ADVANCES IN BASIC SCIENCES FOR ENGINEERING

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MESSAGE FROM THE ADMINISTRATOR

ST. Joseph's College of Engineering and Technology is leading the way and setting the standards in the field of engineering education. The department of Science & Humanities is playing a vital role in making our institution a benchmark.

I am very happy to note that a book on Advances in Basic Sciences for Engineering is published by our college with the contribution of faculty of Science and Humanities. I hope this attempt will be the stepping stone in our march towards excellence.

On behalf of management, I congratulate the subject experts for their contribution to publish this book. I am sure that the team has done a good job and it will be well received by the research aspirants. May this be the splendid initiative of a new chapter. May the Almighty bless all your endeavors to flourish further to attain our academic goals.

Sr.P.Maria Alangaram, DMI
Administrator

MESSAGE FROM THE PRINCIPAL

St.Joseph's College of Engineering and Technology takes immense pride in its consistent commitment for high quality education and research. As a part of this journey, the Institute has brought a book on Advances in Basic Sciences for Engineering. I hope that it enables us to hone the potential of our staff and students, in our march towards excellence.

In the spirit of sharing the knowledge, faculties of Mathematics, Physics and Chemistry have joined hands to write the chapters to explore areas in which research can be carried out. This will be an opportunity for researchers and students to have an idea about recent findings, technology and innovations.

I appreciate the department of Science & Humanities for taking this initiative to bring the current advancements in various fields of science under one roof. Thanks are due to Dr.R.Ambrose Prabhu, RIT, Chennai for being acted as one of the editor. May this be the start of a glorious new chapter and ignite our young minds.

Dr.I.Neethi Manickam
Principal

Chapter 1

A LEARNING ON GENIAL GROUPING AND HARMONIOUS GROUPING IN GRAPH THEORY

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Abstract

In this article, the author introduces a class of cycle related called 'One vertex association of substitute shells with a way at any normal level' and it is shown that the graph is elegant, heartfelt and concedes an - β valuation, which will help to classify the which are smooth and harmonious.

Keywords: cycle related, harmonious graph, smooth graph

Introduction

Around the middle of the 1960s, there was a lot of interest in graph groups thanks to Ringel's (1964) hypothesis and Rosa's (1967) work. The well-known Ringel-Kotzig (1964, 1965) hypothesis, which holds that all trees are smooth, is still disrupted. Throughout his excellent paper, Rosa (1967) introduced a method for deteriorating entire charts: valuation, valuation, and other groupings. The -valuation was subsequently termed smooth naming by Golomb (1972) and at the moment, this is the term that is most commonly used. Sloane & Graham (1980) presented agreeable naming regarding their concentrate on added substance bases issue coming from blunder remedying codes. Agile naming and agreeable marking are the two fundamental naming which were broadly contemplated. Varieties of agile and agreeable groupings to be specific, - valuation, exquisite marking also, and welcoming naming have been presented with various inspirations in the field of chart naming.

Over the time of forty years, in excess of 700papers have surfaced regarding this topic. This demonstrates the field's rapid progress. In any case, the crucial comprehension with the portrayal of smooth & additional named graph gives off an impression of being one of the most troublesome and difficult issues in graph hypothesis. Acknowledgment of the least difficult marked chart, specifically, truth be told cheerful graph, is a NP-complete

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issue, allude Kirchherr (1993). Because of this intrinsic challenges of these groupings, numerous mathematicians have shown interest in giving important circumstances and different adequate circumstances on marked graph wanting to work on the comprehension of the trademark characteristics of the marked graph. However the region of the graph marking fundamentally bargains with hypothetical review, Furthermore, research on graph groups has been conducted in applied disciplines for a considerable amount of time. Noticing that is fascinating the named graph act as helpful models for an expansive scope of utilizations for example, coding hypothesis, X-beam crystallography, radar, stargazing, circuit plan also, correspondence network address(allude Golomb (1972), Bermond (1979), and Bloom and Golomb (1997)).

A graph G grouping (valuation) is a label assignment f from the a set of positive integers to a set of the graph G's vertices that induce a label for every single edge uv determined by the labels f (u) & f (v). In the area of graph groupings, the 2fundamental groupings that were examined were harmonious & smooth grouping.

Definition 1.1.1. The function f is referred to as a smooth grouping of an m-edge graph G, if f is an injection from a set of G's vertices to the set 0,1,2,...,m such that when each edge uv is assigned the label f (u) f (v) then different edge labels are obtained as a result. Smooth graph refers to a graph that allows for smooth grouping.

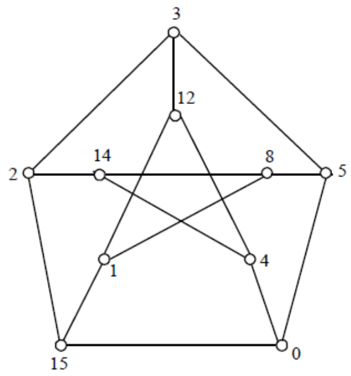

Figure 1.1: Smooth Grouping of Petersen graph

Graham and Sloane (1980) presented harmonious grouping in relation to their error correcting coding study.

Definition 1.1.2. A function f is termed as harmonious grouping of a graph G with m edges, if f is an injection from the set of vertices of G to the group of integers modulo m,

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In order for once every single edge uv is put the label(mod m)f (v)f (u) then unique edge labels are obtained. harmonic graphs are those that allow for harmonic grouping.

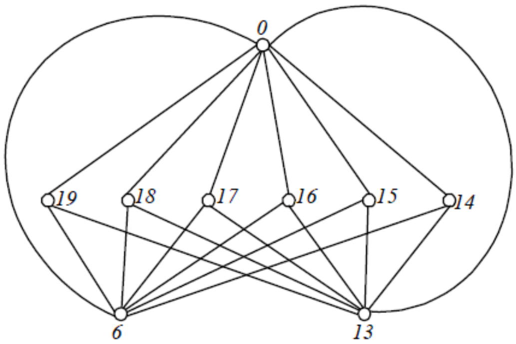

Figure 1.2: Harmonious Grouping of K1, 6, 2

Over the period varieties of the effortless and agreeable groupings were presented with various inspirations. β- valuation is a more grounded form of effortless naming, which was presented by Rosa (1967) in the paper where the effortless naming was first characterized.

Definition 1.1.3. A smooth grouping f of a G graph is known as a graph G -valuation, if there be present an integer like,f (u)f (v)(or)f (v)f (u), for each edge uvE(G) , where the valuation's width is denoted by the integer. Note that a graph that acknowledges β -valuation is necessarily a bipartite graph. Chang (1981) introduced elegant grouping as a variation of harmonious grouping.

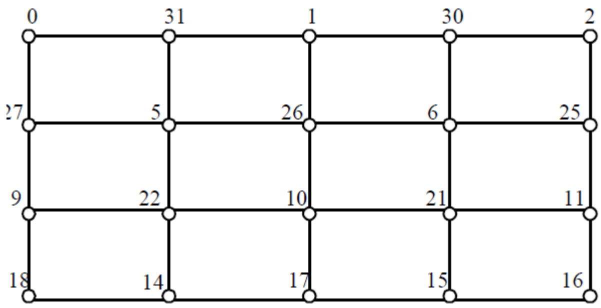

Figure 1.3: β – valuation of P4 x P5

Definition 1.1.4. Elegant graphs are those with m edges in graph G, If an injection foccurs, V (G) 0,1,2,...,m in a way that every single edge's uv assign the label f (u) f (v) (mod m 1) then distinct & non-zero edge labels are the outcome.

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Though the elegant grouping is a slight variation of harmonious grouping, there are graphs which are harmonious but not elegant and vice versa. For example, the cycle 4k 1 C is harmonious but not elegant for k 1.

On the other hand, the cycle 4k C is elegant but not harmonious for k 1, refer Graham and Sloane (1980) and Chang et al. (1981).

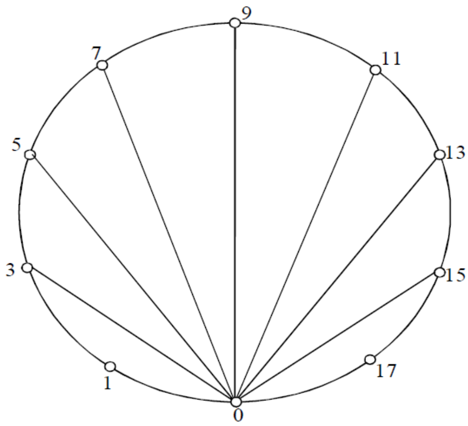

Figure 1.4: Elegant Grouping of C10 with 7 chords

It is quite amazing that many intriguing mathematicians have developed bigger agile graphs or other named graphs from specific natural graphs by utilizing different chart activities. Development and Join activities are utilized broadly to such marked graphs.

A latest dynamic survey of graph grouping by Gallian (2005) listed about six hundreds of papers dealing with various graph groupings. Numerous families of graphs are proved to be smooth / harmonious / elegant / cordial and also some of the families are proved to be non-smooth / non-harmonious. But there is no characteristic results on such labeled graphs are achieved. The following observations by Rosa give some general understanding about smooth graphs. Rosa has resolute basically 3insights the reasons behind a graph's failure to be smooth.

2.0 Main Results

It is shown that the graph $G(2n_{j,}n_j - 2, k, l_c)$, 1vertex union ofk alternate shells $C(2n_{j,}\ n_j - 2)$ using a path P_{2K-1} at whatever standard level l with chords is smooth and admits an β -valuation, for $n_j \geq 3$, $1 \leq j \leq k, k \geq 1$ and the graph G(2n, n 2, k, l) is cordial, for n ≥ 3.

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Algorithm 2.1

Stage 1: Let G be a 3-colorable chart.

Stage 2: Allocate 3 tones to a vertex and the entirety of its neighbors if the level of this vertex is bigger than $\sqrt{n}$.

Step 3: There are all things considered $\sqrt{n}$ such vertices and thusly so far at most $3\sqrt{n}$ tones were utilized.

Stage 4: Now, every one of the degrees in the diagram are not exactly $\sqrt{n}$.

Stage 5 : The eager calculation needs all things considered $\sqrt{n}$ tones to shading the rest of the chart.

Step 6: All together, the calculation utilizes $O(\sqrt{n})$ colors.

On the off chance that all precluded vertices are shaded with a similar shading, then, at that point all things considered $2\sqrt{n}+1$ shadings are utilized prior to applying the eager calculation. Consequently, the calculation utilizes about $3\sqrt{n}$ tones.

The degree arrangement of a diagram is limited, non-diminishing grouping of non-negative numbers whose aggregate is even. Conversely, any non-diminishing, positive succession of numbers whose total is even is the degree grouping of some chart.

A hindrance to k-chromaticity (or k-block) is a subgraph that forces each chart that contains it to have chromatic number more noteworthy than k. The complete diagram $K_{(k+1)}$ is a deterrent to k-chromaticity.

Theorem 2.1. $\chi(G) \leq \max(1\leq I \leq n)\ \min\ \{d_i + 1, i\}$.

Proof. The information request for greedy is $(v_1,v_2...v_n)$

When shading v_i at most $I - 1$ tones are utilized by its neighbors since greedy has hued just $I - 1$ vertices. When shading v_i at most d_i colors are utilized by its neighbors in light of the fact that the level of v_i is d_i.

The info request for greedyis $(v_1,v_2...v_n)$

When shading v_i at most d_i' colors are utilized by its neighbors.

A marginal improvement to the greedy algorithm.

An associated non-clique G can be hued with Δ colors where $\Delta\geq 3$ is the most extreme degree in G.

By induction principle, implying the calculation.

Leave v alone a discretionary vertex with degree d(v).

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Let $G' = G \setminus \{v\}$:

On the off chance that G' isn't an inner circle or a cycle, shading it recursively with Δ colors. If G' is a coterie, then, at that point a K_Δ graph can be colored with Δ colors. G' can't be a $K_{\Delta+1}$) diagram sincethen the neighbors of v would have degree $\Delta + 1$.If G' is a cycle, then, at that point it ought to be hued with $3 \leq \Delta$ colors.If $d(v) \leq \Delta-1$, then, at that point shading v with a free tone (categorize argument).If v has 2 neighbors hued with a similar shading, then, at that point color v with a free tone (categorize argument). From presently on accept that $d(v) = \Delta$ and that each neighbour of v is hued with an alternate tone.

Remark 2.1 In 1999, Irwing and Manlove [16] presented the idea of b-chromatic number. A b-shading of a chart G is a legitimate vertex shading of G such that each shading class contains a vertex that has something like one neighbor in each and every other shading class and b-chromatic number of a diagram G is the biggest number $\varphi(G)$ for which Ghas a b-shading with $\varphi(G)$ colors. A vertex of shading that has any remaining tones in its area is called shading overwhelming vertex. The invariant $\varphi(G)$ has the chromatic number $\chi(G)$ as an inconsequential lower bound, however the contrast between the two of them can be subjective enormous [16]. A unimportant upper destined for $\varphi(G)$ is $\Delta(G) + 1$.

Theorem 2.2. For any $n \geq 3$, $\varphi[P_n \circ_{(n-1)} K_1] = n$.

Proof. Leave P_n alone a way diagram of length n-1. That is, $V(P_n) = \{ v_1, v_2, v_3 \ldots v_n\}$ and $E(P_n) = \{e_1, e_2, e_3 .. e_{n-1}\}$. By the meaning of crown item, connect (n-1) duplicates of K_1 to every vertex of P_n. That is, $V[Pn \circ (n\text{-}1) K_1] = \{v_i/1 \leq I \leq n\}$ $\{v_{ij}/1 \leq I \leq n, 1 \leq j \leq n\text{-}1\}$.

$E\ [Pn \circ (n\text{-}1) K_1] = \{e_i/1 \leq I \leq n\text{-}1\}$ $\{e_{ij}/1 \leq I \leq n, 1 \leq j \leq n\text{-}1\}$.

Consider the shading class $C= \{c_{1,} c_2, c_{3,\ldots} c_n \}$.

Allocate the shading c_i to vertex v_i for i =1,2,3… n and relegate the shading cn+1 to v_{ij} for i= 1, 2… n and j =1, 2, 3… n-1.

Every v_i is contiguous with v_i-1 and v_i+1 for $2 \leq I \leq n\text{-}1$, v_1 is neighboring with v_2 and v_n is adjoining with v_{n-1} , because of this non-nearness condition v_i for $1 \leq I \leq n$ doesn't understands its own shading, which doesn't deliver abdominal muscle chromatic shading.

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Hence we make the shading as b-chromatic, allot the shading to v_{ij}'s as per the following.

For $1 \leq I \leq n$, allocate the color c_i to v_i.

For $I = 1, 2, 3\dots n_{,\ j} = 1, 2, 3\dots n-1$, allocate the shading c_{i+j} to v_{ij} when $I + j \leq n$ and appoint the shading $c_{\ i+j-n}$. At the point when $I + j > n$. Presently the vertices v_i for $I = 1,2,3...n$ understands its own shading which creates a b-chromatic shading. Hence forth by shading strategy referenced above said shading is maximal and b-chromatic.

Remark 2.2. In 1736, Leonhard Euler composed a paper on the Seven Bridges of Konigsberg which is viewed as the primary paper throughout the entire existence of chart hypothesis. Chart hypothesis is a significant apparatus in numerical exploration. A diagram is a theoretical numerical construction shaped by a bunch of vertices and edges joining sets of those vertices. Graphs can be utilized to display the associations between objects, for example, a PC organization can be demonstrated as a chart with every worker addressed by a vertex and the associations between those workers addressed by edges [2,3,11,27].

Theorem 2.3. For the line graph Km,n, $\varphi[L(K_m,n)] = \text{Max}\{m,n\}$ for each $m, n \geq 2$.

Proof. Let Km,n be the total bi-partit graph with bipartition (X,Y) where $X = \{v_1,v_2,v_3..vm\}$ and $Y=\{u_1,u_2,u_3..un\}$. Consider the line diagram of Km,n That is,L (Km,n). Let v_{ij} be the edge between the vertex v_i and u_j for i=1,2,3..m, j=1,2,3..n That is,v_i u_j = $\{v_{ij}: 1 \leq I \leq m, 1 \leq j \leq n\}$. By the meaning of the line diagram, edges in Km,ncorresponds to the vertices in L(Km,n)

That is,V [L(Km,n)] = $\{v_{ij}: 1 \leq I \leq m,\ 1 \leq j \leq n\}$. Note that for every I, we say that $<v_{ij} : j = 1, 2, 3\dots n>$is a total diagram of request n. Likewise we say for every j, <v ij : i= 1,2,3..m >forms a total diagram of request m. Obviously the quantity of clubs in $L(K_{m,n})$ is m+n.

Case 1: when $m < n$

By perception in $L(K_{m,n})$, we have |Kn|>|Km|. Consider the shading class $C=\{c_1,c_2,c_3..cn\}$. Presently allot an appropriate shading to the vertices as follows. First allocate the shadings to the vertices v_{ij} $(1 \leq I \leq m, :1 \leq j\leq n)$ as follows.

Here $<v_{mj}$: j=1,2,3..n >for m=1 structures a total chart of request n. Appoint c_j to v_{1j}

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for j=1,2,3..n, which creates a b-chromatic shading. Assume in the event that we allocate any new shading to the excess completegraph <v_{ij}: i= 2 ,3...n, j=1 ,2, 3... n >, it negates the meaning of b-chromatic shading in light of the fact that the leftover complete diagrams doesn't understand the new shading. Therefore to make the shading as b-chromatic one, relegate the shading as follows.

Appoint the shading c_i to the vertex $v_{ij}$when j=1 ,i= 1,2,3..m and allocate cjto v_{ij}'swhen i=1, j=1,2,3..n. Next for i=2..3..m and j=2,3… n, appoint the shading C_{i+j-1} to v_{ij}'s when i+j $\leq$ n+1 and relegate $C_{i+j-(n+1)}$ when i+j> n+1. Presently all the n vertices understand its own shading, which delivers a b-chromatic shading. Along these lines by the shading strategy the above said shading is most extreme and b-chromatic.

Case 2: when m > n

In $L(K_{m,n})$ we have |Km|>|Kn|. Consider the shading class C={c_1,c_2,c_3..c_n}. Presently allocate an appropriate shading to the vertices v_{ij} (1 $\leq$ I $\leq$ m, 1 $\leq$ j $\leq$ n)as follows.

Here <v_{ni}: i=1,2,3..m>for n=1 structures a total diagram of request n. Appoint cit o vi1for i=1,2,3..m, which creates a b-chromatic shading. Assume on the off chance that we dole out any new shading to the excess complete chart < v_{ij} : i= 2, 3,… m, j = 1, 2, 3...n >,it repudiates the meaning of b-chromatic shading. Therefore to make the shading as b-chromatic one, assignsthe shading to the vertices as follows.

Allot the shading cito v_{ij} when j=1,i=1,2… m and dole out shading c_j to vij'swhen i=1, j=1,2,3..n. Next for i=2,3… ..m and j=2, 3… … n, relegate C_{i+j-1} to vijwhen i+j $\leq$ m+1 and allocate C_{i+j}-(m+1)when i+j> m+1. Here all m vertices understand its own shading, which delivers a b-chromaticcolouring. Hence by the shading system the above said shading is greatest and b-chromatic.Therefore $\varphi[L(K_{m,n})]$ = m.

From all the above cases, $\varphi[L(K_{m,n})]$ = Max{m,n}.

Primary properties of line diagram of complete bipartite graph

Number of vertices in $L(K_{m,n})$ =m+n.

Number of edges in $L(K_{m,n})$ = mn/2 (n+m-2).

Greatest degree of $L(K_{m,n})$ is Δ =m+n-2.

Least degree of $L(K_{m,n})$ is δ =m+n-2.

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End product:

Each line chart of $K_{m,n}$ is a m+n-2 ordinary diagram.

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Chapter 2

Mathematical Tools for Researchers

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Introduction

Mathematics is the foundation of engineering, especially providing the basic concepts for many principles and applications of electronics engineering are built. Electronics engineers will give more interest to a strong grasp of certain mathematical concepts is not just beneficial but essential. They will get a good success in the key areas of mathematics which is a technical dive ,explores the integral to achievements in the field of electronics engineering.

Industries are changed in every aspect by digital transformation. In engineering field , the digital transformation can be used in the strategic integration and digital technologies of traditional practices and processes .The Industries are safe for all aspects by using digital transformation. It can be used in the collaborative culture , empowerment and team work in any workplace.

Probability and Random Variables

Statistical methods are essential for experiments design and data interpretation. Data are collected from various resources for real life problems. Now we can introduce a model in which the variable represents the outcome of a random experiment in probability function. This model gives a widespread applications which will specifically used in traffic flow analyzation, prediction of fault in electric cables , accidents occurring randomly .

Basic concepts
Random Variable:

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A random variable is defined as a function from the set of sample points S into the set of real number R. The random variable denoted by alphabets X,Y… and any particular value of the random variable by x or y.

Discrete Random Variable:

A random variable X can takes a countably infinite number of values or finite number of values is said to be discrete random variable.

Example: Number of patients arriving in a hospital at a finite interval of time.

Continuous Random Variable:

A random variable X can takes all the values in an interval is called a continuous random variable. i.e. infinite number of values can be taken by the random variable X

Example: The operating time between two failures of a machine .

Mathematical Tools

1. Binomial Distribution

The survey from households for Calculating a TRP of a Television channel, whether they watch(YES) the particular channel or not (NO).

The commodity estimation in The manufacturing of raw material for used and unused for estimation of commodity . In these type of situations , the Binomial distribution can be used.

If the random variable X which is discrete, can take the values x = 0, 1, 2,…n, such that

$$P(X = x) = nC_x p^x q^{n-x}, \text{ where } \quad p + q = 1,$$

then X follows a binomial distribution where n and p are parameters. This distribution can be denoted by B(n, p).

2. Poisson Distribution

Poisson distribution is one of the another statistical tool which is used to solve a set of problems which cannot be solved by the binomial distribution. When a single event occurring a given number of times in an interval of (usually) time then the Poisson distribution model is used . The event occurrence must be determined by chance alone and any one event cannot be

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used to predict the occurrence of any other event. In this situation the occurrence of an event can be calculated but the non-occurrence cannot be taken into account.

The Poisson distribution has applied in many situations say email messages arriving at a computer, no of defects occurring when a product is manufacturing etc.

Poisson distribution: Probability Function

A discrete random variable X which can take the values x = 0, 1, 2, 3…. such that $P(X = x) = p(x) = \frac{e^{-\lambda}\lambda^x}{x!}, \quad x = 0,1,2,3,....,\infty$ then X follows a Poisson distribution with parameter λ.

Numerical Illustration:

The manufacturer of an Integrated chips knows that 5% of his product is defective items. If the chips are selled by him, the boxes of 100 and guarantees that not more than 10 chips will be defective. What is the probability that a box will fail to meet the guaranteed quality?.

Let us assume that X be the R.V denoting the no. of defective chips.

Given n=100, p=5% = 5/100=0.05

$\therefore$ Mean $= \lambda =$ n x p $=$ 100 x 0.05 $=$ 5

The probability function of Poisson distribution is, $P(X = x) = \frac{e^{-\lambda}\lambda^x}{x!} = \frac{e^{-5}5^x}{x!}$

P(a box will fail to meet the guaranteed quality) $= P(X > 10)$

$$= 1 - P(X \le 10)$$

$$= 1 - [P(X = 0) + P(X = 1) + P(X = 2) + ... + P(x = 10)]$$

$$= 1 - \left[\frac{e^{-5}5^0}{0!} + \frac{e^{-5}5^1}{1!} + \frac{e^{-5}5^2}{2} + \frac{e^{-5}5^3}{6} + \frac{e^{-5}5^4}{24} + \frac{e^{-5}5^5}{120} + \frac{e^{-5}5^6}{720} + \right.$$

$$\left. \frac{e^{-5}5^7}{5040} + \frac{e^{-5}5^8}{40320} + \frac{e^{-5}5^9}{362880} + \frac{e^{-5}5^{10}}{3628800} \right]$$

$$= 1 - e^{-5}[1 + 5 + 12.5 + 20.8333 + 26.0417 + 26.0417 + 21.7014 + 15.5010 +$$

$$9.6881 + 5.3823 + 2.6911]$$

$$= 1 - e^{-5}[146.36] = 1 - 0.9863 = 0.014$$

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3. Poisson process

Suppose the random events occur throughout an interval and the interval can be divided into finite number of subintervals in which the intervals are so small has the following assumptions :

(i) The probability value of more than one event in the subinterval will be zero.

(ii) In any subinterval, the probability value of one event occurring is proportional to the Subinterval length.

(iii) An event occurring in any one subinterval is independent of any other subinterval then the random experiment is known as a Poisson process.

If the average number of events occurring in the interval (not subinterval) is λ (> 0) then the random variable X representing the actual number of events happened in the given interval is said to follows a Poisson distribution and it can be shown (we omit the derivation) that

$$P(X(t)=n)=e^{-\lambda t}\frac{(\lambda t)^{n}}{n!}, \quad n=0,1,2,....$$

Numerical Illustration:

Suppose it has been observed that, on average, 180 bikes per hour pass a specified stop on a certain road in the morning rush hour. Due to impending road works it is estimated that congestion will occur closer to the city centre if more than5 bikes pass the point in any one minute. What is the probability of congestion occurring?

For this problems we cannot use the binomial model because we cannot have the values of n and p. Essentially we are saying that there is no fixed number (n) of bikes passing the specified point , we cannot calculate the value of p. We are given the average rate at which bikes pass the specified point is 180 per hour.

Let X be the random variable X = number of bikes arriving in any minute. We need to calculate the probability that more than 5 bikes arrive in any one minute. Note that in order to do this we need to convert the information given on the bikes arriving per hour (average rate) into a bikes arriving per minute (value for λ).

This gives the value $\lambda = \frac{180}{60} = 3$ => $\lambda = 3$

Using $\lambda = 3$ to calculate the required probabilities gives:

r	0	1	2	3	4	5	sum
P(X = r)	0.0498	0.1494	0.2240	0.2240	0.1680	0.1008	0.9160

To calculate the required probability we note that

P(more than 5 bikes arrive in one minute) = 1 − P(5 bikes or less arrive in one minute)

Thus $P(X > 5) = 1 - P(X \leq 5)$

$$= 1 - [P(X = 0) + P(X = 1) + P(X = 2) + P(X = 3) + P(X = 4) + P(X = 5)]$$

Then P(more than 5) = 1 − 0.9160 = 0.0840= 0.0840 (4 d.p).

4 Markov Process and Discrete Parameter Markov Chain

Markov Process:

The random process {X (t)} is said to follows a Markov process if

$$P[X(t_n) = a_n / X(t_{n-1}) = a_{n-1}, X(t_{n-2}) = a_{n-2}, ...X(t_2) = a_2, X(t_1) = a_1]$$
$$= P[X(t_n) = a_n / X(t_{n-1}) = a_{n-1}]$$

for all $t_1 \leq t_2 \leq ..... \leq t_n$.

The future behavior depends on the present value but not on the past, then the process is called a Markov process.

Homogeneous Markov Chain:

If the transition probability of one-step does not depend on the step

i.e. $P_{ij}(n-1, n) = P_{ij}(m-1, m)$, the Markov Chain is called homogeneous Markov chain.

Transition Probability Matrix (t.p.m.):

The matrix $P = (p_{ij})$ satisfying the conditions (i) $P_{ij} \geq 0$ (ii) $\Sigma P_{ij} = 1$ is called the transition probability matrix .

Numerical Illustration 1:

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In a Markov chain $\{X_n\}$, n = 1,2,3… … having 3 states 1, 2 and 3, the transition probability matrix is

$$P = \begin{bmatrix} 0.1 & 0.5 & 0.4 \\ 0.6 & 0.2 & 0.2 \\ 0.3 & 0.4 & 0.3 \end{bmatrix} \text{ and the initial distribution is } P^{(0)} = (0.7, 0.2, 0.1)$$

Find (i) $P(X_2 = 3)$, (ii) $P(X_3 = 2, X_2 = 3, X_1 = 3, X_0 = 2)$

Solution:

The given tpm is $P = \begin{bmatrix} 0.1 & 0.5 & 0.4 \\ 0.6 & 0.2 & 0.2 \\ 0.3 & 0.4 & 0.3 \end{bmatrix}$

$$P^{(2)} = P^2 = \begin{bmatrix} 0.1 & 0.5 & 0.4 \\ 0.6 & 0.2 & 0.2 \\ 0.3 & 0.4 & 0.3 \end{bmatrix} \begin{bmatrix} 0.1 & 0.5 & 0.4 \\ 0.6 & 0.2 & 0.2 \\ 0.3 & 0.4 & 0.3 \end{bmatrix} = \begin{bmatrix} 0.43 & 0.31 & 0.26 \\ 0.24 & 0.42 & 0.34 \\ 0.36 & 0.35 & 0.29 \end{bmatrix}$$

Given that $P[X_0 = 1] = 0.7;\ P[X_0 = 2] = 0.2, P[X_0 = 3] = 0.1$

(i) $P[X_2 = 3] = \sum_{i=1}^{3} P[X_2 = 3 / X_0 = i].P[X_0 = i]$

$= P[X_2 = 3 / X_0 = 1].P[X_0 = 1] + P[X_2 = 3 / X_0 = 2].P[X_0 = 2] + P[X_2 = 3 / X_0 = 3].P[X_0 = 3]$

$= P_{13}^{(2)} P[X_0 = 1] + P_{23}^{(2)} P[X_0 = 2] + P_{33}^{(3)} P[X_0 = 3]$

= (0.26)(0.7)+(0.34)(0.2)+(0.29)(0.1)=0.182+0.068+0.029=0.279

(ii)

$P[X_3 = 2, X_2 = 3, X_1 = 3, X_0 = 2] = P[X_3 = 2 / X_2 = 3].P[X_2 = 3 / X_1 = 3]P[X_1 = 3 / X_0 = 2].P[X_0 = 2]$

$= P_{32}^{(1)}.P_{33}^{(1)} P_{23}^{(1)}.P[X_0 = 2]$

$= (0.4)(0.3)(0.2)(0.2)$

$= 0.0048$

Numerical Illustration 2:

A man either drives a car or catches a train to goes his office every day. He never goes 2 days successively in a row by train but if he drives first day, then the next day he is just as likely to drive again as he is to travel by train. Now suppose that on the first day of the week, the man is tossed a fair die and drove to work if and only if 6 appeared.

Find

(i) The probability that third day he takes a train .

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(ii) The probability that in a long run he drives to work.

Since the mode of transport of next day is decided on the basis of today, the travel pattern is a Markov chain where the states are T (train) and C (car).

The t.p.m. is

$$\text{State of } X_{n-1} \begin{array}{c} \\ T \\ C \end{array} \overset{\begin{array}{c}\text{State of Xn}\\ T \quad\; C\end{array}}{\begin{bmatrix} 0 & 1 \\ \frac{1}{2} & \frac{1}{2} \end{bmatrix}} = P$$

If the first day he goes by train, next day he will not go by train

$\therefore P(T \to T) = 0, P(T \to C) = 1, P(C \to T) = \frac{1}{2}, P(C \to C) = \frac{1}{2}$

The probability distribution of initial state is obtained by throwing a die.

$$P(goin\ by\ car) = P(6) = \frac{1}{6} \qquad P(goin\ by\ train) = P(6) = 1 - \frac{1}{6} = \frac{5}{6}$$

The first day state distribution is $P^{(1)} = \begin{bmatrix} \frac{5}{6} & \frac{1}{6} \end{bmatrix}$

The state probability of second day is $P^{(2)} = P^{(1)}P = \begin{bmatrix} \frac{5}{6} & \frac{1}{6} \end{bmatrix}$

$$= \begin{bmatrix} \frac{5}{6} & \frac{1}{6} \end{bmatrix} \begin{bmatrix} 0 & 1 \\ \frac{1}{2} & \frac{1}{2} \end{bmatrix} = \begin{bmatrix} \frac{1}{12} & \frac{11}{12} \end{bmatrix}$$

Third day state probability $P^{(3)} = P^{(2)}.P = \begin{bmatrix} \frac{1}{12} & \frac{11}{12} \end{bmatrix} \begin{bmatrix} 0 & 1 \\ \frac{1}{2} & \frac{1}{2} \end{bmatrix} = \begin{bmatrix} \frac{11}{24} & \frac{13}{24} \end{bmatrix}$

P(he travels by train on the third day)= $\frac{11}{24}$. $= \frac{11}{24}$

(ii) Let $\pi = [\pi_1 \ \ \pi_2]$ be the limiting form of long run probability distribution.

The known condition is that $\pi p = \pi \Rightarrow [\pi_1 \quad \pi_2] \begin{bmatrix} 0 & 1 \\ \frac{1}{2} & \frac{1}{2} \end{bmatrix} = [\pi_1 \quad \pi_2]\ where\ \pi_1 + \pi_2 = 1$

$$[o + \frac{\pi_2}{2} \quad \pi_1 + \frac{\pi_2}{2}] = [\pi_1 \quad \pi_2] \Rightarrow \frac{\pi_2}{2} = \pi_1$$

$$\Rightarrow \frac{1 - \pi_1}{2} = \pi_1 \Rightarrow 1 - \pi_1 = 2\pi_1 \Rightarrow \pi_1 = \frac{1}{3}$$

Put $\pi_1 = \frac{1}{3}$ in $\pi_1 + \pi_2 = 1$ $\Rightarrow \frac{1}{3} + \pi_2 = 1 \Rightarrow \pi_2 = \frac{2}{3}$

P(driving in the long run)=2/3.

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5. Transformation of Two Dimensional Random Variable

Changes in the measurement scale of a variable is a mathematical operation which is called Transformation. This is usually done by a particular statistical test or method. Most of the statistical methods require data that follows a certain kind of distribution, especiallty a normal distribution. The transformation of data is the application of a deterministic mathematical function to each point in a data set say z_i is replaced with the transformed value $y_i=f(z_i)$, where f is a function.

Engineers can use cutting-edge technologies like computer-aided design (CAD), simulation software, and advanced analytics they can apply the transformation method.

Numerical Illustration :

Suppose the Probability Density Function of x and as $f(x,y)=\begin{cases}\frac{1}{2}xe^{-y}, 0<x<2, y>0\\ 0, \quad \text{elsewhere}\end{cases}$

Now find the distribution of X+Y.

Solution

Transformation u=x+y and v=y

Which gives x=u-v and y=v

$$J=\begin{vmatrix}\frac{\partial x}{\partial u} & \frac{\partial x}{\partial v}\\ \frac{\partial y}{\partial u} & \frac{\partial y}{\partial v}\end{vmatrix}=\begin{vmatrix}1 & -1\\ 0 & 1\end{vmatrix}=1$$

The region $0<x<2, y>0$ transforms into 0<u-v<2 and v>0,

The joint probability density function of U and V is given by

$$g(u,v)=\frac{1}{2}(u-v)e^{-v}, 0<v<u, u>0$$

The density function of U=X+Y is obtained by splitting the range of U into two parts.

For 0<u<2, the density of U is

$$h(u)=\int_0^u g(u,v)dv=\frac{1}{2}\int_0^u (u-v)e^{-v}dv \quad =\frac{1}{2}(u+e^{-u}-1)$$

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For 0<u<2, the density of U is $h(u)=\int_{u-2}^{u} g(u,v)dv=\frac{1}{2}\int_{u-2}^{u}(u-v)e^{-v}dv$

Hence $g(u)=\begin{cases}\frac{1}{2}(e^{-u}+u+1), 0<u<2\\ \frac{1}{2}(e^{-u}+e^{2-u}), 2<u<\infty\\ 0, \quad \text{elsewhere}\end{cases}$

6. Recurrence Relation

The basic methods cannot be used in solving some of the Counting problems. It is necessary to apply some advanced counting techniques such as recurrence relations and generating functions. The recurrence relations and generating functions are used to solve some complex counting problems. These powerful problem solving techniques are frequently used in discrete mathematics and computer science.

Recurrence Relation [Or] Difference Equation

Let $\{a_n\}$ be a sequence of real numbers with a_n as the n^{th} term.

A recurrence relation of the sequence $\{a_n\}$ is an equation that expresses a_n in terms of one or more of the earlier terms $a_0, a_1, a_2 \ldots .. a_{n-1}$ for all integers 'n' with $n \geq n_0$ where n_0 is a non-negative integer. A solution of a recurrence relation is sequence whose terms satisfy the relation with the initial condition.

Generating function method :

The generating functions provide a powerful tool in discrete mathematics to study many properties of sequences for proving combinatorial identities for solving recurrence relations etc.

Definition: Generating function method

The generating function of the sequence $a_0, a_1, a_2, \ldots\ldots, a_n \ldots..$ of real numbers is the infinite series $G(x) = a_0+a_1x+a_2x^2+ \ldots\ldots +a_nx^n +\ldots\ldots\ldots = \sum_{n=0}^{\infty} a_n x^n$

$G(x) = a_0+a_1x+a_2x^2+ \ldots +a_n x^n$ is called the generating function for the finite sequence $a_0, a_1, \ldots, a_n$.

Procedure for solving recurrence relations using Generating functions:

Step 1: Rewrite the given recurrence relation as an equation with 0 on RHS.

Step 2: Multiply the equation obtained in step1 by x^n and summing it from

0 to ∞ (or) 1 to ∞ (or) 2 to ∞.

Step 3: put G(x) = $\sum_{n=0}^{\infty} a_n x^n$

Step 4: Decompose G(x) in to partial fractions.

Step 5: Express G(x) as a sum of familiar series.

Step 6: Express a_n as the coefficient of x^n in G(x).

Numerical Illustration: Solve $a_n = 4a_{n-1}$, $n \geq 1$, $a_0 = 2$ by generating function method.

Solution: Let the Generating function of $\{a_n)$ be

$G(x) = \sum_{n=0}^{\infty} a_n x^n = a_0 + a_1 x + a_2 x^2 + \ldots\ldots\ldots\ldots..$

Given recurrence relation $a_n = 4a_{n-1}$

Multiply above recurrence relation by x^n and Summing from 1 to ∞

$$\sum_{n=1}^{\infty} a_n x^n = 4\sum_{n=1}^{\infty} a_{n-1} x^n$$

$$\sum_{n=1}^{\infty} a_n x^n = 4\sum_{n=1}^{\infty} a_{n-1} x^{n-1+1}$$

$$\sum_{n=1}^{\infty} a_n x^n = 4x\sum_{n=1}^{\infty} a_{n-1} x^{n-1}$$

$$[\sum_{n=1}^{\infty} a_n x^n + a_0 - a_0] = 4x\sum_{n=1}^{\infty} a_{n-1} x^{n-1}$$

$G(x) - a_0 = 4x\,[G(x)]$

$G(x) - 4xG(x) = a_0$ [Given $a_0 = 2$]

$(1-4x)\, G(x) = 2$

$G(x) = \frac{2}{1-4x} = 2(1-4x)^{-1}$

$= 2\,[\,1 + 4x + 4^2x^2 + \ldots\ldots + 4^n x^n + \ldots\ldots]$

$a_0 + a_1 x + a_2 x^2 + \ldots\ldots + a_n x^n + \ldots\ldots = 2 + 2(4x) + 2(4^2x^2) + \ldots\ldots\ldots + 2(4^n x^n) + ..$

$\therefore\ a_n$ = Coefficent of x^n is $2 + 2(4x) + 2(4^2x^2) + \ldots\ldots\ldots + 2(4^n x^n) + ..$

$\therefore\ a_n = 2.4^{n,}\ n \geq 0.$

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Summary and Conclusion:

A strong acceptance and understanding of these mathematical concepts is a powerful tool in the electronics engineering field of any aspiring electronics engineer. , these mathematical skills form the backbone of electronic circuit analysis, design, and troubleshooting. The application of mathematics in electronics engineering, making continuous learning and application of these concepts essential for success in this dynamic field as technology evolves. In science and engineering, the "counting principle," also known as the "fundamental counting principle" or "multiplication principle," is a mathematical concept used to calculate the total number of possible outcomes when multiple independent events occur together, essentially by multiplying the number of options available for each individual event. In computer engineering field, the recurrence relations find various applications, especially in analyzing and solving problems related to algorithms, signal processing, control systems, and computational complexity. In engineering field ,mathematics acts as a fundamental tool used to model, analyze, and solve real world problems by providing a precise language to represent physical phenomena.

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Chapter 5

Emerging Techniques in Non-linear Optics (NLO)

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1.1 Introduction to NLO

Nonlinear optics is a science that happens when laser beams interact with materials. This began when lasers were invented in the early 1960s. Every day, this field is growing and becoming more important because it helps in creating new light-based technologies. Nonlinear optics is crucial for many uses, like processing information with light, making super-fast computers, creating very quick switches, producing short laser pulses, making sensors, and boosting laser power, among other things. This special review book on Nonlinear Optics and Applications is made for people who want to learn about the latest technology. It covers recent progress in how nonlinear optics are used. The book focuses on new devices and materials, switching technology, light-based computing, and important experimental findings. It also talks about recent developments that interest researchers and could be useful in creating all-light communication and computing technologies.

Nonlinear optics is like a magical way light behaves when a very strong light shines on certain special materials. Normally, light acts in a predictable way, but in nonlinear optics, it does all sorts of cool and unusual things. For example, it can create new colors of light or change how light bends. When powerful laser beams hit atoms and molecules, they can make light that has a much higher frequency than the original light. This means the new light flashes much faster. Occasionally, it may provide illumination at a rate that is hundreds or even thousands of times faster! High-order harmonics generation (HHG) is the term used to describe this specific method. The new light oscillates at a frequency that is either doubled (second-harmonic generation, or SHG) or tripled (third-harmonic generation, or THG). This serves as a fundamental illustration of this phenomenon. The primary application of HHG is to modify the color of laser light to a shortened wavelength, which is advantageous for a variety of scientific and technological applications.

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1.2 NLO materials in day-to-day lifestyle

After fifty years of development, the laser is now employed in many commonplace tasks. The field of nonlinear optics (NLO) is almost as new as lasers, having just been around for a year. Compared to "Applications of Lasers," which has 18 x 106 webpages, "Applications of Nonlinear Optics" has 5% more (106 vs. 18 x 106). According to Web of Knowledge, the numbers for refereed papers are rather similar at 4%. That nonlinear optics is just 5% as influential as lasers on daily life is one possible reading of this. Despite its underappreciation, nonlinear optics is essential to a number of laser applications, as this paper will show.

Numerous scientists, especially those working in the field, acknowledge NLO's impact on research; the organization has helped bestow nine Nobel Prizes in Chemistry and Physics. In order to generate THz radiation, NLO events have been seen at wavelengths ranging from the deep infrared to the extreme ultraviolet. Occurring in organic substances, polymers, liquid crystals, semiconductors, amorphous materials, gasses, and plasmas are optical nonlinearities.

Nonlinear optics first expanded the usability of lasers via applications such as second harmonic generation, Q-switching, and mode-locking. The negative consequences of nonlinear optics in glass were first shown via fiber optic communications. Ultra-fine resolution spectroscopy was made possible by narrow-line lasers. As of right now, NLO has a number of promising potential future uses, including but not limited to quantum optics, quantum computers, ultra-cold atoms, plasma physics, and particle accelerators.

Although it would have been a massive undertaking, this chapter just addresses the applications that impact daily life. The author has reviewed nonlinear optics (NLO) and its uses, such as harmonic generation, frequency mixing, and optical parametric oscillators, and has looked into $\chi 2$ nonlinearities in this context. Optical bistability, spatial solitons, nonlinear waveguides and interfaces, phase conjugation, photorefractivity, mode-locking, wave-mixing, and self-phase modulation are all effects of the $\chi 3$ nonlinear refractive index. A wide variety of applications fall under the umbrella of nonlinear absorption, including optical limiting, Q-switching, multi-photon filament generation, saturable absorption, and many more. Most often, stimulated Raman and Brillouin scattering are examples of nonlinear optical scattering processes. From the wide variety of NLO effects that showed promise, only a small fraction have been economically implemented.

1.3 Outline for harmonic generations

- The process of second-harmonic generation (SHG), also known as frequency doubling, involves the destruction of two photons to produce a single photon with a frequency that is twice as high as its original value (half the wavelength).
- In third-harmonic generation (THG), three photons are destroyed to create one photon with a frequency three times that of the original light, resulting in a light with a frequency one-third that of the wavelength.
- The process of producing light with much higher frequencies than the original (usually 100 to 1000 times higher) is known as high-harmonic generation (HHG).
- The process of producing light at a frequency equal to the product of two other frequencies is known as sum-frequency generation (SFG); SHG is an example of this.
- The process of producing light at a frequency that is the product of two different frequencies is known as difference-frequency generation (DFG).
- An optical parametric amplifier (OPA) generates an idler wave (sometimes called a direct frequency gain, or DFG) while amplifying an input signal with a pump wave of higher frequency.
- A parametric amplifier in a resonator may generate a signal and an idler wave, a phenomenon known as optical parametric oscillation (OPO), even when no signal input is present.
- Similar to parametric oscillation, optical parametric generation (OPG) uses a very high gain in place of a resonator.
- When the signal and idler degenerate at a single frequency, a specific instance of OPO or OPG is half-harmonic generation.
- Amplification of vacuum fluctuations in the low-gain region, also known as spontaneous parametric down-conversion (SPDC).
- Creation of electric fields that are almost static, also known as optical rectification (OR).
- Nonlinear interaction between light and matter involving free electrons and plasmas.

1.4 Other nonlinear processes

- Optical Kerr effect, intensity-dependent refractive index.
- Self-focusing is an effect resulting from the spatial change in intensity that creates a spatial variation in the refractive index. This variation is induced by the optical Kerr effect and potentially higher-order nonlinearities.Kerr-lens modelocking (KLM) is a mode-locking laser technique that uses self-focusing.
- Self-phase modulation (SPM), an effect due to the optical Kerr effect (and possibly higher-order nonlinearities) caused by the temporal variation in the intensity creating a temporal variation in the refractive index.
- Optical solitons, an equilibrium solution for either an optical pulse (temporal soliton) or spatial mode (spatial soliton) that does not change during propagation due to a balance between dispersion and the Kerr effect (e.g. self-phase modulation for temporal and self-focusing for spatial solitons).
- Self-diffraction, splitting of beams in a multi-wave mixing process with potential energy transfer.
- Through the optical Kerr effect, one wavelength of light can influence the phase of another wavelength of light through cross-phase modulation (XPM).There are more nonlinearities that can lead to four-wave mixing (FWM).Cross-polarized wave creation (XPW) is the process of creating a wave that has a polarization vector perpendicular to the input wave.
- Modulational instability.
- Raman amplification
- Optical phase conjugation.
- Stimulated Brillouin scattering, interaction of photons with acoustic phonons
- Multi-photon absorption, simultaneous absorption of two or more photons, transferring the energy to a single electron.
- Multiple photoionisation, near-simultaneous removal of many bound electrons by one photon.
- Chaos in optical systems.

1.5 NLO for permanent changes in materials

Lasers may permanently alter materials (change their phase, remove or add material, etc.) by means of heat or NLO processes. The latter requires laser pulses that are short enough to reduce heat production, which is an important consideration. Although picosecond and femtosecond pulses have lately grown in popularity, nanosecond pulses have long been the standard.

A spark, or localized plasma, is created during the NLO process by ionization near the laser beam's focus, which often occurs by multi-photon absorption. Ablation is the process of material removal by vaporizing the target with plasma. It just takes one pulse to make a small hole in the sample, and further pulses may either make larger holes or cut lines that, as the sample moves, etch patterns into the surface. Computer control and continuous processing allow for very precise laser machining. A threshold for multi-photon ionization allows holes to be smaller than the diffraction limit. Therefore, multi-photon absorption is the nonlinear process upon which high-quality laser machining is based.
Plasma, which is created in laser machining by multi photon ionization, continues to absorb light and maintain its own energy until the pulse terminates. Once the multi photon ionization threshold is crossed, plasma absorption is not limited to any particular material; in fact, it may even work on reflective surfaces, removing their reflectivity.
One potentially useful byproduct of spark creation during ablation is the introduction of a surface shock wave. Shock waves may be useful in laser desorption, which involves removing surface-attached particles (like dust) with a laser.The semiconductor industry often employs thin film ablation for a variety of purposes, including the removal of conducting ITO electrodes from the margins of solar cells, the trimming of resistors, and the elimination of short circuits. Die cutting and marking, PCB drilling and structuring, and LED chip labeling are all examples of industrial uses for laser machining.
A technique that is comparable to e-beam or ion-beam sputtering but far less messy is multi photon ionization, which involves abrading material and then depositing it on a neighboring substrate to create its own thin layer. Nano-materials, thin dielectrics, oxides, nitrides, metals, and carbon-based compounds have all been deposited onto film using photo-ablation. The process of analyzing biological samples using multi-photon ionization will be detailed in a subsequent section.

Because certain material may splatter or splash out with ns pulses, creating a rough edge, ps and fs pulses have recently replaced ns in laser machining. Clean ablation and hole-digging are possible with ps or fs pulses. The thermal effects that lead to microcracks and molten debris are eliminated by the very short pulse duration. Even though common laser machining struggles with materials like glass, ceramics, and copper, this machine's high peak power makes short work of them. The semiconductor industry often employs thin film ablation for a variety of purposes, including the removal of conducting ITO electrodes from the margins of solar cells, the trimming of resistors, and the elimination of short circuits. Die cutting and marking, PCB drilling and structuring, and LED chip labeling are all examples of industrial uses for laser machining.

Micro-Electrical-Mechanical Structures (MEMS) in silicon and other ultra-fine structures may be produced by micromachining using fs pulses. Manufacturing medical devices is one way that laser micromachining impacts people's everyday lives. Because even minute variations in surface roughness, size, and form may influence the functionality of implants and surgical instruments, these products need sophisticated production procedures. Because they don't lose heat, ultrafast lasers can process almost any material with pinpoint precision and impeccable quality. Thanks to laser micromachining, a new line of coronary stents, catheters with finer processing, and bio-implants with surface textures are now available to patients. The precise removal of undesired material from microfabrication is achieved using computer-guided laser ablation. For materials having a wall thickness of 100μm, a fiber laser may produce a cut width of 15 μm. Presently, nano-structuring and sophisticated additive manufacturing are driving the development of new micro-machining applications.

1.5.1 NLO in telecommunications

This basic limit on the quantity of data that can be sent on a single optical fiber was quickly determined to be NLO upon introduction of fiber optic telecommunications. Increases in laser strength cause NLO to impose restrictions on data speeds, transmission lengths, and the simultaneous transmission of wavelengths. NLO first appeared in underwater installations, which had the longest fiber lengths. It is already common knowledge that NLO is an essential factor to consider when developing cutting-edge fiber optic networks. Important considerations for NLO arise after fundamental linear attenuation and dispersion have been addressed in transmission system design.

1.5.2 NLO in data storage

In most cases, ordinary interferometry follows a straight line. Thus, NLO would not be able to claim holography data storage as its own. At first, the holes were thermally produced and the compact disk masters were manufactured using an argon laser. There is no nonlinearity here, either. However, a somewhat more precise manufacturing method, most likely using multi-photon ionization micro fabrication technologies, is necessary to create the holes seen in modern high-resolution DVDs. To that end, NLO asserts that DVDs are affected. Data storage in three dimensions (as opposed to the two dimensions of CDs) could be where NLO's influence is felt in the future. There have been no commercially viable efforts to store data using lithium niobate's photo-refractive characteristic. Even though they need cryogenic temperatures, other non-local optical technologies, including spectral hole burning, are being investigated for the storing of three-dimensional digital data. Although several companies are working on the technology, it is not yet accessible to the public.

The use of 3D video graphics has skyrocketed in the last several years. In the process of creating 3D images in real time, NLO seems to play a part. Researchers at the University of Arizona have shown that photorefractive polymer films may be used to capture three-dimensional holographic pictures via the use of a lateral field, nonlinear refractive index, and chromosphere absorption. In order to demonstrate telepresence, a holographic 3D display has been created using a novel doped-polymer material that can refresh pictures every two seconds. Telemedicine, advertising, entertainment, updatable 3D mapping, and prototyping are some of the suggested uses. However, these early-stage technologies likely won't make it into commercial markets for quite some time.

1.5.3 NLO sensors

There is no requirement for NLO in the majority of optical sensors (such as laser radar, intrusion detection, temperature sensors, etc.). Nonetheless, NLO might be relevant since optical fibers constitute the basis for many modern optical sensors. Raman fiber sensors are able to detect temperature, but Brillouin fiber sensors are sensitive to a wide range of variables. How many of these sensors make use of the nonlinear properties of the sensing material is a mystery. There seems to be an influx of nonlinear sensors onto the market, but details about these devices' technical specs are often kept under wraps. They may not put NLO to direct use, but they might incorporate it into their products. For instance, NLO is likely used to implement Bragg mirrors inscribed into the fiber, which is used by many sensors.

1.6 Applications of Nonlinear Optics

Telecom, industrial, sensors, manufacturing, healthcare, scientific equipment, and materials processing are just a few of the many areas where nonlinear optics is used, all of which have a major influence on people's day-to-day lives.

1.6.1 Telecommunications

Early on in the history of fiber optic telecommunications, the primary limit on data transmission rates across individual optical fibers was quickly determined to be nonlinear optics. As the strength of the laser increases, the distances and speeds that may be conveyed simultaneously are limited by nonlinear optics. Because of the very lengthy fibers used in underwater applications, the shortcomings of nonlinear optics were first discovered. The importance of nonlinear optics in the development of contemporary fiber optic systems, however, is well-known.

1.6.2 Analytical Tools

When assessing changes in materials, a combination of nonlinear optics and microscopy may be quite helpful. In vivo examination of biological processes and systems may be achieved at the microscopic level using confocal microscopy, for instance, whereas localized functionality and greater resolution pictures can be obtained with nonlinear optics.

1.6.3 Diversifying Lasers and Coherent Light

The use of nonlinear optics into the laser cavity opens the door to novel laser designs and their potential uses. This makes it possible to alter the color and time dependence of the laser beam. To change the output light's coherence, the nonlinear optics part may also be placed outside the laser chamber.

1.6.4 Optical Imaging

When it comes to drug evaluation, nonlinear optical imaging shows promise. It makes use of optical procedures such coherent anti-Stokes Raman scattering, two-photon excited fluorescence, second harmonic generation, and stimulated Raman scattering. Among the many advantages of these imaging methods are their chemical and solid-state specificity, their non-invasiveness, their high optical temporal and spatial resolution, and the fact that they do not need labeling or compatibility in aquatic or biological settings.

1.7 Research Areas in Nonlinear Optics

The simplicity of nonlinear optical systems makes them a great platform for exploring many general principles underlying nonlinear pattern generation.

1.7.1 Biophotonics

The study of how biological materials and light interact is known as biophotonics. When studying biological systems, nonlinear optics offers a number of benefits over linear optics. One example is the use of near-IR excitation, which enables intrinsic 3D optical sectioning and deeper tissue penetration with less photodamage than traditional methods. And by tapping into the inherent nonlinear optical sensitivities of certain proteins, we may achieve label-free biochemical contrast of live tissues.

1.7.2 Terahertz Photonics

Thanks to advancements in nonlinear optics, broadband single-cycle THz pulses may be produced using optical rectification, a major step toward terahertz (THz) technology.The development of powerful single-cycle THz pulses with peak electric fields higher than 107 V/m has been made possible by technological advancements in nonlinear optics and ultrafast lasers. These very brief electromagnetic pulses with a high THz electric field intensity provide a rare chance to study new nonlinear optical effects in the THz spectrum and ultrafast nonlinear processes in the domain of a single cycle.

1.7.3 Quantum Optics

One valuable technique for controlling and designing quantum network interconnects is nonlinear optics. Interconnects such as quantum frequency converters or entangled photon pairs allow nodes in a hybrid quantum network that operates at various wavelengths to communicate with one another. Nonlinear optical phenomena are the basis for these devices. In order to enhance current quantum computing and communication applications, scientists are combining quantum technology with nonlinear optics and integrated photonics to create new integrated quantum optical devices operating at telecommunication wavelengths.

1.7.4 Brillouin Scattering

Researchers in the field of nonlinear optics have been studying Brillouin scattering—a nonlinear optical phenomenon—since the field's inception. This has sped up the development of high-coherence sources, optical phase conjugation, rapid and slow light, microwave processing, and sensing.

1.8 Applications of NLO

1.8.1 NLO for pulsing lasers

In conventional laser cavities, a rod-shaped crystal and a nonlinear element are used to produce brief bursts of light by means of Q-switching or mode-locking in nonlinear optics. Miniature, sturdy diode-pumped microchip lasers with a nonlinear Q-switch are now available, allowing for efficient generation of the second harmonic in a phase-matched $\chi 2$ crystal with high instantaneous power.

1.8.2 Q-switching

The greatest pulse energies, generally measured in nanoseconds, are produced via Q-switching. Nonlinear absorption and/or nonlinear refractive index are the foundations of passive Q-switching. A straightforward and reliable method to achieve peak powers 106 times higher than CW lasers is provided by these nonlinear components. For example, Nd:YAG microchip lasers that are commercially available may produce pulses as brief as 100 ps when used with a semiconductor saturable absorbing mirror (SESAM), or pulses about 1 ns in length when used with a Cr2+:YAG saturable absorber. Extremely high pulse repetition rates—from 100 kHz all the way up to MHz—are possible with these NLO microchip Q-switch lasers. They produce peak powers in the kilowatt range with pulse energies in the microjoule range.

A rare earth doped diode-pumped fiber with a passive Q-switch in its cavity is another possible gain medium. With a pulse length of 400 ns and an average output power of 200 W, the Nd:doped fiber laser can produce pulses with energies of up to 10 mJ at 20 kHz, reaching a peak power of 20 kW.The 1.5-2 εm wavelength range contains high-power fiber lasers that are safe for human eyes. Using Cr-doped ZnSe as a Q-switch, fiber lasers operating at 1 μm, such as Er, Tm, or Ho, completely transform the performance and practicality of high power lasers.

1.8.3 Mode-locking

Depending on the bandwidth of the gain medium, locking all the longitudinal modes in a strongly multimode laser generates pulses that are much shorter, ranging from several to none at all. Saturable absorbers, when used with Nd-doped glass, may generate sub-ps pulses, while Nd:YAG can generate pulses of around 10 ps. This can be accomplished using NLO. An other nonlinear process for these lasers is Kerr-lens mode-locking; SESAMs generate fs pulses from Ti:sapphire lasers. Although it requires precise frequency regulation, active acousto-optic mode-lockers compete with passive NLO mode-locking.

1.8.4 Solitons

The soliton laser is another NLO-based commercial pulsed laser; it offers ultra-stable operation, such as excellent repeatability and clean, transform-limited pulses that do not need a pedestal. The crucial wavelength for telecommunications, 1.5 μm, is used by a fiber-based soliton laser that is both feasible and efficient.

1.8.5 Measuring femtosecond laser pulses

To build femtosecond lasers, it was essential to be able to characterize their pulses. Devices that quantify the phase and amplitude of fs pulses need NLO. Autocorrelation has been very useful for both the continuing characterisation of pulses and the development of fs technology. How much real-world overlap there is dictates how long the temporal pulse lasts. Using an NLO approach, the goal of pulse-overlap monitoring is to differentiate between basic interferometry, which measures spectral width, and actual pulse length. This is commonly accomplished using SHG. Without NLO, the whole field of ultra-fast optics would be severely hindered.

1.8.6 Spatial and frequency control of lasers

Laser beam clean-up using the NLO method of phase conjugation has been achieved, with spatial and frequency modes reduced. Through stimulated Brillouin scattering (SBS) inside a fiber, the Stokes light is retro-reflected, eliminating aberrations and being diffraction-limited. The pump laser is spatially and frequency-amped using SBS. We shall discuss SBS later on, but it limits the maximum power that can be sent over a single fiber and provides a coherent technique to combine several beams. Through the generation of a phase conjugate reflection, which retraces the original phase profile in a second pass through the amplifiers, SBS locks the phases from parallel amplifiers.

A very coherent light source is the Brillouin laser. An example is shown where the frequency noise and RIN are reduced by 20 dB when compared to the source of the narrow-linewidth Er-doped fiber laser pump. Active stabilization is necessary for stable operation in order to lock the frequency of the pump laser to the mode of the Brillouin cavity.

1.9 Conclusion

Commercial lasers, sensors, environmental monitoring, medical, manufacturing and materials processing, scientific instruments, the military, and telecommunications are just a few of the essential areas that benefit greatly from NLO, but it does have certain limits. When together, these applications greatly influence our everyday lives.
It may be argued that NLO has been most influential in promoting scientific progress. That would need at least another study, so we skipped over all the great scientific applications. The majority of the apps that were not covered in this article have not yet been released to the public. NLO has provided an endless supply of unrealized possibilities throughout the years. Optical signal processing is one such field where efforts have so far failed to produce desirable outcomes, but where quantum interference and computing seem to have promising prospects.

This chapter examines contemporary technical uses of nonlinear optics (NLO). NLO has enabled micromachining, provided high-resolution spectroscopy, new tools for materials characterization, high-capacity communications, and a variety of sophisticated lasers and coherent sources. If NLO didn't exist, we wouldn't have access to the internet's best fiber optic networks, state-of-the-art medical device technology, green laser pointers, air and water pollution monitoring, crucial analytical tools for medical diagnosis, material characterization, and more.

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Chapter 3

CORROSION CONTROL ON METALS WITH ECO-FRIENDLY GREEN INHIBITOR

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INTRODUCTION

Corrosion is the irreversible deterioration of a metal surface caused by chemical reactions that, in a corrosive environment, transform a pure metal into its more stable form, such as oxides, hydroxides, sulfides, etc. Any form of corrosive environment, such as a solid, liquid, or gas, is possible. Most people believe that corrosion is a universal phenomenon. Corrosion problems have become a major obstacle to the industry's use of metallic materials for scientific and engineering purposes over the years. The annual loss resulting from corrosion problems has been quite concerning, amounting to trillions of dollars. Reverse extractive metallurgy, or corrosion, is influenced by temperature, stress, erosion, and environmental concentrations. It produces significant economic losses for any country, ranging from 1% to 5% of GNP annually. Furthermore, rust is not only a factor in component costs but also a cause of fatalities and safety hazards.

Corrosion problems have become a major obstacle to the industry's use of metallic materials for scientific and industrial purposes over the years. The annual loss resulting from corrosion problems has been quite concerning, amounting to trillions of dollars. Recent years have seen an increase in interest in green corrosion inhibitors as an efficient and environmentally beneficial method. Plant extracts, prescription medications, ionic solutions, and synthetic inhibitors are a few popular sources of environmentally benign corrosion inhibitors. The wide variety of green corrosion inhibitors found in various acidic conditions are mostly derived from plants (i.e., extracts and oils) because of their adaptable physical, chemical, and biological characteristics.

For carbon steel, applying corrosion inhibitors is an affordable method of reducing corrosion. The creation and application of inexpensive, biodegradable, and ecologically friendly inhibitor compounds is receiving more attention. Numerous studies have assessed plant-based

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extracts utilizing a range of electrochemical processes and characterization approaches. While plant extracts seem like viable substitutes for commercially manufactured inhibitor formulations, a great deal of optimization is still needed. The effect of other synergistic combinations in commercial inhibitor formulations is not well-explained by most plant extract research studies.

FACTORS AFFECTING CORROSION

The most stable state of steel corrosion can be reached most quickly and easily. Both man-made and natural factors can lead to corrosion. The natural and inevitable loss of the desired product as a result of interaction with particular elements found in the environment is the general definition of metal corrosion. It has been established that corrosion poses a risk to both human health and the environment. Issues related to corrosion are currently being assessed from distribution of gas and oil to pipes carrying drinking water. It should be noted that most physical processes like evaporation, melting, or mechanical cracking are not included in the term corrosion; instead, corrosion reactions are primarily electrochemical in nature. In acidic and neutral/alkaline environments, two countermeasures that aid in the corrosion process are hydrogen generation and oxygen reduction. Many factors contribute to the corrosion of steel and alloys; pollutants, bacterial actions, acids and bases, moisture, temperature, surface areas, and oxygen concentrations are some of the most significant environmental factors.

CORROSION PROTECTION

The most significant factor in stopping corrosion is protective coatings. Numerous coatings, including paint, polymers, metallic coatings, and phosphating coatings, are employed in this context. However, in their use, metal parts corrode at every stage of the production cycle. Using a corrosion inhibitor is one of the easiest and most effective ways to stop steel from corroding, particularly in acidic environments. In the gas and oil business, synthetic organic compounds have proven to be effective corrosion inhibitors. However, because of their toxicity, damage to the environment, and increased concern for the preservation of ecosystems, their usage is currently limited and regulated. This has led to the current trend of looking for and creating inexpensive, non-toxic, biodegradable, and environmentally friendly green inhibitors. On the metal surface, the corrosion inhibitor creates a protective layer. A thin layer that has adsorbed on the metal surface prevents corrosion by keeping the metal apart from its surroundings. The effectiveness of green inhibitors in preventing steel

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corrosion has been documented by a number of researchers, especially in acidic settings. Nonetheless, a number of concerns regarding inhibitor composition, adsorption processes, and formulation remain unresolved in the context of using green inhibitors.

CORROSION INHIBITORS

The impact of corrosion and related issues on a nation's economy have garnered significant attention from manufacturers, traders, and consumers of metals and their alloys, according to recent surveys. Although there is no way to totally solve this issue, it can be greatly mitigated. Numerous effective techniques, including paints, coatings, cathodic and anodic protection, alloy creation, and corrosion inhibitor use, are employed to manage corrosion issues. Using corrosion inhibitors is one of the oldest, most cost-effective, and most dependable methods that companies utilize to control corrosion-related issues among all other procedures. Ordinary metallic building materials can be used in extremely aggressive and hostile settings where expensive, particularly engineered materials would otherwise fail catastrophically thanks to corrosion inhibitors. The fact that no significant changes to the current plant and machinery are needed when transitioning from one inhibitor to an upgraded one is an additional benefit of utilizing inhibitors to reduce corrosion.

GREEN CORROSION INHIBITOR

Green corrosion inhibitor is a technology that is becoming more and more popular because it is environmentally friendly. There are numerous sources of environmentally friendly corrosion inhibitors, such as synthetic inhibitors, chemicals, ionic liquids, and plant extracts. Due to their diverse range of physical, chemical, and biological characteristics, plants (such as extracts and oils) are significant green corrosion inhibitors that are frequently employed in a variety of acidic environments. Natural product-derived chemicals have gained popularity as anticorrosion agents in recent years. Furthermore, because using expired chemicals as corrosion inhibitors can lower disposal costs and environmental pollution, this practice is becoming more and more popular. Over the years, a lot of environmentally conscious people have been the subject of studies and analyses.

MECHANISM OF CORROSION INHIBITION

Plant extracts are known to contain phytochemicals that have significant concentrations of phenols and heteroatoms that contain aromatic hydrocarbons (N, O, etc.). Protonated phytochemicals are the neutral molecules orcations that are present in aqueous acidic

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solutions. The metal and heteroatoms (N, O) share electrons when the chemical absorption method is applied to remove water molecules from the metal surface. Donor-acceptor interactions between the electrons of the phytochemicals and the vacant d-orbitals of the metal can cause the neutral phytochemicals to be adsorbed on the metal surface by chemical adsorption. However, the adsorption of protonated phytochemical molecules may be facilitated by electrostatic interaction, or physical adsorption, between the positive molecules and anions that have previously been adsorbed.

ROLE OF GREEN CHEMISTRY IN SUSTAINABLE CORROSION INHIBITION

One of the most practical methods for protecting metal against corrosion reactions is the application of corrosion inhibitors. The corrosion inhibitors' capacity to adsorb on metal surfaces results in corrosion inhibition primarily through the blocking of several active sites. The severe disadvantages of using organic corrosion inhibitors—most notably, their high environmental toxicity—have prompted more research on safe and biodegradable substitutes, like using environmentally friendly and sustainable inhibitors. For this particular purpose, phytochemicals and secondary metabolites that can be isolated from a variety of plant species can be employed. Among the many benefits of naturally extracted phytochemicals are their low cost, abundant availability, ease of renewable energy, ecological acceptability, and friendliness.

The three primary mechanisms by which plant extracts reduce corrosion are physisorption, chemisorption, and retrodonation. Physisorption, chemisorption, and retrodonation of various functional groups of phytochemicals, such as carbohydrate, lipids, terpenoids, phenolic acids, alkaloids, and other nitrogen-containing metabolites, with steel surfaces in the presence of HCl and H2SO4 function as corrosion inhibitors.

PLANT EXTRACTS AS GREEN CORROSION INHIBITOR

The creation of green corrosion inhibitors (GCIs) is one of the most comprehensive studies. The most extensively researched GCIs are made from plant extract because they are low cost, renewable, biodegradable, and, most importantly, safe for the environment and people. Gravimetric analysis, electrochemical testing, theory, and computational studies are used to assess the performance of GCIs. It is well reported that the inhibition performance computed from these methods under different conditions is compiled. Plant extracts have been shown to be effective corrosion inhibitors, with an inhibition efficiency of more than 80%. The

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development of novel plant-based corrosion inhibitors for metal exposed to diverse environmental conditions is a major undertaking. Toxic inhibitors that are used to reduce the corrosion of different metals and alloys in aqueous solutions have spurred these efforts to replace them. In most systems, plants are being investigated as a potentially useful source of compounds that could replace synthetic inhibitors that are toxic for protecting against metal corrosion. The high concentration of phytochemicals, an active component, is responsible for this high efficiency.

PHYTOCHEMICALS AS STEEL CORROSION INHIBITOR

Plant-based products have many benefits, such as low cost, wide availability, and an almost limitless supply of new products. They are generally well-liked by society and have favorable effects on the environment. The anticorrosive qualities of phytochemicals found in plants have been studied. The ability of plant extract to inhibit corrosion in 1M HCl solutions is investigated using weight-loss techniques and isotherm adsorption. The findings demonstrated that extracts greatly decreased corrosion. As the concentration of extract increased, so did the inhibitory effectiveness. The adsorption mechanism's existence is supported by weight-loss study results and adsorption isotherms (Temkin and Freundlich). You can simulate the corrosion of steel by putting a plant extract in an acidic environment. In order to act as corrosion inhibitors, various functional groups of phytochemicals, such as lipids, carbs, terpenoids, phenolic acids, alkaloids, and other metabolites containing nitrogen, engage in physisorption, chemisorption, and retrodonation with steel surfaces in the presence of HCl and H_2SO_4. The presence of such a phytochemical in plant extracts determines the precise mechanism of inhibition.

CORROSION INHIBITORY POTENTIAL OF FLAVONOID DERIVATIVES

Flavonoid molecules are a class of plant metabolites that are present in a variety of fruits and vegetables. It is well known that they provide health advantages via the cell signaling pathway and have been demonstrated to display a variety of biological activities, including antioxidant qualities. Like other chemicals produced from plants, these compounds are likewise categorized as environmentally benign corrosion inhibitors. Because flavonoids are mostly derived from plants, they may be used as corrosion inhibitors when their molecular structure permits.

GALLIC ACID AS A CORROSION INHIBITOR

It has been discovered that galic acid (GA) inhibits the corrosion of carbon steel (CS). It can be used as both a reductant and a corrosion inhibitor in diluted decontamination formulations that operate in the regenerative mode due to its inherent resilience against radiation degradation compared to other reductants and its anionic nature regarding removal using an ion exchange column.

ANTICORROSION PROPERTIES OF COUMARIN'S DERIVATIVES

Coumarin is abundantly distributed in certain common plants. Gravimetric and electrochemical methods were used to study the corrosion of mild steel (MS) in 1.0 M aqueous HCl as green biodegradable inhibitors. Finally, in order to ascertain how the evaluated chemicals interacted with the metallic surface, the molecular electrostatic potential (MEP) was investigated via the use of density function theory (DFT).

ANTI-CORROSIVE PROPERTIES OF ALKALOIDS

Many organic inhibitors have been reported to be employed to block the corrosion of different metals; however, the most effective inhibitors are heterogeneous ring compounds with larger electronegativity atoms (such as N, O, S, and P), polar functional groups, and conjugated double bonds. Alkaloids that have been investigated as metal corrosion inhibitors in corrosive conditions include strychnine, quinine, papaverine, nicotine, and others.

This chapter was conducted on the effects of alkaloids on corrosion inhibition of different metals in different corrosive media at room temperature and higher temperatures. Quantum chemical investigations, surface morphology, electrochemical tests, and weight reduction. Utilizing the weight loss method, electrochemical measurements, surface analysis, and quantum chemical computations, the inhibitory behavior of alkaloid inhibitors on metals was evaluated. The majority of alkaloids operated as mixed-type inhibitors, and they are all effective corrosion inhibitors. When different adsorption isotherms were examined, it was discovered that most alkaloids adhered to the Langmuir adsorption isotherm, whereas a small number did so for Bockris-Swinkels and Temkin's adsorption.

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CHARACTERIZATION TECHNIQUES

Weight loss, potentiodynamic polarization, and electrochemical impedance spectroscopy (EIS) methods were used to assess the rates of corrosion. Excellent inhibition efficiency was demonstrated by the extracts using electrochemical techniques like potentiodynamic polarization, electrochemical impedance spectroscopy (EIS), and weight loss. It has been demonstrated that charge transfer processes, which act as mixed type inhibitors, regulate the corrosion mechanism. The Langmuir adsorption isotherm was presented. As the inhibitor concentration rises, the efficiency of inhibition increases and eventually reaches at least 80%.

A number of experimental approaches are available to help with the correct characterization of the extracts that have been presented as corrosion inhibitors. A metal's vulnerability to localized corrosion, such as pitting and crevice corrosion, can be assessed using cyclic potentiodynamic polarization. Polarization tests, like PP, rely on measuring and examining the current generated in a working electrode by a changing potential. Another method that is frequently used to examine anti-corrosion performance in relatively short testing periods is electrochemical impedance spectroscopy. Using this method, one can ascertain a system's impedance in terms of a variable potential's frequency. Nyquist plots are the most often used graphical depiction of EIS results, and the study of its results is dependent upon models with analogous electrical circuits. EIS displays additional information, such as the system's resistance and mechanism. Using the link between electrochemical potential and produced currents on charged electrodes, one way to calculate the corrosion rate is linear polarization resistance.

The weight loss method (WL), which is based on the mass lost due to corrosion and is directly monitored to determine the corrosion rate, is less complex and time-consuming. The inhibition efficiency can be calculated using some characteristics that can be measured both with and without the material employed as a corrosion inhibitor, such as the corrosion current density determined by PP. The common methods used to address surface characterization are spectroscopy and microscopy techniques. Together with other morphological details, a scanning electron microscope allows for a good comparison of the metal surface with and without a corrosion inhibitor. In a similar vein, the atomic force microscope uses topographical imaging and comparison to gather data on the metal surface's geometry. Stoichiometry, electronic state determination, and oxidation states are frequently assessed

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using X-ray photoelectron spectroscopy. Fourier transform infrared spectroscopy is typically used for complementary characterizations in order to gather details on the vibrational modes and functional groups of the corrosion inhibitors.

Corrosion inhibitors can be categorized as cathodic, anodic, or mixed-type based on how they prevent corrosion. Inhibiting the processes that occur at the cathode, such as oxygen reduction and hydrogen evolution, cathodic corrosion inhibitors lower the corrosion potential towards lower values. Anodic corrosion inhibitors interact with the reactive sites on the metal surface to passivate them and shift the corrosion potential towards higher values. Inhibitors that fall outside of the cathodic or anodic categories are called mixed-type inhibitors. These inhibitors have the ability to physisorb, chemisorb, and form films to protect the metal surface. The electrostatic interaction between the inhibitor molecules and the metal surface drives physisorption, while donor-acceptor interactions occur when free electron pairs in the inhibitor and vacant orbitals on the metal surface interact to cause chemisorption.

MOLECULAR MODELLING OF COMPOUNDS USED FOR CORROSION INHIBITION

Computational software has made molecular modeling of organic compounds a viable method for determining the ability of organic compounds to inhibit corrosion. Density functional theory (DFT), molecular dynamics (MD) and Monte Carlo (MC) simulations, artificial neural networks (ANNs), and quantitative structure-activity relationship (QSAR) are a few of the frequently used methods in theoretical investigations of corrosion inhibition potentials and mechanisms. Chemical reactivity and the ability of organic molecules to suppress corrosion can be described by computational modeling. When screening organic compounds for corrosion inhibition potentials prior to their wet laboratory production, modeling can be thought of as a time- and environmentally-efficient method. An further benefit of computational modeling is the ability to anticipate the orientation of organic compounds and the molecular sites (adsorption or active sites) that interact with metallic surfaces. The nature of the metal-inhibitor interactions and the inhibitor's inhibitive efficacy can also be anticipated using various theoretical descriptors and characteristics.

ADVANTAGES OF USING PLANT EXTRACT AS INHIBITORS

The application of environmentally friendly alternatives is gaining attention in the fields of science and engineering due to the development of the idea of green chemistry and

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sustainable advancements. Plant extracts are receiving a lot of attention in contemporary corrosion inhibition systems (MCISs) because of their natural and biological origin. MCISs entail the retardation of metallic corrosion inhibition by correct planning, materials selection, and application of corrosion inhibitors. According to a review of the literature, several papers have been written about their ability to prevent corrosion in metals and alloys. Plant extracts include complex phytochemicals with electron-rich sites that strongly interact with metallic surfaces. These phytochemicals are frequently combined with polar functional groups and a range of multiple bonds in broad conjugation.

CONCLUSION AND RECOMMENDATION

Corrosion inhibitor use is one of the most important strategies for safeguarding our metal cultural heritage. Regrettably, preservative inhibitors can also be harmful. There is a growing emphasis on developing renewable solutions as a result of people's growing concerns about the environment and the need to create more environmentally friendly technology. One of the most popular methods for preserving metallic cultural heritage is the application of green corrosion inhibitors. An overview of the most significant issues in this vital field of study, including the effects of safety, economic, and environmental factors on the corrosion of metal artifacts and the protective techniques used to prevent it, the different types of metal and their chemical and electrochemical properties, doable procedures for pre-surface treatment prior to inhibitor use, and the different kinds of green inhibitors and their characteristics. Methods for analyzing metal artifact surfaces both surface-wise and electrochemically prior to and during inhibitor application are described.

Today, anti-corrosion chemicals are strictly forbidden and regulations are made by environmental organizations in many countries due to increased health awareness. These rules stipulate that chemicals have to be safe and environmentally friendly. This has led to years of intensive research into the development of green corrosion inhibitors derived from plant extracts. These substances show promise as safe, affordable, biodegradable substitutes for hazardous corrosion inhibitors because they are easily accessible. In this chapter, a recent compilation of significant papers on the application of plant extracts as environmentally friendly and sustainable corrosion inhibitors. Plant extracts contain complex phytochemicals with electron-rich sites that strongly interact with metallic surfaces. These phytochemicals are frequently combined with polar functional groups and a range of multiple bonds in prevalent conjugation.

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Chapter 4

GREEN SYNTHESIS AND APPLICATIONS OF NANOPARTICLES

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INTRODUCTION

The importance of green nanoparticles has gained more attention in the twenty-first century because of their many uses. Research on nanotechnology has exploded in the last ten years because of its many uses in a variety of industries, such as food safety, transportation, sustainable energy, environmental science, catalysis, and medicine. Nanomaterials, which range in size from 1 to 100 nm, have unique properties that make them ideal for a variety of applications. Because green synthesis methods eliminate harsh operating conditions, hazardous chemicals, and the need for external stabilizing or capping agents, the nanoparticles produced using these methods are particularly desirable. In an effort to optimize processes in a way that is both economical and ecologically safe, a variety of plants, microorganisms, and animals are being tested (Dikshit et al., 2021). According to Pechyen et al. (2024), these techniques provide biologically and environmentally acceptable substitutes for traditional chemical synthesis methods.

The chapter focuses on the synthesis, characteristics, and uses of a number of metal nanoparticles, specifically palladium (PdNPs), zinc oxide (ZnONPs), iron oxide (FeONPs), copper (CuNPs), silver (AgNPs), gold (AuNPs), and platinum (PtNPs). Green synthesis techniques, a genuinely novel approach, make use of biological materials like yeast, bacteria, fungi, plant extracts, and animal extracts. Green synthesis of nanoparticles is environmentally safe and ought to be investigated and promoted widely because a wide variety of natural source can produce these nanoparticles (Abada et al., 2024). Recent research used animal sources for metallic nanoparticle synthesis, as known, zoosynthesis metallic nanoparticles are similar to phytosynthesis (Karnan *et al.*, 2023b).

PLANT EXTRACT MEDIATED SYNTHESIS OF NANOPARTICLES

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The primary chemical methods used to create nanoparticles typically use toxic reactants as reducing agents, which further generate toxic byproducts that are environmentally dangerous. The goal of these studies is to combine particular qualities obtained from plant extracts, such as anti-inflammatory or anti-cancer properties, with the inherent biocidal qualities of nanoparticles. Multi-drug resistant bacteria can be defeated by using antibacterial/antifungal coatings made of nanoparticles with biocidal qualities. Effective biocidal properties against microorganisms have been demonstrated by metal oxide nanoparticles (TiO_2, ZnO, and MgO) and noble metal nanoparticles (Ag, Au, and Pt). In contrast to metal nanoparticles, which interact with surface membranes and can penetrate bacteria to cause apoptosis, metal oxide nanoparticles' antibacterial activity is primarily ascribed to the generation of reactive oxygen species. In this case, a promising substitute for traditional antibiotics is provided by a different mechanism of bacterial growth inhibition (Küünal et al., 2018).

MICROBE-MEDIATED SYNTHESIS OF NANOPARTICLES

The goal of recent developments in nanotechnology is to create nanoparticles and materials through innovative, safe, and environmentally friendly methods. Using the microbial machinery to biosynthesize nanoparticles of a desired nature and structure is not only faster and safer than traditional methods, but it is also more environmentally friendly. Recently, the synthesis of metal, metal oxide, and other significant NPs through intracellular and extracellular processes has been investigated in a variety of microbes, including bacteria, actinobacteria, fungi, yeast, microalgae, and viruses. The ability to create unique nanomaterials like exopolysaccharides, nanocellulose, nanoplates, and nanowires is possessed by certain bacteria and microalgae. Furthermore, genetic engineering techniques can be used to improve their capacity to create nanoparticles. Therefore, the synthesis of nanoparticles using microorganisms is novel and has a bright future. The current chapter offers detailed information on various methods for creating nanoparticles from microbial cells, as well as their uses in bioremediation, agriculture, medicine, and diagnostics, as well as their potential for the future (Koul et al., 2021).

ANIMAL MEDIATED SYNTHESIS OF NANOPARTICLES

This term refers to the use of zoo-chemicals from zoo-extract, which contains zoo-chemicals, as reducing agents in zoochemical-mediated nanoparticle synthesis. There is a connection between phytochemical-mediated and zoochemical-mediated nanoparticle synthesis. Animal compounds known as zoochemicals are comparable to phytochemicals found in plants. As an

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alternative source of pest management with specific targets and a reduction in negative environmental effects, modern nanotechnology holds promise for the agricultural sector (Karnan et al., 2023a; Karnan et al., 2023b).

SILVER NANOPARTICLES (AgNPs)

Silver nanoparticles (AgNPs) are produced biogenically from a variety of plants and have antibacterial, antifungal, antioxidant, anticancer, anti-inflammatory, and antidiabetic properties. Additionally, because only natural materials are used in the production process, the naturally produced particles are stabilized, coated, and essential to these biomedical functions. This study has also reported on the characterization of AgNPs, the potential for preparing AgNPSs with various shapes using biological methods and their effects on functions and toxicities, the influence of size, shape, and other properties on AgNPs functions and toxicity profiles, limitations, and future prospects of green mediated AgNPs. Their understudied antioxidant, antibacterial, anticancer, antidiabetic, antifungal, and anti-inflammatory abilities are the main objectives of this AgNPs synthesis (Akhter et al., 2024).

ZINC OXIDE NANOPARTICLES (ZnONPs)

Zinc oxide nanoparticles (ZnONPs) are highly desirable in many industries due to their unique properties. However, the toxic substances used in traditional ZnO-NP production methods are associated with health and environmental risks. According to research, ZnO nanoparticles are made using a variety of plant extracts. Included in these extracts are leaves, fruits, seeds, roots, and entire plants. Among the phytochemicals found in these biological matrices are terpenoids, flavonoids, alkaloids, and phenolic compounds. Compounds perform as stabilizing and reducing agents and exhibit a bioreduction mechanism. By varying the plant extract type, concentration, and synthesis conditions, ZnO nanoparticles (NPs) can have different characteristics, such as size, shape, and crystallinity. Greenly produced ZnO nanoparticles have a wide range of biomedical applications, including advantageous properties like antibacterial activity against different pathogens, anti-inflammatory properties, and potential anticancer properties. Green-processed zinc oxide nanoparticles (ZnO NPs) are highly desirable for use in biomedical contexts due to their improved biocompatibility and decreased toxicity when compared to conventional methods (Al-darwesh et al., 2024).

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COPPER OXIDE NANOPARTICLES (CuONPs)

Copper oxide nanoparticles, are extremely valuable and have applications in a variety of fields, including catalysis, biomedical drug delivery, antioxidants, and antimicrobials, due to their multifaceted potential. Technologies known as nanoparticles (NPs) have been used extensively in medicine to work closely with biomolecules that are helpful in cancer treatment and diagnosis. The biological technique is more cost-effective, less hazardous, and easier to use when producing a variety of metal oxide nanoparticles, including copper oxide (CuO). Other types of methods have also emerged, each with their own advantages and disadvantages, such as the chemical and physical methods of synthesis. Green routes of CuO have recently gained popularity as photocatalysts that can speed up reactions in a variety of pollutant removal processes, whether in the wastewater industry or product manufacturing. Green practices have fewer and more benign side effects (Nazri and Sapawe, 2020).

GOLD NANOPARTICLES (AuNPs)

Gold nanoparticles (AuNPs) are being produced environmentally using these biological resources. Among traditional chemical and physical methods for the availability of natural components, biological synthesis of AuNPs is widely used. In the analytical and electroanalytical domains, bio-assisted AuNPs are widely used for protein separation, hazardous chemical detection, and heavy metal tracing in a variety of samples. In order to determine the morphology, functional groups, stability, elemental composition, and crystallinity of the synthesized AuNPs, a variety of analytical techniques are employed (Khan et al., 2022). Gold nanoparticles' anti-microbial, anti-cancer, and catalytic uses (Dash et al., 2022).

IRON NANOPARTICLES (FeNPs)

The effectiveness and potent catalytic properties of iron nanoparticles (Fe-NPs) have led to their increasing use in environmental applications. Due to their green synthesis, which efficiently reuses biological resources during the polymerization reactions, nanoparticle science has drawn a lot of attention from researchers. Therefore, using plant extracts to synthesize Fe-NPs could be regarded as the sustainable, economical, easy, quick, energy-efficient, and environmentally friendly method. Green-synthesized Fe-NPs are more reactive and stable because some of the biomolecules in the extracts undergo metal salt reduction during the production process. This reduction can act as a capping and reducing mechanism.

Numerous possible sources for the environmentally friendly synthesis of Fe-NPs were made available by the diversity of species. It will be simpler to find and use new, promising plant materials for the synthesis of Fe-NPs as our knowledge of the precise biomolecules involved in the bioreduction and stabilization processes advances. Comprehensive details on different plant materials that can produce useful biomolecules with a range of possible uses in environmental safety. Future opportunities and challenges related to the environmentally friendly synthesis of Fe-NPs would spur innovative nanoparticle research in new directions (Haider et al., 2024).

TITANIUM DIOXIDE NANOPARTICLES (TiO_2NPs)

Recent advances in green synthesis methods have improved the cost, safety, and ease of use of nanoparticle synthesis. The production of titanium dioxide nanoparticles (TiO2 NPs) that is dependable, efficient, and environmentally friendly has gained attention recently. Although this semiconductor material has a number of drawbacks, it is well-known for its photocatalytic properties, particularly with regard to the degradation of dye pollutants. The production of this safe substance has been made possible by the use of reducing and capping agents, such as bacteria and plants. Therefore, it is essential to examine and comprehend the advancements made in the green synthesis of TiO2 materials (Langa and Hintsho-Mbita, 2023). In consumer goods based on nanotechnology, TiO2NP is one of the most widely used engineered nanomaterials (Sunny et al., 2022).

COBALT NANOPARTICLES

Cobalt nanoparticles have drawn a lot of interest from researchers due to their unique uses in a variety of fields, including electrochemical sensing, photocatalysis, and antimicrobial activity. As a result, several studies have been published recently that employ green synthesis techniques based on physical, chemical, and plant extracts. The green route based on plant extracts has been regarded as a valuable alternative to other methods for the synthesis of nanoparticles because it is a low-cost, biocompatible method that is easy to scale up and completely eliminates the need for additional stabilizing agents during the synthesis process. additional benefits of cobalt nanoparticles in a range of applications, including electrochemical sensing, antimicrobial activity, and photocatalytic environmental application for water pollution remediation (Singh, 2022).

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CALCIUM OXIDE (CaO) NANOPARTICLE

CaO nanoparticles mediated by plants exhibited the highest level of inhibition on E. coli, with other strains following suit. As opposed to the moderately active CaCl2 and CaO compounds, the plant-mediated CaO NPs in MIC exhibited high activity against every test organism. The synthesis of plant-mediated CaO NPs offers numerous benefits, including economic viability and scalability. Because of the bactericidal, wound-healing, and other medical uses of these environmentally friendly nanoparticles, this technique has the potential to be used for the large-scale synthesis of inorganic materials (Marquis et al., 2016). Calcium oxide nanoparticles have found extensive use in the fields of microelectronics, antimicrobials, therapeutics, detection and diagnostics, and catalysis (Marquis et al., 2016).

MAGNESIUM OXIDE NANOPARTICLES

Green synthesis-produced magnesium oxide nanoparticles (MgONPs) made from plant extracts have become a material of choice for a variety of uses. Known as natural and renewable reducing, chelating, stabilizing, and precipitating agents, polyphenols are phytochemicals that contribute to the formation of MgONPs. Green MgO has seen a remarkable expansion in applications in the last few decades, primarily in the fields of materials, biomedicine, and the environment. The potential uses of green magnesium oxide in medicine and agriculture include antibacterial, antimicrobial, antioxidant, and anti-cancer properties. MgO-induced photodegradation of a variety of pollutants has also been reported. The main aspects of MgO synthesis by plant extracts are covered in this chapter. The experimental conditions that affect the formation and properties of MgONPs are covered, along with the primary characterization techniques used to identify the magnesium compounds formed and the most widely reported uses of MgONPs in the fields of materials science, biology, medicine, and the environment (Silva et al., 2022).

GREEN SYNTHESIS METALLIC NANOPARTICLES CHARACTERIZATION TECHNIQUES

Characterization for various properties, including size, shape, capping materials, stability, etc., must come after the synthesis of metallic nanoparticles. This helps to clearly define the synthesized nanoparticles based on the observed properties (Kumar et al., 2023). Spectroscopy and microscopy studies are used in conjunction with appropriate analytical chemistry techniques to characterize the obtained metal nanoparticles (Bordiwala, 2023).

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Their characterization is essential, and a variety of instrumentation analyses, including atomic force microscopy (AFM), annular dark-field imaging (HAADF), scanning electron microscopy (SEM), transmission electron microscopy (TEM), Fourier transform infrared spectroscopy (FT-IR), atomic force microscopy (AFM), intracranial pressure (ICP), and transmission electron microscopy (TEM) are used to confirm the characteristics of nanoparticles (Vijayaram et al., 2024; López-Miranda et al., 2023).

GREEN SYNTHESIS METALLIC NANOPARTICLES APPLICATIONS

Green nanotechnology is a new scientific discipline that focuses on how living cells use biological processes to produce nanoparticles. Information on green synthesized metal nanoparticles, which are useful to enhance biomedical and environmental applications, is particularly provided in this chapter. According to Salem and Fouda (2021), nanoparticles (NPs) produced using a green approach can be used in a variety of biotechnological fields as antioxidant, antimicrobial, and antitumor agents; as phytopathogen control; as bioremediative factors; and in the food and textile industries, smart agriculture, and wastewater treatment. The biogenic MNPs' improved biological characteristics confirm their value in medicine (Aboyewa et al., 2021). Metallic nanoparticles (MNPs), especially those of silver, gold, cobalt, and zinc, have been used as antimicrobial, anticancer, drug delivery, contrast, and bioimaging agents.

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