

IISc THESES ABSTRACTS

Thesis Abstract (Ph.D.)

Some nonlinear surface wave propagation problems by E.A. David.

Research supervisor: Renuka Ravindran.

Department: Applied Mathematics.

1. Introduction

The thesis contains the results of investigations of some specific nonlinear surface wave propagation problems. In general for nonlinear wave propagation problems neither the methods of solution nor the main characteristics of the motion are well understood. To understand the phenomena of wave motion from the theoretical standpoint, it is necessary to segregate the wave motion into different classes. Wave motion as a whole is classified into two main classes, namely, hyperbolic and dispersive, which overlap each other. In the case of wave propagation problems involving more than one spatial variable, there is a need for another classification depending on whether the 'propagation space' is the same as the 'physical space' or not. In this case, the waves are classified as 'modal' or 'local' depending on whether the physical space is the product of a propagation space and a cross space, or the physical space is the same as the propagation space, respectively. For a modal wave appropriate boundary conditions are prescribed on the cross space. These boundary conditions, together with the differential equations, lead to an eigenvalue problem giving the dispersion relation connecting the frequency and wave number in the propagation space for the linearized problem. A few waves of such type are dealt with in this work.

2. Discussion

In solving nonlinear wave propagation problems, the difficulty in obtaining exact global solutions had led to the emergency of approximate methods which usually give an asymptotic estimate of the solution. For each type of wave propagation (dispersive or nondispersive) problem, fairly general methods of solution have been and are being developed. In this thesis a singular perturbation technique has been employed to analyse modal boundary value problems which are nondispersive. Also, the modified *Fourier series* method has been used to study boundary value problems, which are dispersive in nature.

The thesis contains the details of the singular perturbation method used to study the asymptotic behaviour of the nonlinear surface acoustic waves on an isotropic elastic solid. A uniformly valid solution in the interior of the medium is derived. Also, numerical solutions are obtained to study the growth-decay cycles of various harmonics. The growth-decay cycles show clearly the continuous transfer of energy back and forth among the harmonics. In surface acoustic waves the odd harmonics dominate over the even harmonics. Perspective drawings to show the

shock formation have also been done. The drawings clearly show that the displacement profiles do not become discontinuous and the velocity will become discontinuous in finite time. The study of two modal equations with harmonic initial conditions has also been done. This is to simulate the velocity components and the displacement components in the nonlinear propagation of surface acoustic waves on an elastic solid.

The systematic derivation of the infinite set of coupled amplitude equations governing the propagation of surface waves generated at the interface of an elastic membrane and a fluid medium has been undertaken. Here the modified Fourier series method is adopted to study the problems analytically. Analytical solutions to the fundamental mode and the second harmonic are derived. For large values of the wave number the system under study behaves like a nondispersive system. Numerical solutions for the membrane displacement and velocity components of the fluid medium have been obtained. The figures drawn clearly show the effect of compressibility, that is to decrease the phase velocity and hasten the formation of discontinuities.

In the study of nonlinear Kelvin waves, the infinite set of coupled amplitude equations governing the propagation of nonlinear Kelvin waves with geostrophic approximation in an area of constant depth is obtained. Results are obtained for the propagation of nonlinear Kelvin waves without geostrophic approximation in a channel of finite width. A conservation law governing the amplitudes has been found in this case.

The modified Fourier series method is applied to the problems of propagation of nonlinear Poincare waves in a channel. The ultimate aim of obtaining the infinite set of coupled amplitude equations governing this type of surface wave propagation is achieved here also.

3. Conclusion

The problems investigated show clearly that the methods employed in this thesis can be exploited fruitfully to study nonlinear surface wave propagation problems with cross-space boundary conditions. A computer program has been suitably developed to simplify the numerical study of these problems. It has been shown that when the modified Fourier series method is applied to study a dispersive system, the computations become laborious. The methods used give a good insight to the nonlinear propagation characteristics such as, growth-decay cycles of amplitudes, asymptotic variation of velocity components and displacement components, and shock formation.

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Thesis Abstract (Ph.D.)

Studies on covalently linked bisporphyrins by D. Jeyakumar.

Research supervisor: V. Krishnan.

Department: Inorganic and Physical Chemistry.

1. Introduction

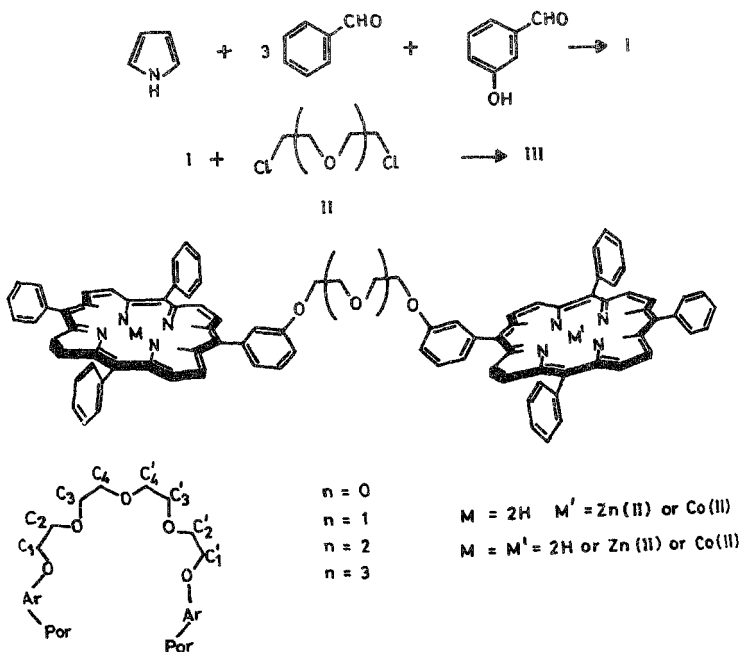
The primary reaction in photosynthesis involves photoinduced charge separation where in a 'special-pair' chlorophyll functions as donor entity¹. This observation has stimulated considerable interest in the model studies comprising of bisporphyrin systems². Often it has been found that the model, covalently linked bisporphyrin systems do not exhibit any specific interactions and thus fail to duplicate photosynthetic functions. The studies reported in this thesis propose new singly linked bisporphyrin systems and the different ways in which the specific interaction could be induced in such systems. In addition, the thesis embodies results obtained on porphyrin donor systems and possible mechanistic pathways for photoinduced electron transfer reactions.

2. Experimental programme

Several covalently linked bisporphyrin systems, free base, (PH₂~PH₂), hybrid bisporphyrins, (MP~PH₂) and metal (II) dimers, (MP~MP) where M = Zn(II), Cu(II) and Co(II) and ~ represents covalent linkage. In these systems, two porphyrin units are linked through one of the aryl groups via ether linkages of variable length. The covalent linking group is varied from glycol, digol, trigol and tetragol (n = 0, 1, 2 and 3 respectively). The synthetic strategy adopted for the preparation of bisporphyrins is shown (scheme 1). The metallation studies into the two porphyrin units have been carried out either by controlling the metal concentration or from the partially metallated derivative. Column and thin layer chromatography methods form the separation and purification procedures. Diverse spectroscopic techniques, ¹H NMR, EPR, optical absorption and emission and electrochemical methods have been employed in the studies³.

3. Main results and conclusions

The optical absorption data on these bisporphyrin systems indicate the presence of inferring interactions which is exhibited in the change of fwhm values of Soret band and in the decrement of the ϵ values of the visible band. Selective photoexcitation of Znp~PH₂ leads to singlet-singlet energy transfer from Znp* to PH₂ unit. The efficiency of this process (θ_{et}) varies with the interchromophore separation as glycol < digol > trigol > tetragol. The maximum efficiency is found to occur in digolbisporphyrin indicating critical dependency of distal separation on the Φ_{et} values. Exciton coupling mechanism has been advanced to provide explanation of the observed behaviour. Moreover, the ¹H NMR results on CoP~PH₂ have been utilised to arrive at the solution structure of these bisporphyrins. The geometric factor $(3\cos^2\theta) - 1/r^3$ obtained for isotropic proton shift data indicates the existence of 'closed' conformers in these systems. It is demonstrated that the tendency to form 'closed' conformer decreases with increasing interchromophore separation. These results have been rationalised in terms of computer stimulation of several geometries from which it is concluded that the closest distance between two porphyrin units occur in digolbisporphyrin (10 Å). The EPR data CuP~CuP dimers provide support for this observation.



Scheme 1

The studies on intermolecular interaction between the bisporphyrins and π -acceptor, sym-trinitrobenzene (TNB) reveal that the two porphyrin units cooperatively bind a TNB molecule. The binding constants (K) are dependent on the nature of covalent linkage and varies as glycol < digol > trigol > tetragol, irrespective of the nature of the bisporphyrin (Table I). The K values are found to be wavelength specific in $ZnP^+ \sim PH_2^-$ systems. A similar trend has been observed in the bimolecular quenching constant (K_{sv}) values. It has been proposed that the singlet quenching of porphyrin fluorescence essentially arise from exciplex formation. It has been possible to arrive at the energies of the CT states $ZnP^+ \sim PH_2^-$: from the cyclic voltametric studies. It is suggested that a critical distance between the two porphyrin units necessary for the maximum intramolecular interaction and for the observance of maximum cooperative intermolecular binding with an acceptor.

The investigations on porphyrins covalently linked to 2-methylnaphthoquinone ($H_2P \sim NQ$) have been useful to arrive at the contributions of the distal and orientation factors to the rate of photoinduced charge-separation reactions. The orientation factor in these systems have been varied by changing the nature of the substitution of the acceptor, NQ to one of the *meso*-aryl

Table I
Physical parameters of zinc(II) hybrid bisporphyrins $ZnP\sim PH_2$ with varying interchromophore separation

Physical constants	Nature of the covalent linkage			
	Glycol	Digol	Trigol	Tetragol
$a\Phi_{et}$	0.13	0.67	0.61	0.33
$b_{D_{512}^{ox}}$ in volts	1	0.79	0.76	0.78
	2	1.07	1.04	1.08
c_k, mol^{-1}	1	37 ± 3.2	123 ± 11.5	54 ± 6.0
	2	50 ± 5.5	163 ± 15	100 ± 10.0
$d \Delta\delta_{TNB}$ in ppm	0.64	0.93	0.64	0.62

$a\Phi_{et}$: refers to efficiency singlet-singlet energy transfer from ZnP unit to PH_2 unit.

$b_{D_{512}^{ox}}$: denotes the first ring oxidation potential of the porphyrin. The first entry corresponds to ZnP^+ and the second entry refers to H_2P^+ .

c_k : binding constants for TNB complexation equilibria. The first and second entries denote the wavelengths 515 and 550 nm respectively at which k values have been evaluated.

$d \Delta\delta_{TNB}$: the proton resource of TNB in the (1:1) molecular complex.

groups. The quantum yields of the radical pair, $ZnP^+\sim NQ^{\cdot-}$ and $H_2P^+\sim NQ^{\cdot-}$ are evaluated from the integrated intensity of light-induced radical-pair EPR signals. These are correlated with the energies of CT states and solvent reorganisation energies. It is demonstrated that polarity of the solvent molecules has a pronounced effect on the extent of radical-pair formation. It is concluded that a critical distance of 8–10 Å with coparallel orientation of donor and acceptor are essential for the photoinduced charge separation.

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Thesis Abstract (Ph.D.)

Studies on the metabolism of the plant sulfolipid: Sulfoquinovosyldiacylglycerol by Sita Devi Gupta.

Research supervisor: P.S. Sastry.

Department: Biochemistry.

1. Introduction

Sulfur-containing lipids, 'The sulfolipids', are widely distributed in the membranes of animals, plants and bacteria. These are of two types. In the first, sulfur is linked to a hydroxyl group on a carbon by ester linkage (C-O-S) and are referred to as 'sulfatides'. In the second, sulfur is linked directly to carbon (C-S) as sulfonic acid derivative and are described as 'sulfolipids'. A good example of sulfolipid is sulfoquinovosyldiacylglycerol (SQDG), widely distributed in the plant kingdom and in the photosynthetic bacteria. It accounts for about 10% of the total plant glycolipids¹ and contains high amounts of palmitic and linolenic acid². SQDG has been shown to be an essential lipid constituent of the thylakoid membranes of the chloroplast and there is a strong evidence that it is necessary for the photosynthetic function.

The biosynthesis and degradation of SQDG in plants is of interest because of its unique structure. In addition, animals, particularly herbivores, consume large amounts of SQDG through their diet and therefore its absorption and degradation in the gastrointestinal tract assumes significance. The catabolism of sulfatides has been studied in animal tissues and sulfatases were shown to hydrolyse the sulfate ester bond³. The cleavage of the C-S bond, as exists in SQDG has not been demonstrated. However, in both lower and higher plants, SQDG was shown to be deacylated to SQG⁴. There are some reports suggesting further degradation to sulfoquinovose (SQ), sulfolactaldehyde and sulfoacetate in plants⁴. Surprisingly, except for a brief report that SQDG is susceptible to pancreatic enzymes⁵, the metabolism of SQDG in the gastrointestinal tract has not been studied. The proposed pathway for its biosynthesis is not substantiated with experimental evidence. Therefore, the present investigation was carried out to understand the metabolism of SQDG in animals and plants.

2. Experimental programme

Animals and their tissues: Fresh sheep pancreas and small intestines were obtained from a slaughter house and transported to the laboratory in ice. Guinea pigs and albino rats (IISc strain) were decapitated under light anaesthesia. Their small intestines and pancreas were quickly removed and washed with ice-cold physiological saline. The intestinal mucosa was scraped and collected.

Plants: Groundnut (*Arachis hypogaea*) seeds were germinated on cotton and then planted in pots and grown under field conditions. Young, tender leaves harvested from the plants between the period 25 and 40 days after planting were used for the experiments.

Incorporation of [³⁵S] labelled compounds: Leaf discs (100 mg) were incubated in 1.5 ml of distilled H₂O containing appropriate amounts of [³⁵S] SO₄²⁻, [³⁵S] SQG, [³⁵S] SQ or [³⁵S] cysteic acid. After required time of incubation, the medium was withdrawn, leaf discs were washed with ice-cold H₂O and lipids extracted⁶. Aliquots of the chloroform and the methanol water phases were counted and analysed for the metabolites formed.

Enzyme assays: The characteristics of the various enzymes catalysing the degradation of SQDG were determined using purified [^{35}S] SQDG and saline extract of acetone powder of animal tissues or groundnut leaf homogenate as enzymes source. The product in the lipid and the methanol-water phases were analysed.

3. Results and conclusions

In vivo experiments with guinea pigs: After 1–3 h of administration of [^{35}S] SQDG (mixed in groundnut oil) into the stomach of overnight-starved guinea pigs, of the total recovered radioactivity, only 1 to 5% was present in lipids of intestinal mucosa, blood and liver whereas, more than 95% of the radioactivity was present in the water-soluble products in these tissues. This suggested the extensive metabolism of SQDG prior to absorption in the gastrointestinal tract. Analysis of the methanol-water-soluble production, the intestinal mucosa revealed the presence of SQG and SO_4^{2-} whereas in blood and liver only SO_4^{2-} was observed. This indicates that in the intestinal mucosa, SQDG is metabolised to SQG and SO_4^{2-} and it is the inorganic sulfate which is absorbed and transported to other tissues *via* blood. Experiments with everted intestinal sacs of guinea pigs confirmed the existence of a mechanism for the cleavage of the C–S bond in this tissue which results in the formation of SO_4^{2-} . In addition, hydrolysis of acyl ester bonds yielding sulfoquinovosylmonoacylglycerol (SQMG) and SQG was observed.

In vitro studies: Incubation of purified [^{35}S] SQDG with sheep pancreatic acetone powder extract resulted in the formation of SQMG and SQG, SQMG (sulfolipase A activity) was formed at a rate of 12 nmoles/min/mg protein and SQG (sulfolipase B activity) at a rate of 7.2 nmoles/min/mg protein. Sulfolipase A showed two pH optima *viz.*, pHs 5.0 and 7.4 and had K_m and V_{max} of 0.15 mM and 16 nmoles/min/mg protein, respectively. In the partially purified preparation, sulfolipases were colipase-dependent and the preparation was relatively specific for the hydrolysis of SQDG.

Table I

Comparison of sulfolipase A and B activities of pancreas and intestinal mucosa of various animal species

Species	Pancreas		Intestinal mucosa	
	nmol/min/mg. protein			
	Sulfolipase A	Sulfolipase B	Sulfolipase A	Sulfolipase B
Sheep	12.0	7.2	0.20	0.17
Guinea pig	39.9	21.8	1.06	0.91
Rat	1.3	0.9	0.07	0.04

The enzymes assayed as described in Methods with saline extracts of acetone powder of pancreas and intestinal mucosa. [^{35}S] SQDG (92 nmol; sp. act. 1658 cpm/nmol) and enzyme protein (100 μg , sheep and guinea pig pancreas; 200 μg , rat pancreas and 100 μg , intestinal mucosa of all the species) was incubated at $37 \pm \text{C}$ for 15 min in the case of pancreatic enzymes and for 30 min in the case of intestinal mucosa enzymes.

Sheep intestinal mucosa also hydrolysed SQDG to SQMG and SQG. Sulfolipases were found to be widely distributed in the tissues of several species (Table I). The guinea pig tissues showed much higher activity than sheep and rat tissues. In all the species, both sulfolipase A and B of the intestinal mucosa exhibited only 2 to 3% of the activity found in pancreas of the same species.

Degradation in plants: The products of hydrolysis of SQDG in total homogenate of groundnut leaves were SQMG, SQG and SQ. The rate of sulfolipase A and B were 0.28 and 0.03 nmole/min/mg protein, respectively. This indicates that the plant enzymes are considerably less active than the pancreatic enzymes. From these results, the pathways of sulfolipid degradation in animals and plants can be envisaged as shown in fig. 1. Even though the lipolytic activities are present in both the systems, products of further metabolism differ. Thus in plants, SQ was formed by glycosidase action and further metabolites could not be detected. In contrast, there was no evidence for glycosidase action in animal tissues, but there is clear proof for the cleavage of the C-S bond.

Biosynthesis of SQDG in higher plants: In the proposed pathway for its biosynthesis, 3'-phosphoadenosine 5'-phosphosulfate (PAPS) acts as a sulfur donor and 2-phospho-3-sulfolactic acid, 3-sulfolactic acid, L-cysteic acid, 3-sulfo-D-lactaldehyde and SQ are the

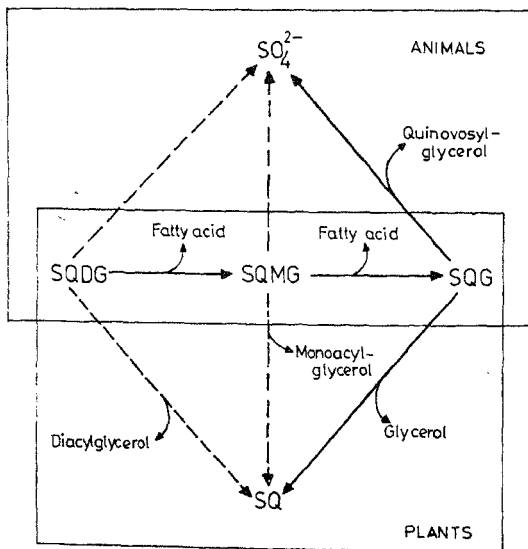


FIG. 1. Pathways of SQDG degradation in animals and plants. — — — Reactions not observed.

intermediates but this pathway is not established. In the present studies, $[^{35}\text{S}] \text{SO}_4^{2-}$ was readily taken up by the groundnut leaf discs and rapidly incorporated into SQDG. Analysis of the $[^{35}\text{S}]$ labeled water-soluble compounds showed that the rates of labeling of the proposed intermediates are about 20 to 40 times less as compared to that of SQDG. Unlabeled cysteic acid had no effect on the incorporation of $[^{35}\text{S}] \text{SO}_4^{2-}$ into SQDG. $[^{35}\text{S}]$ -Cysteic acid was taken up by the leaf discs and metabolised to sulfolactic acid but was not incorporated into SQDG. Sodium molybdate inhibited the incorporation of $[^{35}\text{S}] \text{SO}_4^{2-}$ into SQDG implying the involvement of adenosine 5'-phosphosulfate or PAPS in the biosynthesis of SQDG as sulfur donors. $[^{35}\text{S}]$ SQ was taken up by the leaf discs and incorporated into SQDG but only at a very low rate. Some evidence was obtained for the formation of nucleoside diphosphate derivative of SQ. $[^{35}\text{S}]$ SQG, though taken up by the leaf discs, was not incorporated into SQDG. The observations do not support the proposed pathway but indicate that SQ may be an intermediate. Thus, the results show that the formation SQDG from SQ may be a minor pathway and a direct sulfonation of glycosylglyceride may be the major pathway as indicated by the labeling of SQDG with $[^{35}\text{S}] \text{SO}_4^{2-}$ (fig. 2).

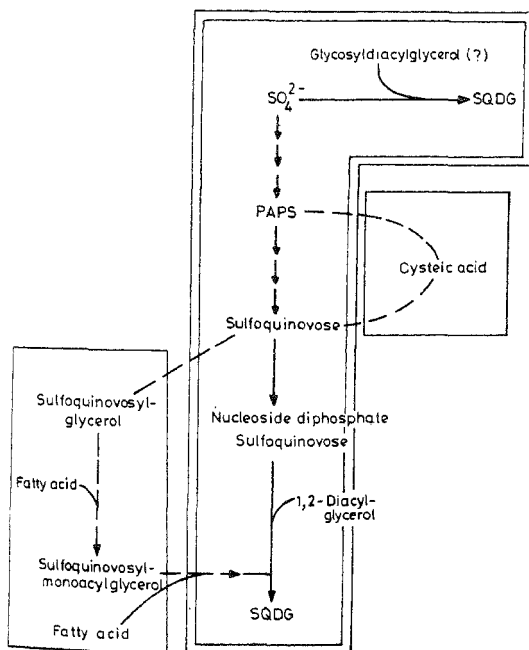


FIG. 2. Biosynthetic pathways for SQDG in higher plants. — Reactions observed; $\rightarrow\rightarrow\rightarrow$ Reactions probable; ---- Reactions not observed.

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Thesis Abstract (Ph.D.)

Antibodies to isopentenyl adenosine: Characterisation and applications by M. Viswanathan.

Research supervisor: T.M. Jacob.

Department: Biochemistry.

1. Introduction

N^6 (Δ^2 -Isopentenyl) adenosine (i^6A) is an important biomolecule modulating cell division and differentiation in plants and probably in animals also¹⁻³. Antibodies specific to i^6A are useful as probes for this molecule in various biosystems⁴. The objectives of the studies reported in the thesis were mainly two. The first one was to extend the use of i^6A -antibodies in tRNA research, with a view to develop good model systems to study protein-nucleic acid interactions. The second objective was to understand the biological role of i^6A in mammalian systems, either as free i^6A or as a constituent of tRNAs.

2. Experimental programme

Antibodies were raised in rabbits against the hapten, isopentenyl adenosine, after coupling it chemically to bovine serum albumin (BSA). The specificity of the antibodies was determined by binding to $3H-i^6A$ or $^3H-i^6A^{ox-red}$ and competing with nonradioactive i^6A and related compounds. The method used for estimating radioligand binding was nitrocellulose filter assay⁵. The antibodies were fractionated on AH-Sepharose- i^6A column. i^6A -containing tRNAs were isolated using Sepharose-anti- i^6A column. For isolating i^6A -containing tRNA fragments also Sepharose-anti- i^6A column was used. i^6A in tRNA hydrolysates were estimated by radioimmunoassay using anti- i^6A . IgG levels in rabbit sera were estimated by gel filtration, gel electrophoresis or single radial immunodiffusion method.

3. Main results and conclusions

Nitrocellulose filter binding is used widely in the thesis for the assay of hapten-antibody interaction. Hapten retention on nitrocellulose filter depends on the type and input of hapten, type

of filter; pH and salt concentration. Retention of $^3\text{H-}i^6\text{A}$ is 40% higher at pHs 7.5 and 11 compared to that at pHs 7 or 8.

All the 12 rabbits immunized with bovine serum albumin (BSA) conjugates of $i^6\text{A}$ gave hapten specific antibodies. Increase in the hapten density from 4 to 27 molecules of $i^6\text{A}$ per BSA molecule and larger number of immunizations showed beneficial effect on the titres of $i^6\text{A}$ -antibodies.

$i^6\text{A}$ -antibodies were fractionated on Sepharose-AH- $i^6\text{A}$ column, using pyridine, $i^6\text{A}^{\text{ox-red}}$, guanidine hydrochloride and NaOH for elution. These fractions bind to $^3\text{H-}i^6\text{A}$ better than to $^3\text{H-}i^6\text{A}^{\text{ox-red}}$. tRNA-binding activity was studied in detail using pyridine-eluted fraction. The binding increased with NaCl concentration (up to 2M) showing that it is not an ionic reaction and probably a hydrophobic interaction.

Affinity columns prepared from Sepharose and $i^6\text{A}$ -antibodies were used to purify $i^6\text{A}$ -containing tRNAs from *Candida tropicalis* to almost 100% purity. When ^{32}P -labelled tRNAs were digested with RNase T_2 and spleen phosphodiesterase in the presence of $i^6\text{A}$ -antibodies, $i^6\text{A}$ -containing oligonucleotide fragments remained undigested. The chain length of the oligonucleotides varied from three upwards.

Lymphosarcoma cells have been shown to have higher levels of $i^6\text{A}$ in tRNAs compared to normal lymphocytes⁶. It was of interest to check whether organisms multiply well in human body, for example pathogenic organisms have higher levels of $i^6\text{A}$ -containing tRNAs compared to related non-pathogenic organisms. Studies on the levels of $i^6\text{A}$ in tRNAs of five species of the genus *Candida* show that the highly pathogenic species, for example, *Candida albicans* and *Candida tropicalis* show high levels of $i^6\text{A}$ in tRNAs.

It has been observed by earlier workers⁷ that $i^6\text{A}$ conjugates of BSA elicit a high titre of antibodies. Since $i^6\text{A}$ is a cytokinin in plants and it perturbs a variety of biological functions in mammalian cells in culture, it was of interest to investigate whether $i^6\text{A}$ by itself has any effect on the levels of antibodies in the sera of rabbits. $i^6\text{A}$ was injected into rabbits in different doses and the levels of IgG in the sera was estimated over a period of time. The results show that $i^6\text{A}$ injections gave a boost to IgG levels (2- to 5-fold) in experimental rabbits.

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Thesis Abstract (M.Sc. Engng)

Spherical shell with a conical nozzle by J. Jayaraman.

Research supervisors: K.P. Rao and R. Peravali (ADE).

Department: Aeronautical Engineering.

1. Introduction

Spherical shells are commonly used in industries as they are most efficient in carrying pressure loads and for ease of fabrication. Openings are introduced to facilitate operation or accessibility. These openings may be closed by covers or nozzles and may also be edge-reinforced. An exact estimate of the stresses around such discontinuities is important as they give rise to stress concentrations.

In this thesis the stress analysis of a spherical shell with a conical nozzle subjected to internal pressure and thermal loadings is presented. The problem of a junction reinforced spherical shell with a conical nozzle is also considered.

A general survey of literature pertaining to studies on stress concentration at shell intersection is presented. The presentation is made in the following sub-sections: i) spherical shells with discontinuities, ii) thermal stress studies, iii) studies using finite elements, and iv) studies using experimental stress analysis.

2. Pressurized spherical shell with a conical nozzle

Reissner's¹ spherical shell equations are used to obtain the stresses in the spherical shell while those of the conical nozzle are expressed in terms of Bessel functions². The nozzle is considered as an elastic discontinuity in the spherical shell. The stresses and displacements in the spherical shell and nozzle are obtained by superposing the perturbation caused by the discontinuity on the membrane state that exists in the structure without discontinuity, and its effect is assumed to be local in character. Sufficient number of equations to solve for the unknowns in the solution are obtained by considering the equilibrium of forces and moments and by satisfying the capability conditions at the shell-nozzle junction. The total solution to the problem is obtained by superposing the perturbation component of stresses on the undisturbed membrane state of stress in the shell and the nozzle.

It is found that the curvature parameter β_s (defined as $\beta_s^2 = (a^2/Rt_s) [12(1 - \gamma_s^2)]^{1/2}$ where 'a' is the radius of the opening at the junction, R and t_s are the radius and thickness of the shell and γ_s is the Poisson's ratio) plays a significant role in determining the stress concentration at the junction. The effect of various parameters on the stress concentration at the junction is considered and results are presented in the form of carpet plots which help in design.

3. Junction-reinforced spherical shell with a conical nozzle

An analytical solution to the problem of a junction-reinforced spherical shell with a conical nozzle under internal pressure is presented. The method followed is the same as that for a pressurized spherical shell with a conical nozzle. Herein the reinforcement is also considered to be an elastic discontinuity in the spherical shell. It is assumed to be rectangular in cross-section possessing extensional and bending rigidities.

Outside reinforcement is found to be far superior to inside reinforcement. With increasing λ (the parameter representing the volume of the material used in the reinforcement in comparison with the material removed) the stress concentration is found to decrease both in the shell and nozzle. The parameter μ (square of the radius of gyration of the reinforcement to the shell thickness) has very little effect on S.C.F. It is found that H_c/t_c (eccentricity with respect to nozzle middle surface) has a very small effect whereas H_s/t_s (eccentricity w.r.t. the shell) has a significant effect on the S.C.F.

4. Thermal stresses in a spherical shell with a conical nozzle

Stresses are obtained in a thermally loaded spherical shell with a conical nozzle. Thermal loading consists of steady temperature which is uniform on the inner and outer surfaces of the shell and cone but may vary across the thicknesses. Thermal stress problem is converted into an equivalent static loading problem and the solution is obtained by a continuum approach. The effect of various parameters on the S.C.F. is studied and presented in a form useful to designers.

5. Conclusion

The method developed is simple to apply and covers a wide range of discontinuity dimensions including those for which Esslingers³ or Geckeler's assumptions are valid. Limiting cases considered using the present analysis leads to results which compare well with existing analytical solutions. Main findings are summarised and scope for further work is discussed.

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