively (opposite to incident ray).[30]

Re-drawn from "Tretyakov, S., Nefedov, I., Sihvola, A. , Maslovski, S. &Simovski, C. (2003). Waves and energy in chiral nihility. *J. Electromagn. Waves Appl. 17*(5), 695–706."

Maxwell's equations for chiral nihility media. Refer to Eq. (11) and Eq. (12)

$$\nabla \times \vec{E} = k_0 \kappa \vec{E} \tag{11}$$

$$\nabla \times \vec{H} = k_0 \kappa \vec{H} \tag{12}$$

Where k_0 is wavevector in vacuum and κ is chiral parameter. Chiral parameter lifts the degeneracy and show different refractive indices for different handed circularly polarized lights. Solutions of Maxwell's equations of chiral nihility media are the eigenvectors of the curl operator and represent circularly polarized waves with helicity parameter $k_0 \kappa$. Cantarella et al. discuss the complete derivation of helicity[31] where the helicity parameter can either be positive or negative.

Tretykov et al. did mathematical calculations and proved that when linearly polarized waves travel through chiral nihility materials, double refraction takes place and one of the two eigen waves with a positive group velocity has a negative phase velocity, so that one of the waves is backward wave and shows negative refraction. Both refracted rays are circularly polarized with

one ray refracting positively (normal refraction) and the other refracting negatively (negative refraction) as shown in Figure 21. These materials were not realized practically then. Later researchers put this theoretical aspect into practical realization.

Tretyakov et al. studied chiral composites to observe negative refraction and discussed it in terms of the strong resonant interaction between chiral particles and dipoles, giving rise to a stop band where negative refraction is observed. Propagation constants of two eigen waves in isotropic chiral media is $\beta = (n \pm \kappa)\, k_0$, where $n = \sqrt{\varepsilon\mu}$ is the refractive index, κ is the chirality parameter and k_0 is wavenumber. Near the resonant frequency of chiral particles, n (refractive index) becomes less than (κ) chirality parameter so that negative refraction takes place and one of the eigenwaves shows negative refraction while the other is positively refracted.[32]

Wang et al. did experiments and numerical calculations for chiral metamaterials and were able to show optical activity and circular dichroism exhibited by the metamaterial and were able to discover one more complimentary property of the chiral metamaterial-negative refractive index[33] with no requirement for negative permittivity and negative permeability. When different handed circularly polarized light falls on the chiral metamaterials, they derive strong gyrotropy and different handed circularly polarized light shows two different values of refractive indices.[34]The refractive index is increased corresponding to one circular polarization and reduced for the other. Due to it one circular polarization being positive and other negative,[35-36] work as well theoretically supports the idea that chiral materials can work as NIMs. Hence, it supports how chirality in the system is sufficient to introduce negative refractive index.

Artificially fabricated chiral metamaterials that exhibit negative refractive index properties as well.

a) Zhou et al. fabricated a unique chiral metamaterial on a copper clad FR-4 board. Asymmetric bilayer cross wires were fabricated on both sides of the board. (Figure22) Due to its asymmetrical structure, light propagated through such a metamaterial is split into right circularly polarized light (RCP) and left circularly polarized light (LCP) and shows strong chirality at resonant frequencies. This asymmetric structure shows optical activity, circular dichroism, and strong chirality.

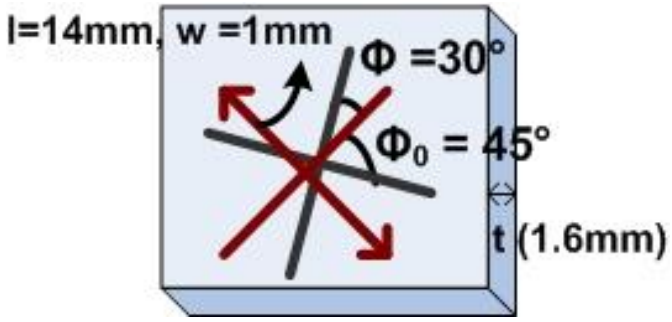


Figure 22: Schematic of chiral metamaterial prepared by Zhou et al. Asymmetric pattern is fabricated on both sides od FR-4 board.[37]

Re-drawn from "Zhou, J., Dong, J., Wang, B., Koschny, T., Kafesaki, M. & Soukovlis, C.M. (2009). Negative refractive index due to chirality. *Phys. Rev. B, 79*(12), 121104(1–5)."

The paper focuses on how strong chirality in the system is sufficient to make metamaterial negative refractive index too and how chiral parameter plays an important role to achieve it with no requirement of negative permittivity (ε) and permeability (μ). The refractive index for RCP (+) and LCP (-) are $n_{+ \text{ and }} n_{-}$ respectively and κ is the chiral parameter refer to Eq.(13).

$$n_{\pm} = \sqrt{\varepsilon\mu} \pm \kappa \quad (13)$$

For RCP (+) refractive index value was observed to be -2.5 at 6.8 GHz and for LCP, -1 at 7.8 GHz. In the system, both circularly polarized light were able to show a negative refractive index but RCP shows more negative refractive index value compared to LCP. Hence negative refractive index for RCP and LCP in the system had developed due to the chiral parameter (κ). Same simulation performed on achiral material shows no different graphs for RCP, LCP, and for n (conventional refractive index). The system had no chirality; hence no negative refractive index was observed.[37]

J B Pendry manufactured simple chiral design, a chiral structure by winding a continuous insulated metal tape onto a cylinder [38]. The coiled helix structure give inductance, inner and outer layers of the helix give capacitance (Figure23(b)). Chiral materials are able to achieve single gap because their intersecting bands do not hybridize (Figure23(a)). This single gap eliminates the problem of two resonances and gives a smooth path to achieve a negative refractive index. Hence, the chiral structure with a single band gap makes the material have a negative refractive index too.

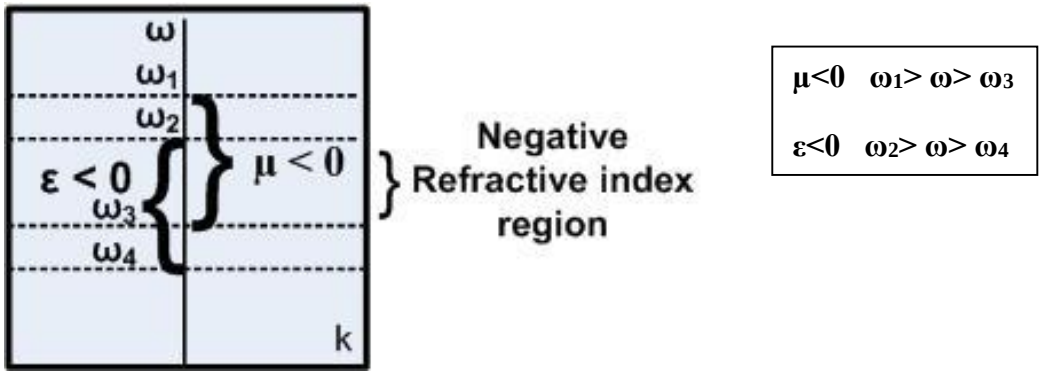
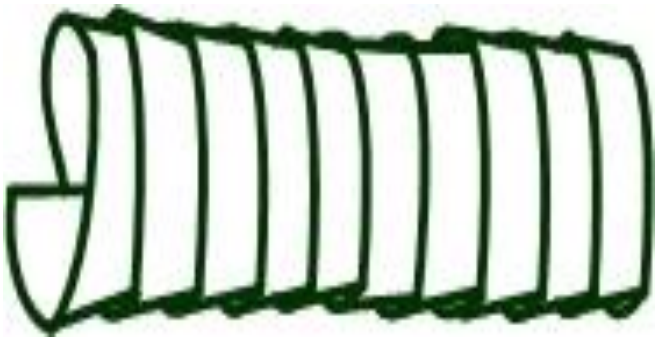


Figure 23: (a) Stop bands showing negative refractive index region



(b) A chiral metamaterial prepared with insulated strip of metal wound in a form of overlapping helix.[38]

Re-drawn from "Pendry, J. B. (2004). A chiral route to negative refraction. *Science, 306*(5700), (1353-1355)."

b) Zhang et al.[35] proposed metamaterial made up of gold that show chiral nature and at terahertz frequency range work as NIM. Due to strong chirality, right circularly polarized light (RCP) and left circularly polarized light (LCP) show different refractive indices. The system acts as a chiral resonator with the inductor formed by the loop and capacitor formed between two metal strips (Figure 24). When an electromagnetic wave falls on this chiral metamaterial, cross coupling takes place between the electric and magnetic dipoles in the same direction. It breaks degeneracy between two circularly polarized waves and refractive index is increased for one circular polarization and decreased for the other.

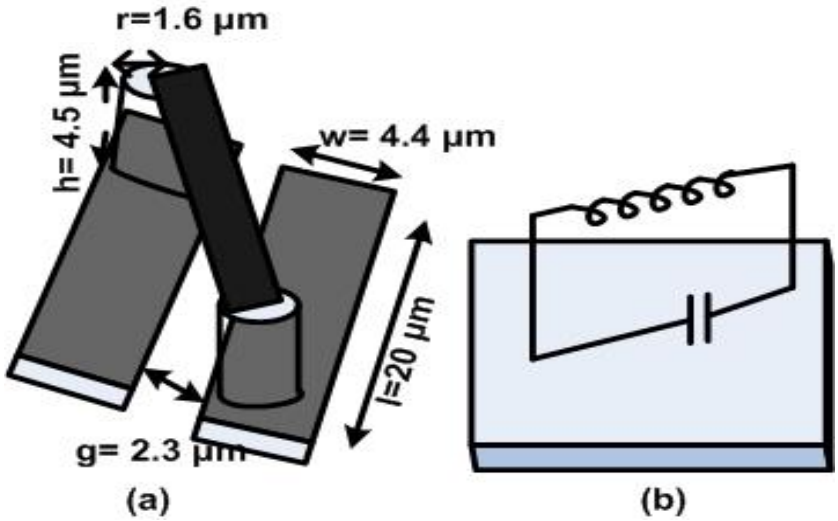


Figure 24: Schematic of chiral metamaterial prepared by Zhang. Two vertical metallic Cylinders of height 4.5µm and radius 1.6µm on two 4.4µm bottom strips of thickness. 6 µm that are spaced at 2.3µm. One strip of thickness. 3µm is bridged on top of the vertical cylinders. The bottom strip makes an angle of 29.25˚with the top strip.[35]

Re-drawn from " Zhang, S., Park, Y. S., Li, J.,Lu, X., Zhang, W. & Zhang, X. (2009). Negative refractive index in chiral metamaterials., *Phys. Review Letters, 102*(2),023901(1–4)."

The material is characterized by terahertz time domain spectroscopy and time domain simulation software. Chiral metamaterial is placed between two polarizers kept either parallel or perpendicular to each other and transmission spectra for RCP and LCP are recorded. Both measured and simulation data showed that LCP had strong amplitude and phase modulation while RCP showed less modulation. Large modulation helps LCP to achieve (-5) negative refractive index and less modulation for RCP and it remains positive for the entire frequency range. Here, chirality is enough to make it NIM with no requirement of negative permittivity (ε) and negative permeability (μ).

Future Directions

Present work will definitely help to understand Negative refractive index metamaterials and their specific properties and one can understand how they are different, compared to positive refractive index materials. Their difference makes them eligible to do tasks that are completely strange and lie in human imaginations. These practically realized metamaterials have changed the world in several aspects. Chiral metamaterials sustaining their own properties give an

alternate route to achieve negative refractive index with no requirement of negative permittivity and negative permeability.

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Glossary

Refractive Index-It is a parameter that indicates light bending ability of the medium.

Metamaterials-Meta means beyond. Materials that are artificially made in labs to manipulate light.

Negative refractive index metamaterial-A metamaterial whose refractive index is made negative artificially for a certain frequency range. It bends light in opposite direction in comparison to conventional materials.

Chiral metamaterial- Artificially structured materials that rotate the plane polarized light and lack mirror symmetry. Lack of mirror symmetry means the object and image are not exactly the same.

Polarizability- The term polarizability is defined as how easily the electron cloud of an atom or molecule is distorted to form an induced dipole.

Permittivity-It is a measure of an electric polarizability and ability of the material to transverse electric fields. When electric field is applied on an atom electrons are displaced from the nucleus. Due to this displacement, an electric dipole is produced within the atom. This dipole moment is directly proportional to electric field strength (E). Hence electric polarizability of an atom is the ratio of dipole moment to the electric field strength.

Permeability-It is a measure of magnetic polarizability and ability of the material to transverse magnetic lines. When magnetic field acts on an atom, the magnetic dipole moment is directly proportional to the magnetic field strength. Hence, magnetic polarizability is the ratio of magnetic dipole moment and magnetic field strength.

Polarized light – Light is an electromagnetic wave; whose electric field vectors vibrate in all planes perpendicular to the propagation direction. If electric field vector is confined to a single plane, it is termed as polarized light.

Optical rotation-The ability to rotate plane polarized light with certain angle. Rotation of plane polarized light can either be clockwise or anticlockwise

Circular Dichroism-The difference in absorption of left and right circularly polarized light. Also known as CD.

Plasma frequency-Plasmons have an equal concentration of positive and negative charges. In solids, positive charge is fixed in the core and free negatively charged electrons are present around it, balancing the equal concentration of positive and negative charges. When electromagnetic radiation falls on the material, electrons are displaced due to the photoelectric effect Once electrons are displaced, positive charges at the core exert an electrostatic attraction on the electrons and brings them back to equilibrium. As a reaction to this displacement, electrons start to oscillate with (ω_p)plasma frequency.

Evanescent waves-Evanescent waves carry subwavelength information of an object and decay exponentially in normal lenses.

Chiral nihility-Chiral nihility materials permittivity and permeability is zero and (κ) chiral parameter is non-zero for certain frequency range.

Viral Video Advertising on Social Media Networks

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Abstract

Social Media Marketing has transformed the way business organizations operate today. The fabric of consumer communication has changed with the emergence of two-way communications. The consumer is capable of liking, sharing, or co-creating the content. Good and indulging content finds its way to the hearts and minds of consumers. Due to access to the internet and smartphones, video virality is becoming the accessible and cost-effective mode of brand communication. Marketers are exploiting opportunities of creating content that is appealing and compulsive. This paper reviews available data on creative determinants positively impacting content engagement and sharing.

Keywords

viral marketing, creative determinants, Facebook, YouTube, viral video advertising

Introduction

The emergence of the internet has transformed the brand communication landscape. Internet's wide accessibility is a significant advantage. The consumer can send or receive a message with a larger audience without the constraint of distance and time. It makes digital communication a convenient means of transmitting information. On a social network, a virtual group or community offers opportunities to bring people from various backgrounds and allows them to find common grounds for their beliefs and interests.[1] In present times, with increased internet reach and the growth of social networking platforms, there is a shift in content consumption. The increased content consumption makes it difficult for marketers to engage customers.

The following sections explore social media and Web 2.0, internet and social media consumption in India and worldwide, and leading social networking platforms. The later part of the paper focuses on viral video advertising, social media engagement dynamics, viral video measurement, viral videos in India, and creative determinants that impact video virality.

Introduction to Social Media

Social Media Marketing is a type of internet marketing that exploit 'Social Networking Service tools' for marketing and deploys technique that aims at social sites to spread brand awareness to promote a product or services.[2] In recent times, social media platforms like Facebook, Instagram, and LinkedIn have transformed the communication landscape for organizations, brands, and individuals.[2] Social Media is also changing how people prefer to engage and interact with their social circles. With the emergence of social media, traditional groups and communities have been challenged as communities exist in the physical and virtual worlds that operate via the internet.[3]

Social media empowers consumers to talk, converse, provide feedback, and write a review following their observations and experiences. Consumer influences larger audiences by sharing a positive or negative review about a product or service. Marketers realized that social media users could effortlessly inquire and test the quality or price claims, find a substitute, and most importantly, review products or services and share their own experiences to large circles.[4] The social media platforms have changed the power structure in the business and marketplace; evidence indicates a significant power shift taking place and the surfacing of a new breed of sophisticated and powerful customers, hard to influence, convince and retain.[4] Social Media

enabled the customer to be more sophisticated and helped them develop new tricks in searching, evaluating, choosing, and buying services and goods.[5]

Social Media and Web 2.0

To communicate and advertise on social media, an organization must anticipate and organize a consumer-friendly eco-system. As stated by Constantinides, Effectively engaging the social media as part of the corporate marketing strategy requires company's Web 1.0 legacy is in good shape; the corporate web site must be in a position to serve as the corporate platform meeting the expectations of the online customer.[4] The majority of the social media marketing strategic objectives require a robust company website that is secure, functional, efficient, trustworthy, organizationally integrated, and customer-oriented.

Web 1.0 is a one-way communication medium that allows the organization to connect with relevant stakeholders. Still, it doesn't offer tools to stakeholders to engage or reciprocate with the firm. Web 2.0 is a two-way communication medium. Web 2.0 is the point where the concept of interaction and engagement took place. Web 2.0 offers new horizons for exchange and sharing systems, making it significantly easy to share texts, pictures, music, and other products in digital media.[6] As mentioned by Constantinides, Web 2.0 is a collection of interactive, open-source and user-controlled internet applications enhancing the experience, collaboration, knowledge and market power of the users as participants in business and social processes. Web 2.0 applications support the creation of informal users' networks facilitating the flow of ideas, information, knowledge and promote innovation and creativity by allowing the efficient generation, dissemination, sharing and editing of content.[4]

Web 2.0 opened up a range of new social media platforms to interact, influence, and engage consumers. Furthermore, with the express speed of E-commerce growth, organizations sighted a unique opportunity to alter consumer action towards products or services.

Access to Internet & Social Media

The growth of the internet is changing the way we observe and react to the world around us. The Internet is transforming the way we create, curate, and consume content. The growth of the internet is surpassing all other ways to reach a mass audience. As per the Hootsuite report:[7]

- 67% of the world population (5.155 billion out of a total population of 7.734 billion) is unique mobile users.
- 58% of the world population are internet users (4.479 billion)
- A total of 3.725 billion (48% of the total population) are active social media users
- 47% of Social Media users (out of a total of 48% of social media users in the world) own a mobile as a social media consumption medium (3.660 billion)

According to the Hootsuite 2019 India Report:[8]

- 1.190 Billion mobile subscriptions in India. Which is 87% of the total population.
- There is a gap between the number of mobile subscriptions and the number of people who use the internet. Out of 87% of mobile subscriptions, 41% (560.0 Million users) use the internet.
- A total 310 million (23% of the total population) are active social media users, and 21% of them prefer to use social media over mobile than any other device. 290 million (21% of the total population of India) have access to social media via mobile.
- India ranked first on absolute internet growth with 97,885,011 new internet users in 2018.

The cut-throat competition in the telecom industry pushed providers to offer cheaper data plans. Prime reasons for video consumption growth are affordable data plans and unlimited video streaming packages.[9] Indian users spend 2.4 hours on social media a day (slightly below the global average of 2.5 hours).[10]

Mobile is convenient and flexible compared to other sources like personal computers and laptops. The convenience of internet usage leads to an increase in video streaming. As per the Nokia Mobile Broadband Index 2019 report, video streaming accounts for 70-80% of total mobile data traffic on Mobile.[10]

The video streaming upsurge surpasses the rest of the mobile traffic mediums like browsing and social networking. A close look into the video streaming may reveal the specific websites/apps that hold significant traffic for video streaming. YouTube has traffic of 245 Million monthly active users in India, ahead of premium video streaming services like Hotstar (150 Million) and Jio TV (70 Million) combined.[9] The surge in internet usage reflects in the TRAI report. The Total Data usage of India is 80.000.00 Million GB in 2019.[11]

The growth of opportunity also infuses viral video consumption and viral video advertising. The following sections explore a literature review in this area.

Facebook and Youtube: Leading Social Networking Sites

54% of the world's population uses Facebook.[12] In India, 281 million people use Facebook, and it is expected to grow 58% and reach 444.2 million users by 2023.[13] The popularity of Facebook draws attention from the business. It has also encouraged various marketing initiatives to exploit the new platform.[1] Marketers have multiple reasons for not ignoring Facebook and YouTube in their marketing plan. Facebook delivers access to a global audience spread across vast demographic audiences available for targeted advertising.[14] Facebook is not just a sweet spot of marketing for large organizations. Many organizations tiny businesses review Facebook as an effortless way to develop marketing tools that help attract new customers and support them in interaction with existing customers.[1]

YouTube provides a platform for users to watch, rate, review, comment, share, and upload videos. The service is well-known for offering a space for individuals to create and share content with the world. These video contents include but are not limited to video shows, video clips, TV shows, music videos, news videos, educating videos, entertaining videos, movie trailers, live streams, and vlogging. YouTube ranked as second most used social network globally with 1900 million active users.[15] As per the livemint report, YouTube has 265 million monthly active users in India.[16] As per Alexa, YouTube is the 2nd most visited website of 2022.[17] On the other hand, YouTube is the 2nd most visited app of 2022.[18]

People engage with content on different levels and degrees. The following section deals with the engagement dynamics on social networking platforms.

Social Networking Sites: Engagement Dynamics

Organizations can interact and engage with the consumer on Facebook in various ways. What organizations share on Facebook is mainly dependent on their budgets and goals behind engagement on Facebook. Facebook permits the brands to engage with Facebook users in two different ways: The first is an organic way (free), which subsumes brand pages that users can like and share, and posts contain video or photos on the pages that allow for interaction and engagement of brand and TG.[14 19]

Organic Way (Free)	Paid Promotion
• Brands intend to post interesting and engaging posts. • The post does not necessarily promote the brand. • It may or may not involve organization/product/service information.	• Post sponsored by an entity. • Boosting posts or promotion pages, • Pay-per-click type of advertisement, • Carousel advertisement, • Click-to-site advertisements, • Plug-in or app and stories sponsored

Table: 1 - Facebook's User Engagement Model

The customer interested in the specific products or services expects regular communication from the respective brands. The engagement on Facebook yields tangible and intangible outcomes. A product or service sale is an actual outcome, while consumer awareness branding is an example of an intangible result. Facebook users can exhibit interest in a Facebook post or a Facebook brand page by liking it. The user can share a post from a brand page in their profile, which is termed a 'wall', which will show up on the newsfeed of the respective user.[14 20] The most significant advantage to the consumer is the 'ability to react'. The consumer can raise his voice about his feelings, thoughts, and experience toward the brand. The Facebook user can also use comment functionality to comment on a post. This functionality allows them to express their feeling and thoughts towards it to those who see the post. The user can redirect to the website or Facebook brand page.[20] The reach of a consumer's voice depends on his reach and social circles.

Viral Video Advertising

The enormous growth in video streaming is an opportunity for marketers in India. This consumption also points to platforms for consumer engagement. Marketers aim to create content that creates deep engagement with the viewer, making a video viral.

The viral-ability of the content is a crucial factor in ensuring engagement at a large scale. Peter and Golan suggested the following definition of viral video advertising - Viral video advertising is unpaid peer-to-peer communication of provocative content originating from and identified sponsor using the internet to persuade or influence an audience to pass along the content to others.[21] In the past few years, internet marketing strategy has shifted away from an emphasis on paid media, where a brand pays to advertise, to earned media. The customers themselves become the channel of delivery.[22] The broad scope of word-of-mouth in the social

network offers a geographic and timeless impact. It allows the customers/followers to influence the brands' image and change the perception of other consumers.[23] The viral quotient depends on the marketers' ability to stand out and engage the viewer in a meaningful or entertaining way.

There is uncertainty and a vague approach to viral marketing definition by scholars. They interchangeably use stealth marketing, buzz marketing, viral marketing, and viral advertising.[21] Porter and Golan observed that viral marketing is different from viral advertising.[21] While Viral Marketing refers to a comprehensive marketing strategy that may include several (viral) components, viral advertising refers to specific online advertising practices.[21] At the initial stage of the video release, marketers spend on promoting the video to ensure that a video reaches a broader audience. Although, spending on promotion has little effect on video virality. Primarily, the high video virality depends on consumer engagement and voluntarily shares with their social circle.

Viral Video Measurement

Marketers are investing time, money, and efforts to ensure the success of video advertising. The success of a video depends on factors like the number of views, likes, comments, and shares. The number of views on a video is a decisive criterion for video success. However, there is no unanimity regarding the different standards that define a video's success. As per the Feed report, Marketers still have not established a benchmark for success. Some 27.8% say a video must get more than one million views to be considered a success, but 22.2% would say so if it was viewed 100,000 times, 250,000 times, or 500,000 times.[24] Techcrunch, one of the well-known website & blog, considers videos to be a success when they have traveled on the internet and been shared on social media platforms like YouTube, Facebook, blogs, etc. in other words' videos with millions and millions of views.[25] As per Verticalrail.com, Some video data analysts argue the benchmark of 100,000 views, since 53% on YouTube videos have fewer than 500 views, with less than 1% having more than 1 million views.[26]

Viral Video Cases in India

Marketers are creating and distributing content that viewers pick up & share. There are viral video cases in India wherein the organization received views of millions on YouTube, indicating these videos' success.

Viral Videos in India as of 25th March 2021

Name of the video:	Hyundai | Celebrating 20 Years of Brilliant Moments | duty
Name of the brand:	Hyundai India
Published date:	17-Jul-18

The popularity of the video over leading Social media platforms

	YouTube	Facebook	Total
Link	https://youtu.be/cJ1kUHrhk0A	https://www.facebook.com/HyundaiIndia/videos/1773003189444098/	-
Duration of video	171	172	-
Number of shares	NA	209000	209000

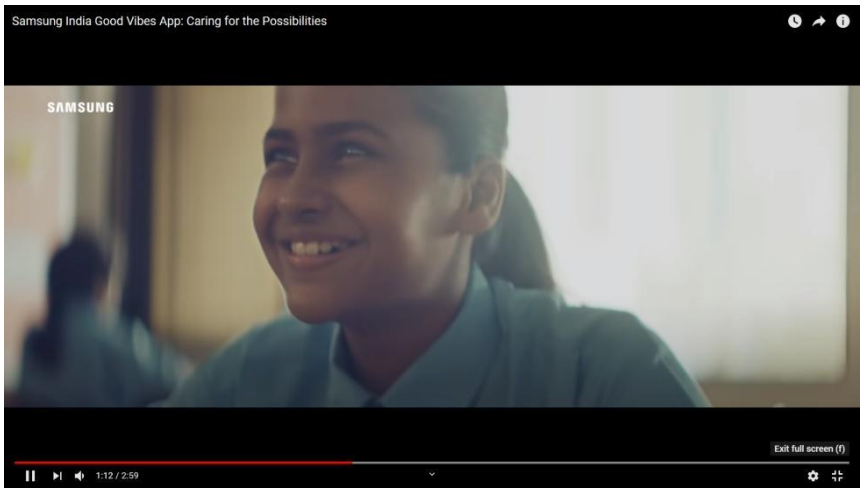
Number of comments on the video	7471	17000	24471
Number of likes	191000	384000	575000
Number of views	203,214,165	37000000	240,214,165
Comments on video uploading	-	-	-

Name of the video:	Samsung Bixby Voice Assistant-MND mother helps daughter with #VoiceForever
Name of the brand:	Samsung India
Published date:	13-Sep-18

The popularity of the video over leading Social media platforms

	YouTube	Facebook	Total
Link	https://youtu.be/5OhJ00an0mI	https://www.facebook.com/SamsungIndia/videos/301818797268218/	-
Duration of video	178	179	-
Number of shares	NA	180000	180000

Number of comments on the video	10281	20000	30281
Number of likes	155000	1400000	1555000
Number of views	201,515,465	99000000	300,515,465
Comments on video uploading	-	-	-



Name of the video:	Samsung India Good Vibes App: Caring for the Possibilities		
Name of the brand:	Samsung India		
Published date:	8-Sep-19		
The popularity of the video over leading Social media platforms			
	YouTube	Facebook	Total
Link	https://youtu.be/9djutxpXaQE	https://www.facebook.com/SamsungIndia/videos/1130343187173439/	-
Duration of video	180	180	-
Number of shares	NA	127000	127000

Number of comments on the video	3432	36000	39432
Number of likes	130000	1900000	2030000
Number of views	205,284,778	86000000	291,284,778
Comments on video uploading	-	-	-

The success of viral video advertising depends on multiple factors, including Creative determinants that positively affect viewing, liking, commenting, and sharing the video.

Creative Determinants Impact Video Virality

Many factors impact video virality. The researcher examined 32 factors during the literature review process. These factors are diverse and impact video virality on different levels and degrees. The researcher categorized these factors into six clusters based on the factor type.

The researcher reviewed literature published between 2004 to 2018. The literature covers topics like viral marketing, viral content on social media, creativity in advertising, YouTube viral content, global viral content, and a few.

The creative determinant is a term that refers to a bunch of creative factors that influence video consumption and virality. The researcher categorized the creative factors based on the nature and types of factors. This research paper divides these factors into six clusters - video as a whole unit, message factor, emotion, treatment factor, video attribute, and time factor.

1. Video as a whole unit: Some factors affect video virality to a large extent. These factors are macro factors for video virality, and their impact is profound and beyond the video creation/video tactics. These factors are:
    a. Emotional Tone: The emotional connection of the video plays a significant role in word of mouth. Emotional tone functions in a linear relationship with both attitudes and intentions. The choice to forward the video and attitude toward the ad/brand was most favorable with a positive emotional tone.[27]

The emotional appeal focuses on the texture of the emotion brought forwards to engage the customer in a meaningful way, including product or brands communication.

b. Human interest: An essential criterion of a viral video is the ability to connect with the audience. Very few videos hold a high degree of human interest factor. As per one of the studies, only one video, from the list of videos observed on three Facebook pages, possesses the human interest factor.[28]

2. Message Factors: The characteristics of the message are influential in viewer engagement. These factors are:
   a. Distinctiveness (originality) - The originality of the content inspires the viewer to pass on the content to their social circles. Amusing and interesting content can lead to sharing the video ad if it helps users make a statement of distinctiveness in social networks.[29]
   b. Encourage participation - Video inviting people to be a part of the more significant cause can go viral. Encourage participation is one of the ten commandments of the viral marketing technique for Indian marketers.[30]
   c. Fluency - It is the capacity to produce many ideas inside a specific - more than expectations.[31]A large number of views provide an option to extend the campaign for the desired outcome for a long time.
   d. Arousal Response: Video content with high arousal (degree of sensory alertness due to positive or negative emotion) tends to go viral.[32]
   e. Flexibility: The capacity to produce diverse ideas. The capability to move from one kind of theme to another. Illogical ideas or unpredictable.[31]
   f. Use universal language: Communication that emphasizes compelling visuals or non-verbal communication generates greater attention from the viewer.[30]
   g. Unusual perspective: content that breaks the stereotype or invites people to view the situation and circumstances differently yields more views and virality.

3. Emotion: There are very few creative determinants as effective as emotion for viral video advertising. Major emotional appeals are:

a. Altruism[29]: when brands aim to generate a video that refers to the topic with a social cause, it invites viewers to pass on a good message in their social circles.
b. Enjoyment[33]: Positive content or endearing content can hold the customer engagement in a meaningful way for a longer duration. Viewers would like to indulge in a video that weaves a story of enjoyment.
c. Humor (laughter)[31]: Here, laughter is an emotional appeal / a mood or state that the viewer is induced into when seeing the content. Humor appeal is one of the positive emotional appeals a human being wants to indulge into.
d. Affiliation[29]: The emotional appeal of being associated with some entity also increase engagement. The association can be towards the county, religion, caste, gender, etc.

4. Treatment factor: The creative process differs from person to person. The creative journey of the video depends on the creative person involved in the process. How does the creative person craft the video, and what kind of response does it evoke? It depends on the treatment factors of the video. The primary treatment factors comprise but are not limited to:
    a. Generate curiosity[30]: The craft of the video impacts the viewers' mindset. Content that generates curiosity and holds suspense can gain customer liking and sharing.
    b. Involvement[33]: The process of content creation that immerses the viewer. It involves imagination, ease of access or use of the product, etc.
    c. Narration[28]: The way the message is delivered to the audience is the art of story narration. The art of narrating and editing the content is also decisive for video engagement.
    d. Poetry[28]: The lyrical form of communication is a way to gain more viewing across social media networks.
    e. Satire in content[28]: The use of irony, criticism or the act of ridicule is also a way to gain eyeballs for the video.
    f. Richness and colorfulness of imagery[31]: The colors and rich image retain the attention and increase the video engagement. When the cinematography is good, it creates a visual appeal for the video.

5. Video Attributes: Video attributes are the characteristics of the video which make it engaging and inspire the viewer to forward the video to social circles. These attributes are

    a. Dramatic effect[28]: The exaggeration of the act, task, or situation also helps in virality - the more engaging drama in the content, the more engagement for the video.

    b. Elaboration[31]: Ensuring the right amount of explanation of the video also helps the viewer gain knowledge about the video and forward in social circles.

    c. Fantasy[31]: Fantasy refers to the out-of-the-world and unimaginable non-real situation that helps surprise the audience and engage the customer.

    d. Element of irony[34]: Content that contradicts societal expectations and creates tragedy out of the situation.

    e. Element of surprise[34]: The viewer likes the content that surprises him in unexpected ways. Surprise brings novelty to the video.

    f. Music quality[34]: The background score, the lyrics, and the music play a crucial role in stimulating emotions in the consumer's mind.

    g. Celebrity[28]: Brand endorsement pushes the video for viewing and circulation among celebrity fans.

    h. Credibility[28]: A known face can also bring authenticity and credibility to the associated brands, which helps gain more mileage.

6. Time: Time refers to video duration and day and time selection for broadcasting. A few of the most important factors are

    a. Peak day prediction[35]/proper timing[30]: A right time posting of content is essential for video engagement. For example, patriotic content on independence day gains more viewing and sharing than on a regular day.

b. Time duration[35]/runtime[36]/short duration[30]: The duration of the content is crucial. Considerable time duration can make the content less exciting, and the short video can lead to less information delivery to the viewer.

Some factors fall outside the categories mentioned in the above 6 clusters. These factors are Popularity of the uploader[35], Synthesis[31], Non-Socialness[35], Socialness[37], Title length[34], Resistance to premature closure[31].

The observance of creative determinants in the top three viral videos is presented below.

Creative Determinants Observed in the Top Three Viral Videos

	FACTOR	VIDEO 1	VIDEO 2	VIDEO 3
1. Video as a whole unit				
a.	Emotional Tone	Hyundai video used 'patriotism' as an emotional anchor to engage the customer in the video.	This video is a story of a 'mother-daughter relationship' inspired by a real-life event. It refers to the concept of how Samsung helps patients with MND. The love (emotion) between mother and daughter is the video's central theme.	This video features a 'vibe' mobile application for the deaf and dumb. The video presents emotional content and showcases parents' hardship with a specially-abled child.
b.	Human interest	Patriotism is a broader subject that connects and inspire people from diverse background.	The mother and daughter relationship is very core to each human being and it generates interest in the content.	Featuring specially-abled child in the video, generate interest and engagement in the video.
2. Message Factors				

a.	Distinctiveness (Originality)	The story refers to the help a common help can render to the Indian army.	The idea is that technology can help people connect with their loved ones even after their death.	Mobile can help specially-abled people to connect with their loved ones.
b.	Encourage participation	The video encourages people to share similar stories with Hyundai Santro.	NA	NA
c.	Fluency	NA	NA	NA
d.	Arousal Response	NA	NA	NA
e.	Flexibility	NA	NA	NA
f.	Use universal language	The topic 'Indian army' has the potential to reach a larger audience because of the nature of the topic.	The mother-daughter relationship is universal, and everyone can correlate with this relationship.	Content having a story of 'mother-daughter relationship' and specially-abled child is making is more appealing to a larger audience.
g.	Unusual perspective	NA	Technology helps a minor age girl to preserve her mother's memories.	Technology helps a specially-abled child and her family face challenging times.
3. Emotion				
a.	Altruism	An ordinary person selflessly helps a soldier reach his destination.	NA	NA
b.	Enjoyment	NA	NA	NA
c.	Humour (laughter)	NA	NA	NA
d.	Affiliation	NA	NA	NA
4. Treatment factor				

a.	Generate curiosity	The story unfolds in various layers, and each time the viewer is curious about how the story is unfolding.	In this video, the story is narrated to build curiosity about the 'voice of mother' and how technology is helping the daughter save her mother's voice and memories.	The life of the disabled's family is narrated so that it builds curiosity about the condition and solution a brand offers for that problem.
b.	Involvement	NA	NA	NA
c.	Narration	The story is narrated in first-person, sharing his Kargil experience with fellow soldiers. The narration makes it more engaging.	The voice-over and mix of music & dialogue are instrumental in creating a solid narrative.	
d.	Poetry	NA	NA	NA
e.	Satire in content	NA	NA	NA
f.	Richness, and colorfulness of imagery	The video is video recorded in the mountains. The long shots in more expansive scenery make it colorful and rich.	NA	NA
5. Video Attributes				
a.	Dramatic effect	The presentation of a soldier's life and the adversary involved in it dramatize with the help of cinematography and music	The musical dialogue and emotional appeal enhance the drama in the video.	The video increases the drama with the help of high pitch music with the presentation of extreme emotional appeal.
b.	Elaboration	NA	NA	NA
c.	Fantasy	NA	NA	NA
d.	Element of irony	NA	NA	NA

e.	Element of surprise	NA	This video presents the aid and tools that help MND patients and their families. The innovation itself is a surprise element.	The video refers to the challenges of deaf and dumb and also introduces a new technology that helps especially abled people to converse with their loved ones. This new technology itself is a surprise for people.
f.	Music quality	The musical song in the background enhances the impact of the video.	The combination of music and dialogue deepens the emotional appeal and connection towards the audience.	The video has high pitch music that helps the brand to weave an extremely emotional story.
g.	Celebrity	A Bollywood actor Atul Kulkarni is cast in the role of soldier for the video.	NA	NA
h.	Credibility	NA	NA	NA
6. Time				
a.	Peak day prediction	NA	NA	NA
b.	Time duration /Runtime/Short duration	NA	NA	NA

7. Other Observation

	-	~ Along with the rich storytelling, the brand also invites Hyundai Santro owners to share their memorable stories with them and win exciting prices. ~ The story has been talking about 20 years earlier event. And the car has been showcased in that era.	~ The emotional connection of the video is powerful. ~ The role of music is very prime in the video. ~ approx. three minutes of video, still the engagement is very high because	~ The video posted in the third quarter of 2019. Which makes it relatively new compared to other viral videos. It also implies that the video might generate virality momentum in the future. ~ The central tone of the communication

		In a way, the brand wants to establish its 20 years of emotional association with the consumers. ~ Instead of talking about the feature of the product, the brand prefers to tell a story engagingly. ~ The brand intentionally keeps the brand mention very low in the communication to give more weightage to the idea of the story. ~ The video duration is relatively longer (172 seconds) than other videos on the list. However, still, it manages to engage the viewer & retain the top rank because of the universally appealing idea of duty towards the nation.	of the broad appeal of the plot. ~ It has been mentioned in the end part of the video that it has been inspired by the life of Ms. Sonal, a patient suffering from Motor Neuron Disease (MND). MND patients lose their ability to move & speak. In a way, this brings the brand's love and care for the consumer.	is 'Samsung helps the deaf dumb live a better life. ~ The communication revolves around the high emotional content of sorrow and grief experienced by the family of deaf dumb and how Samsung brought the solution. ~ The role of music is very prime in communicating the emotional content to the consumer.

Data in the above table indicates that various creative determinants influence a video to a different degree. In the three videos reviewed, emotional appeal is strongly present, with a unique concept that surprises and engages the customer - the storyline is developed in a way that builds curiosity for the video. The video topic is universal and appeals to a larger audience. The drama orchestrated with compelling music also plays a crucial role in video impact.

Few creative determinants have a moderate impact on three videos, i.e., human interest, encourage participation, unusual perspective, altruism, narration, richness and colorfulness of imagery and celebrity.

A bunch of creative determinants has less or no influence on three videos: fluency, arousal response, flexibility, enjoyment, humor, affiliation, involvement, poetry, satire in content, elaboration, fantasy, element of irony, credibility, peak day prediction, time duration/runtime/short duration.

Limitations of the Research

This research is limited to papers and data available on web analytics platforms. The paper focuses only on the secondary data and analysis of three videos based on the creative determinants observed during the study. Further primary research in this area may help explore these factors in detail and identify other factors over and above mentioned in this paper. Future research could focus on the optimum combination of these variables that generate word-of-mouth amongst the consumer/viewer base.

Conclusion

In an era of digital communications, it is critical to evaluate consumer communication tools and techniques. Brands aim to create content that churns high reach and effectiveness with optimum cost. Therefore, brands need to identify and appreciate creative variables that cause virality. This study attempts to review these variables based on the existing research in this area and segregate them into six clusters, i.e., Message Factors, video as a whole, emotion, treatment factors, video attributes, time, etc. There is scope for future researchers to explore the patterns of optimum combination of variables that yield maximum viewing with limited resource

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