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MICHAEL CONDENSATION

By

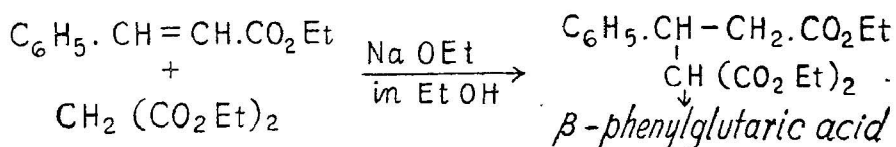
D. K. BANERJEE

Professor of Organic Chemistry, Indian Institute of Science, Bangalore.

Michael reaction is a base-catalysed addition to a carbon-carbon double bond of a conjugated unsaturated ketone, ester, nitrile etc. by attack of an anion formed from compounds containing reactive methylene group, e. g. pseudo-acidic ketone, ester, nitrile, nitro-compound, etc.

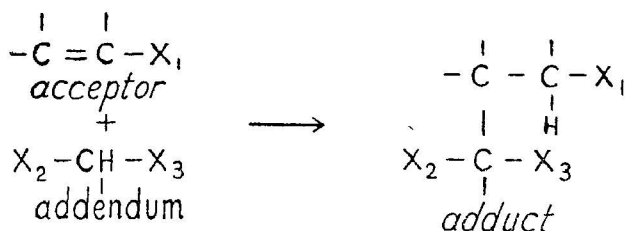
In 1887, Michael¹ first carried out the addition of ethyl malonate to ethyl cinnamate in the presence of an ethanolic solution of sodium ethoxide and the resulting addition product could be hydrolysed, and decarboxylated to β -phenylglutaric acid :

FIG. 1



Since then a very large number of active methylene components and acceptor components have been used successfully¹ and on the basis of accumulated experience Michael condensation may be generally represented as follows :

FIG. 2



Examples have been reported in which X_1 is $-\text{COOR}^1$, $-\text{COR}^3$, $-\text{CN}^4$, $-\text{CONH}_2^5$, $-\text{NO}_2^6$, $-\text{SO}_2\text{R}^7$, or $-o-$ or $p-$ $\text{C}_6\text{H}_4\text{N}^{2b}$, and in which X_2 , X_3 , or

both are $-\text{COOR}^1$, $-\text{COR}^{1b}$, $-\text{CN}^8$, $-\text{CONH}_2^9$, $-\text{NO}_2^{10,2c}$, $-\text{SO}_2\text{R}^{11}$, $-\text{CHO}^{12}$, or $-\text{o}-\text{C}_6\text{H}_4\text{N}^{2d}$. One of the two negative groups in the addendum may be aryl^{11,13}. If a very effective negative group is present in the addendum, a second negative group may be unnecessary^{14,2d}. The acceptor may be acetylenic¹⁵, rather than olefinic. Either the acceptor¹⁶ or the addendum¹⁷ may be vinylogues of the structures indicated above.

Experimental conditions: (a) *Catalyst* (b) *Solvent* (c) *Temperature*.

(a) Following catalysts have been employed with success: (1) Sodium or potassium alkoxide in different proportion (ii) metallic sodium (iii) sodamide (iv) piperidine (v) diethylamine and (vi) triethylamine.

Amines have been found to be the safest catalyst in that they seldom cause any reaction other than normal condensation. One-sixth to one-third of an equivalent of sodium alkoxide or one equivalent of sodium alkoxide with two equivalent of the addendum may cause condensation in cases where amines do not, and is less likely to cause side reactions than the use of one equivalent of the alkoxide with one equivalent of the addendum. If a reactant or product undergoes alcoholysis readily in the presence of alkoxides or if the metallic derivative of the active methylene compound is not readily formed, the derivative may be prepared by the use of metal itself or its amide. Potassium alkoxide is found to be more effective than sodium alkoxide.

(b) Following solvents are commonly used: (i) methanol (ii) ethanol (iii) *t*-butanol (iv) benzene (v) ether (vi) dioxane. A homogeneous solution of reactants may be treated with amines without using any solvent.

(c) Most Michael additions are exothermic, and so a larger yield of addition product results at lower temperatures. With alkoxides as catalyst the best results are obtained by allowing the reaction to stand at room temperature for twenty to one hundred-fifty hours. Higher temperatures may give lower yields, presumably because they favour retrogression and increase the side reactions. However, if ring closures or the formation of trimolecular compounds are desired, the reaction may be carried out under reflux. With amines the reaction is slow and a long reflux period is necessary.

The nature of X_1 , X_2 and X_3 .

An arrangement of labilising groups in the order of their ability to activate the double bond of the acceptor, or the addendum would be very useful. Unfortunately such data are not available. Generally, it can be said that an unsaturated ketone is more reactive than the corresponding

ester and the latter more reactive than the nitrile. Cyanoacetic esters give generally higher yields of addition products than do malonic esters.

Effect of the substitution on the α and β atoms.

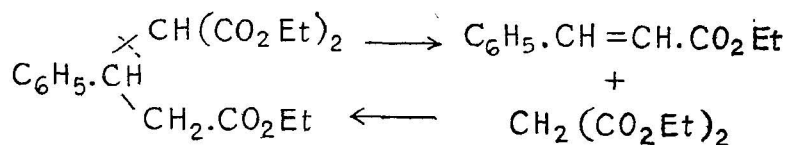
1. The reactivity of the acceptor decreases as the hydrogens are replaced by larger groups. This is true for both α - and β - positions. Preparative yields of Michael addenda with ethyl malonate or ethyl cyanoacetate may be obtained, when one phenyl group is, or two methyl groups are, present in the acceptor; but not when two such phenyl groups, or three methyl groups, are present.

2. The reactivity of the acceptor is decreased if the substituent is alkyl^{18,8,14a}, aryl, ethoxycarbonyl, or acyl. The case of ethyl cinnamate not reacting with anthrone, in contrast to the formation of the condensation product in good yield with ethyl benzalmalonate (the α -ethoxycarbonyl derivative of ethyl cinnamate), provides an exception to this generality.

Retrogression.

The reversibility of Michael reaction was first noticed by Vorlander¹⁹ and it was thoroughly studied by Ingold^{17b,c} *et al.* They reinvestigated the condensation of ethyl malonate with ethyl cinnamate and showed that the addition product, ethyl β -phenylpropane- α, α, γ -tricarboxylate, on being heated with an ethanolic solution of an equivalent quantity of sodium ethoxide reformed 60% of the original acceptor and addendum components. That this was the equilibrium mixture was proved by the fact that whether the starting-point was the pure adduct, or a mixture of equivalent quantities of constituent components, or any mixture of this mixture with the adduct, the end reaction product had the same composition :

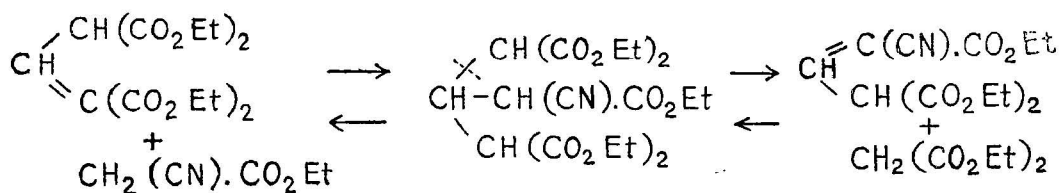
FIG. 3



In certain cases fission of the adduct occurs to yield components different from the starting materials. For example^{17e}, when ethyl cyanoacetate is allowed to interact with ethyl dioxycarbonylglutaconate in the presence of one molecular

proportion of sodium ethoxide, the isolable products are ethyl cyanooxycarbonylglutaconate and ethyl malonate only :

FIG. 4

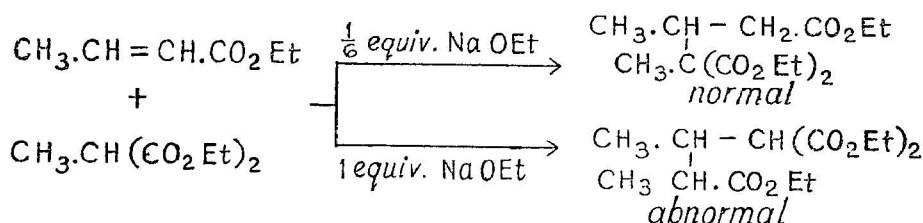


The adduct is formed as the principal constituent when amines are used a catalyst.

Abnormal Michael Condensation^{20,28}.

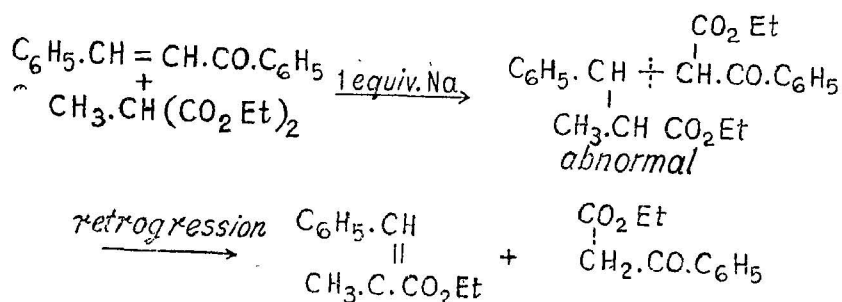
In this case a rearrangement addition product is formed in which neither the carbon skeleton of the addendum nor the acceptor molecule remains intact. An example²⁰ of this is the formation of ethyl α, β - dimethyl - α' - ethoxycarbonylglutarate, instead of α, β - dimethyl - α - ethoxycarbonylglutarate, by the interaction of ethyl crotonate and ethyl methylmalonate using one equivalent of sodium ethoxide. However, the use of one sixth equivalent of sodium ethoxide yields the normal addition product.

FIG. 5



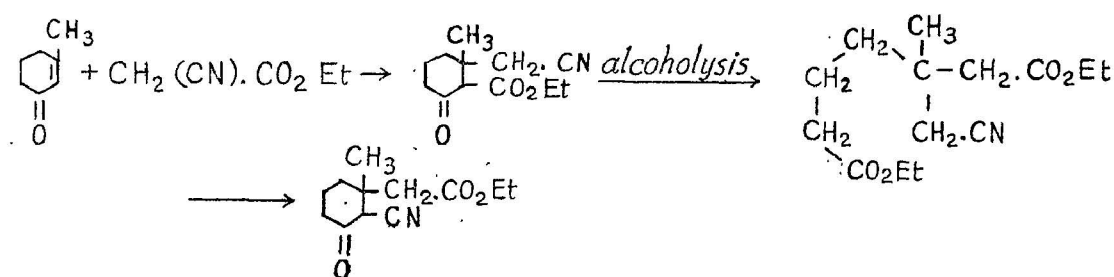
An abnormal Michael condensation may be followed by retrogression to yield rearrangement-retrogression products. The condensation of benzylideneacetophenone with the sodio derivative of ethyl methyl malonate to yield ethyl benzoylacetate and ethyl α - methylcinnamate provides an example²¹.

FIG. 6



An unusual type of transformation²⁷ following abnormal Michael condensation is illustrated by the interaction of 3-methyl-2-cyclohexenone and ethyl cyanoacetate.

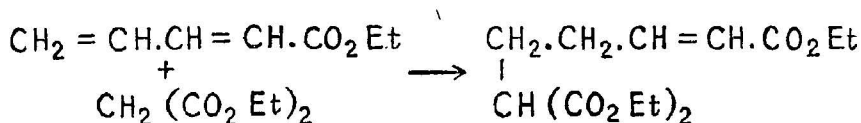
FIG. 7



Addition to conjugated systems.

The addition of ethyl malonate to β -vinylacrylic ester takes place exclusively at the δ -position.

FIG. 8



The effect²² of methyl substitution in β -vinyl-acrylic ester on the propor-

tion of β - and δ - addition has been summarised in the table below :

FIG. 9

Esters on the percentage of β -adduct in Michael addition

V. A. E. (=Vinylacrylic ester): $\begin{matrix} \delta & \gamma & \beta & \infty \\ \text{C}=\text{C}-\text{C}=\text{C}-\text{CO}_2\text{Et} \end{matrix}$

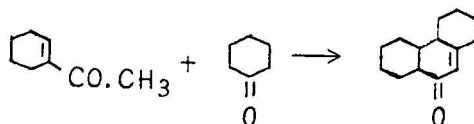
V. A. E.	Parent	δ -Me	α , δ -DiMe	β , δ -DiMe	γ , δ -DiMe
V. A. E.+malonate	0	9	—	—	—
V. A. E.+cyanoacetate	—	10	0	0	72

δ -Phenyl-substitution leads exclusively to β -addition²³. The addition of methyl malonate to the hexatriene ester, under mild condition, i.e. low concentration of alkali, gave only the β -adduct and the ζ -adduct, with the former preponderating, and no detected amount of δ -adduct²⁴.

Addition with ring closure.

An example²⁵ of this is the condensation of cyclohexanone with acetylcyclohexene in the presence of sodamide to yield 9-keto-1:2:3:4:4a:5:6:7:8:8a:8b:-dodecahydrophenanthrene²⁵.

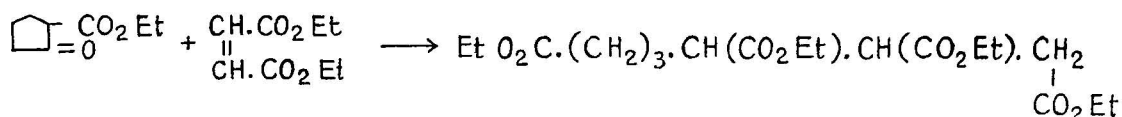
FIG. 10



Addition with alcoholysis.

The condensation of ethyl cyclopentanone - 2 - carboxylate with ethyl maleate to give ethyl hexane-1:2:3:6-tetracarboxylate provides an example²⁶.

FIG. 11

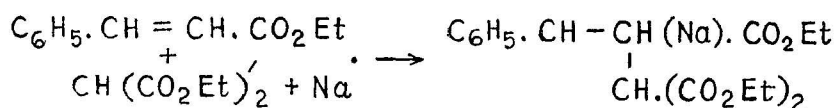


The use of piperidine in this case yields the normal product,

Mechanism of Michael condensation.

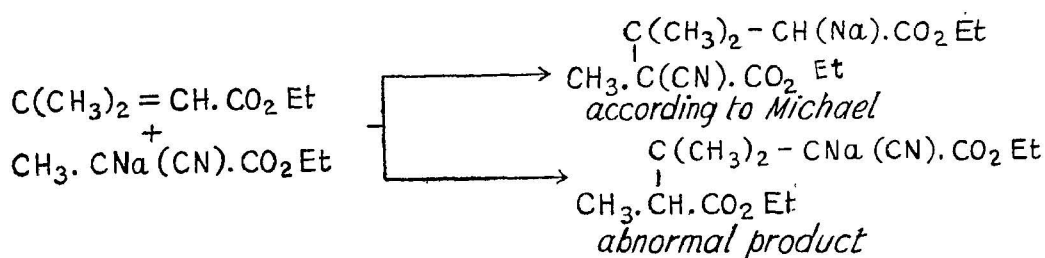
Michael^{1b} originally formulated the addition process as the simple union of the unsaturated system with the sodio-compound in its ionic components, Na^+ and $\text{CH}(\text{CO}_2\text{Et})_2^-$, the former attaching itself to the α -carbon atom and the latter to the β -carbon atom.

FIG. 12



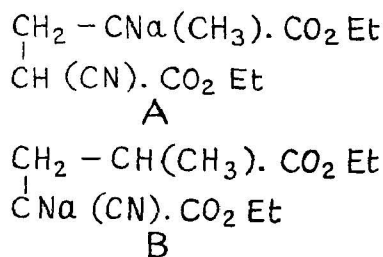
Thorpe and Young²⁹ investigated the products formed by heating ethyl β , β -dimethylacrylate with ethyl sodiomethylcyanoacetate and found that only the abnormal condensation product was formed.

FIG. 13



Thorpe *et al.*³⁰ also studied the action of ethyl sodiocyanoacetate on α -methylacrylate and found that the properties of the adduct did not correspond with the structure (A) but with the isomeric structure (B).

FIG. 14



On the basis of these observations Thorpe advanced the hypothesis that the reactive parts of ethyl sodiocyanoacetate and ethyl sodiomethylcyanoacetate are H and $\text{CNa}(\text{CN}).\text{CO}_2\text{Et}$, and CH_3 and $\text{CNa}(\text{CN}).\text{CO}_2\text{Et}$ respectively and these add on to the unsaturated ester.

The fact that in Michael reaction the use of small quantity of sodium ethoxide gives the normal adduct, whereas the use of one equivalent of the alkoxide forms the abnormal product, led Michael and Ross²⁰ (Fig. 5) support the hypothesis of Thorpe, assuming that sodium ethoxide in the former case acts 'catalytically' to promote direct union of the free malonic ester with the unsaturated compound.

It has then been suggested by Holden and Lapworth²¹ that the abnormal addition product with a structure expected from Thorpe's theory could result equally well by migration, during the addition process, of an ethoxycarbonyl group from the malonic ester part of the adduct, through Dieckmann type condensation followed by decomposition of the cyclobutanone derivative.

FIG. 15

Interpretation of Michael's product²⁰ according to Lapworth

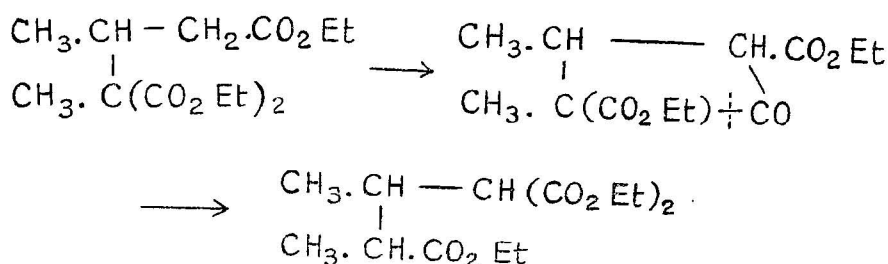
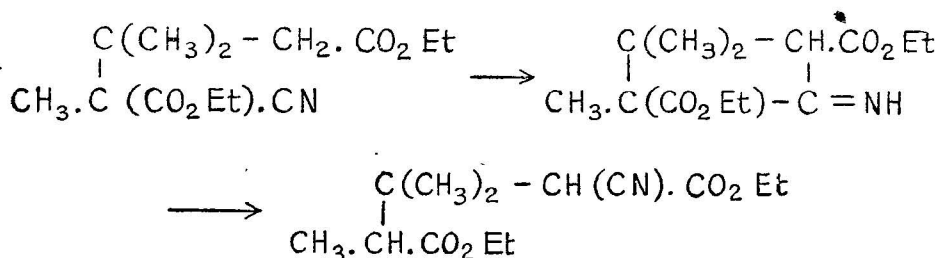


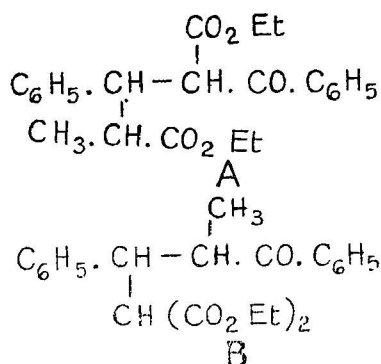
FIG. 16

Interpretation of Thorpe's product²⁹ according to Lapworth



Lapworth then condensed benzylideneacetophenone with the sodio-derivative of ethyl methylmalonate (Fig. 6). This reaction according to Lapworth's mechanism should yield (A) and according to Thorpe (B) as the abnormal product. As mentioned before, from this reaction there was isolated ethyl benzoylacetate and ethyl α -methylcinnamate, which could have been formed only from A by retrogression reaction.

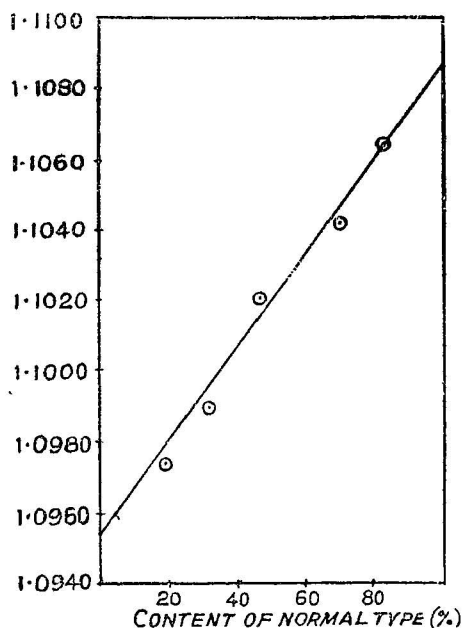
FIG. 17



Gardner and Rydon³¹ have subsequently shown that all the then observations can be accounted for on the basis of the Holden-Lapworth mechanism. They also suggested that the course of the addition reaction is affected markedly not only by the amount of condensing agent but also by the structures of the reactants.

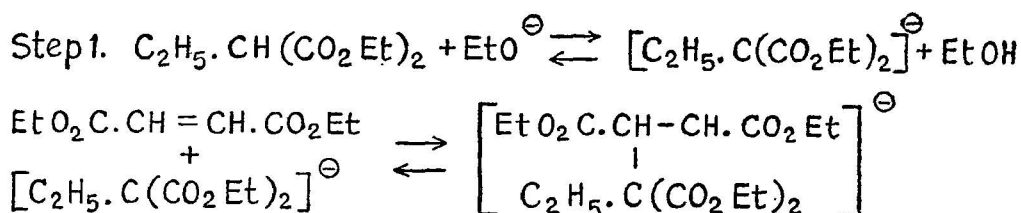
Tsuruta, Yasuhara, and Furukawa³² studied the reaction between ethyl ethylmalonate and ethyl fumarate, and determined the ratio of the normal and the abnormal products under various conditions by measuring the specific gravity of the mixtures of these adducts.

FIG. 18



These workers suggested that the reaction proceeded in two stages, (1) rapid formation of an adduct anion, (2) the successive interaction with free ethyl malonic ester or the slower isomerisation to the abnormal product.

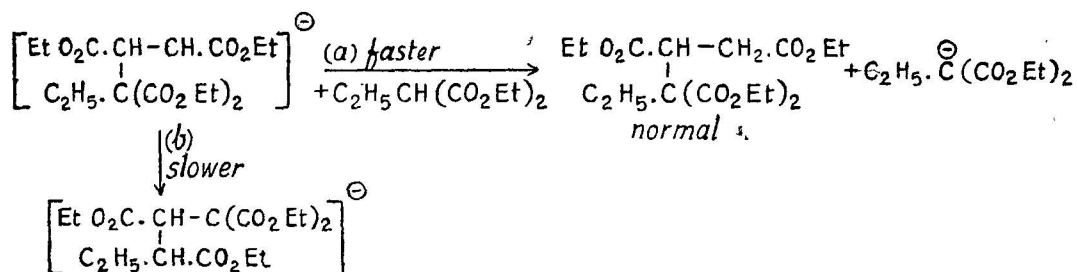
FIG. 19-a



Step 2. (a) Stabilisation by interaction with free ethylmalonic ester to form the normal adduct, which is faster than the isomerisation to the abnormal product.

(b) Isomerisation to the abnormal type, a slower reaction.

FIG. 19-b

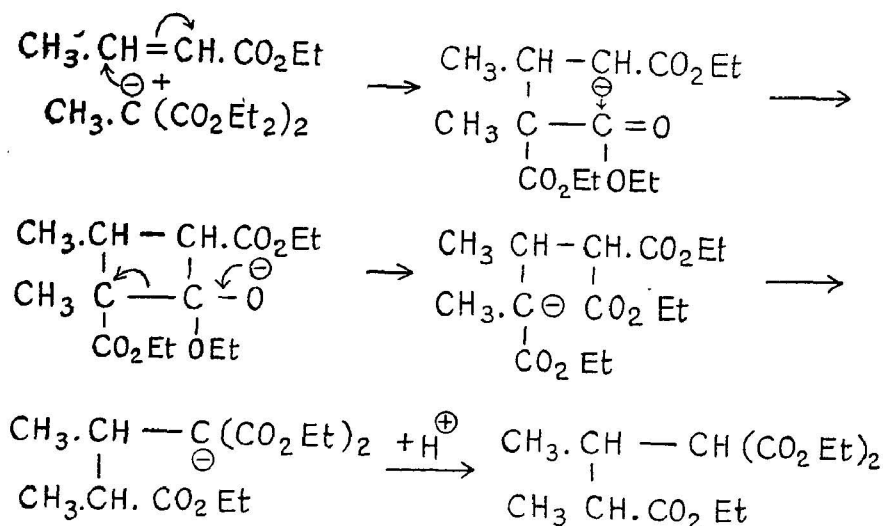


According to this view, when smaller quantity of sodium ethoxide is used the normal adduct is formed due to the presence of free ethylmalonic ester, and the isomerisation to the abnormal product should not take place if free malonic ester is present in an effective concentration. As a matter of fact when fumaric ester was treated with two equivalents of ethylmalonic ester, even in the presence of one equivalent of sodium ethoxide only the pure normal adduct was formed. However, these workers did not suggest any mechanism for the isomerisation of the adduct anion to the abnormal product.

Lapworth's mechanism for the formation of the abnormal product, requiring the migration of the ethoxycarbonyl group from the malonic ester moiety to

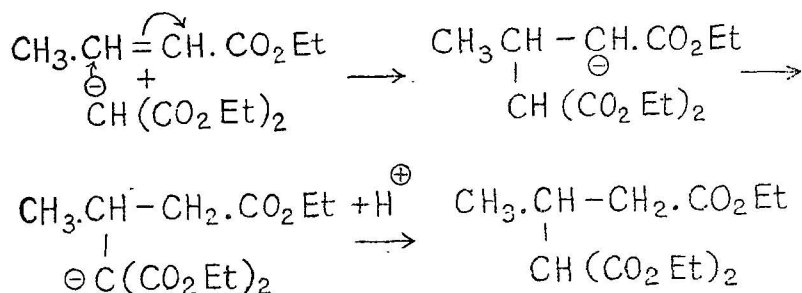
the carbon atom α to the ester group in the acceptor component, has received confirmation by the work of Simamura, Inamoto, and Suehiro³³, who carried out the Michael addition of ethyl methylmalonate to ethyl crotonate-(carbonyl- C^{14}) with one equivalent of sodium ethoxide. The addition product, ethyl α -ethoxycarbonyl- β , γ -dimethylglutarate, was hydrolysed and the resulting acid decarboxylated by heating. The evolved carbon dioxide contained 42% of the radiocarbon of the original ethyl crotonate. This could have happened only if the aforementioned migration occurred according to Lapworth's mechanism (Figs. 15, 16). These Japanese workers elaborated the mechanism in the light of the findings of other group of Japanese workers³² as follows :

FIG. 20



Later Simamura and Inamoto³⁴ studied the Michael addition of ethyl malonate to ethyl crotonate-(carbonyl- C^{14}) with one equivalent of sodium ethoxide. The adduct, ethyl α -ethoxycarbonyl- β -methylglutarate, on hydrolysis and decarboxylation yielded β -methylglutaric acid showing most of the radioactivity originally present in the ethylcrotonate. This proved that the migration of the ethoxycarbonyl group did not take place in this case, and this was explained by the stabilisation of the adduct-anion by internal transfer of the lone pair of electrons to the malonic ester moiety of the adduct, which carried a hydrogen atom in this case. This type of stabilisation was foreseen by Holden and Lapworth²¹,

FIG. 21



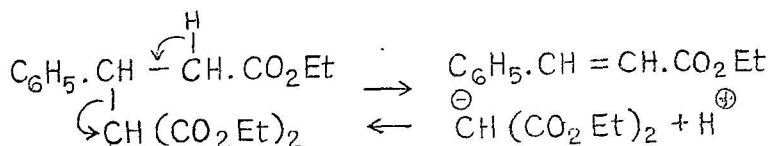
Explanation of the effect of the substitution on the α and β atom ^{35a}.

Alkyl groups, and still more aryl groups, in either the α - or the β - position of the acceptor are thermodynamically inhibitory towards addition¹⁷. Presumably this is because they hyperconjugate or conjugate with the double bond, thereby tending towards its preservation. A primary steric effect may also contribute to the result ^{17b}.

Mechanism of retrogression.

The retrogression of the Michael adduct may take place through the following mechanism :

FIG. 22

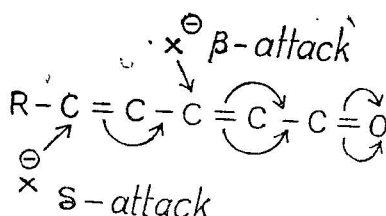


The equilibrium will depend upon the comparative acidity of the pseudo-acidic adduct and the pseudo-acidic addendum or upon the comparative stability of the anions formed by them.

Explanation for the mode of addition to the conjugated system ^{35b}.

In Michael addition to vinylacrylic ester derivatives, either the β - or the δ - position is positively polarisable, and is therefore the potential place for attack by the addendum anion :

FIG. 23

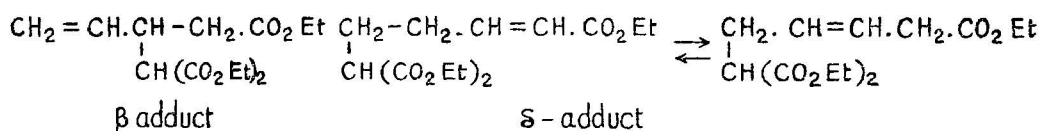


In the case of a β -attack the protonic part of the addendum will necessarily enter the α -position, whereas in a δ -attack the proton may enter the α -or the γ -position. The kinetic control would send the proton into the α -position, while its thermodynamically most stable position would depend on the substituents present.

In a kinetically controlled reaction, the anion uptake should be at the δ -carbon atom, as the polarity in a freely conducting, linear system is developed at its ends. But in an equilibrated reaction, the final attachment(s) will depend upon the character of the substituents.

Generally Michael additions are run to equilibrium, hence the orientation of addition in observed cases has been considered as thermodynamically controlled. In case of the addition of malonic ester to β -vinylacrylic ester the relative stabilities of the following structures has to be considered :

FIG. 24

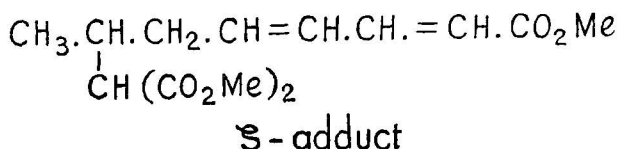
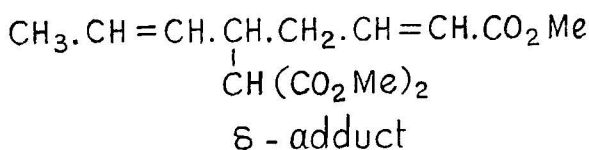
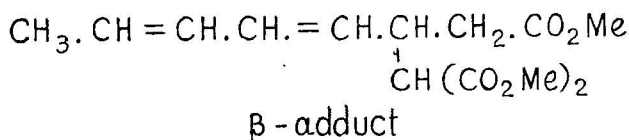


The exclusive δ -addition to the vinylacrylic ester may be due to the stabilisation of δ -adduct by conjugation between the olefinic bond and the terminal oxycarbonyl group, while the β -adduct has no such compensating factor of stability. However, the δ -methyl substituent present in the sorbic ester, by its hyperconjugation with the γ , δ -olefinic bond of the β - adduct, confers on the latter a partly compensating stability, resulting in its presence in appreciable quantity in the equilibrium product. An α - or β - methyl substituent confers extra stability on the more stable δ - adduct, by hyperconjugation with its α , β - olefinic bond, whereas a γ - methyl substituent, in addition to the δ - methyl substituent, further stabilises the β - adduct by hyperconjugation, making this

product more stable than any form of the δ - adduct. A δ - phenyl substitution in vinylacrylic ester results in exclusive production of the β - adduct in equilibrium. This is due to the dominating energy effect of the phenyl-to-vinyl conjugation.

The absence of δ - adduct, in the condensation products of methyl malonate and hexatriene ester, is due to the fact that its formation would break up a butadienoid conjugation, which the β - or ζ - adduct can preserve. In the equilibrium product, the most stable ζ - adduct should have preponderated, and the preponderance of the β - adduct can be explained by the fact that reaction was carried out in low concentration of alkali and the reaction was not allowed to reach the equilibrium point.

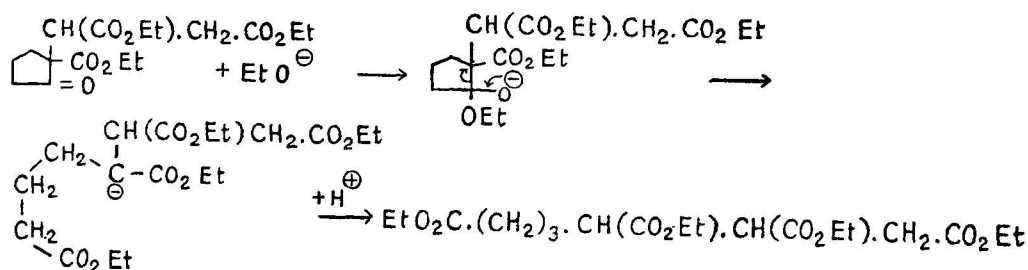
FIG. 25



Mechanism of the alcoholysis of the Michael adduct :

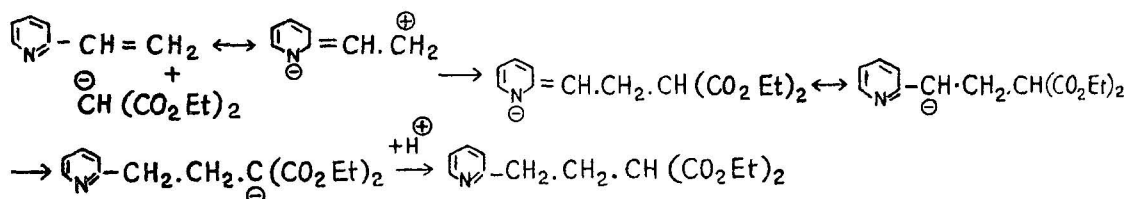
The attack of the ethoxyl ion on the adduct followed by the uptake of a proton may result in the fission product by the following mechanism :

FIG. 26



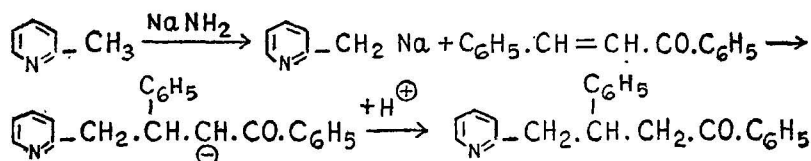
Example where the pyridine residue acts as the activating group in the acceptor ^{2b}.

FIG. 27



Example where the pyridine residue acts as the activating group in the addendum ^{2d}.

FIG. 28



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QUANTUM THEORY OF VALENCY

By Rev. Fr. L. M. YEDDANAPALLI,

S. J., Ph. D. (Princeton) D. Sc. (Louvain) F. R. I. C.

Head of Chem. Dept. & Rector, Loyola College, Madras—31.

LECTURE 1.

Synopsis : Mathematical Introduction. Differential equation for simple harmonic motion and its complete solution. Equation for wave propagation and its solution. The principle of superposition and its important applications. Progressive and standing waves. Eigenvalues and eigenfunctions. Derivation of Schrodinger's equation. Meaning of the amplitude function. Atomic orbitals.

Schrodinger's equation is the starting point of quantum or wave mechanics, and hence of the wave mechanical approach to the problem of the chemical bond. The fundamental mathematical concepts, principles and procedures involved in handling this equation can conveniently be illustrated by a study of the motion of a harmonic oscillator, such as is obtained when a particle of mass m is acted upon by a restoring force f which is directly proportional to the displacement from equilibrium position. The equation of this motion is given by

$$f = -kx$$

Since f is also equal to ma which in turn can be expressed as $m \frac{d^2x}{dt^2}$ we can write

$$m \frac{d^2x}{dt^2} = -kx \quad (1)$$

Representing (dx/dt) by p ,

$$\frac{d^2x}{dt^2} = \frac{dp}{dt} = \frac{dp}{dx} \cdot \frac{dx}{dt} = p \cdot \frac{dp}{dx}$$

so that eqn. (1) becomes $p \frac{dp}{dx} + \frac{k}{m}x = 0$ which on integration gives

$p^2 + \frac{k}{m}x^2 = \text{Constant}$. At $x = A$ (the maximum amplitude), the kinetic energy is zero and hence $p = 0$, and the value of the constant is $(k/m)A^2$.

$$\text{Hence, } \left(\frac{dx}{dt}\right)^2 = \frac{k}{m}(A^2 - x^2) \text{ or } \frac{dx}{(A^2 - x^2)^{1/2}} = \left(\frac{k}{m}\right)^{1/2} dt$$

or $\sin^{-1}(x/A) = (k/m)^{1/2} \cdot t + \text{Const}$. Again at $t = 0$ and $x = 0$, const. is equal to zero. Consequently $x = A \sin (k/m)^{1/2} \cdot t$. If now, $(k/m)^{1/2}$ is set equal to $2\pi\nu$ then $x = A \sin 2\pi\nu t$,

The graphical representation of this expression is shown in Fig. 1.

Since ν is the frequency of motion, that is the number of vibrations per unit time, $(1/\nu)$ is the period of motion τ , the time taken for a single motion.

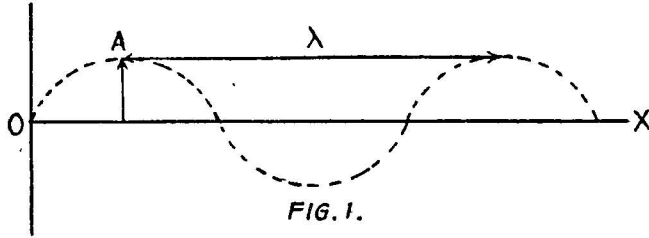


FIG. 1.

A is the maximum amplitude, so that at $x = A$, the oscillation reverses direction and the kinetic energy is zero, and the potential energy, maximum.

If the harmonic oscillator is placed in a fluid medium, it will set up a disturbance which will be periodic not only in time but also in space, so that a wave is generated similar to sound waves set up by a tuning fork or electromagnetic waves by an oscillating electric dipole.

The sine wave represented by Fig. 1, is the profile of the wave in one direction, say, the x -direction. At $x=0$, the magnitude of the disturbance ψ will be zero, and it will be zero at $x=\lambda, 2\lambda, \dots n\lambda$, where λ is the wave length and is a measure of the wave's periodicity in space just as τ is the measure of its periodicity in time. The profile of the wave can be expressed by

$$\psi = A \sin 2\pi \frac{x}{\lambda}$$

If the velocity of the wave in the medium is c , then in time t , it will move a distance ct , and the equation for the moving wave becomes $\Phi = A \sin 2\pi/\lambda (x-ct)$ which can also be written as $\Phi = A \sin 2\pi(kx-\nu t)$ where $k = 1/\lambda$, the wave number. This is one solution of the general partial differential equation of wave motion applicable to all sorts of wave from tidal to radio waves, and the equation in one dimension is

$$\frac{\partial^2 \Phi}{\partial x^2} = \frac{1}{c^2} \cdot \frac{\partial^2 \Phi}{\partial t^2}$$

and in three dimensions it is,

$$\frac{\partial^2 \Phi}{\partial x^2} + \frac{\partial^2 \Phi}{\partial y^2} + \frac{\partial^2 \Phi}{\partial z^2} = \frac{1}{c^2} \cdot \frac{\partial^2 \Phi}{\partial t^2}$$

$$\text{or } \nabla^2 \Phi = \frac{1}{c^2} \cdot \frac{\partial^2 \Phi}{\partial t^2}$$

where $\nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}$ is the Laplacian Operator.

Now this is a homogeneous linear partial differential equation. One specific property of this equation is that if Φ_1 and Φ_2 are any two solutions of the equation, then a new solution can be obtained by a linear combination of them :

$$\Phi = a_1 \Phi_1 + a_2 \Phi_2$$

where a 's are constants. This is an illustration of the principle of superposition which is of fundamental importance in quantum or wave mechanics. The principle states that any number of solutions of the differential equation for a wave motion can be added together to give a new solution. It is in virtue of this principle that a complicated vibratory motion can be broken down into its normal modes, or a periodic function can be represented by a Fourier series. Note also its application in the quantum mechanical concept of resonance and of resonating canonical structures in connection with molecular structure (cf. later).

For the present, one important application of the principle of superposition is the addition of two wave functions, similar in every respect but for their travelling in opposite directions, to get a new solution thus,

$$\begin{aligned}\Phi &= A \sin 2\pi (kx - \nu t) + A \sin 2\pi (kx + \nu t) \\ &= 2A \sin 2\pi kx \cos 2\pi \nu t\end{aligned}$$

$$\text{using the relationship } \sin x + \sin y = 2 \sin \frac{x+y}{2} \cos \frac{x-y}{2}$$

The new wave moves neither forward nor backward, and is therefore a *stationary* or *standing* wave, whereas the original two waves are progressive waves.

A special feature of the stationary waves is that the disturbance Φ , whatever the time t , disappears at points at which

$$\sin 2\pi kx = 0, \text{ or } x = \frac{1}{2k}, \frac{2}{2k}, \frac{3}{2k} \dots \dots \frac{n}{2k}$$

These points are the nodes, at which the amplitude is zero, and the disturbance between successive nodes is $\frac{1}{2k}$ or $\frac{\lambda}{2}$ a half wavelength (cf. Fig. 1). The anti-nodes just midway between the nodes correspond to the maximum amplitude of the disturbance. In the case of progressive waves, the amplitude is continually changing with the distance x .

It may be noted that the wave equations to be derived later to describe the behaviour of electrons in atoms will be quite similar to those just employed for describing the stationary waves. It may therefore be useful to examine them in greater detail.

The above equation $\psi = 2 A \sin 2\pi kx \cos 2\pi \nu t$ can conveniently be written in the form $\psi = f(x) \cos 2\pi \nu t$

On differentiating with respect to x , we get

$$\frac{\partial \psi}{\partial x} = \cos 2\pi \nu t \frac{\partial f(x)}{\partial x}$$

$$\frac{\partial^2 \psi}{\partial x^2} = \cos 2\pi \nu t \frac{\partial^2 f(x)}{\partial x^2}$$

and with respect to t ,

$$\frac{\partial \psi}{\partial t} = -f(x) \sin 2\pi \nu t \times 2\pi \nu$$

$$\frac{\partial^2 \psi}{\partial t^2} = -f(x) \cos 2\pi \nu t \times (2\pi \nu)^2$$

Our equation of a wave motion is

$$\frac{\partial^2 \psi}{\partial x^2} = \frac{1}{c^2} \cdot \frac{\partial^2 \psi}{\partial t^2}$$

On substitution, one gets

$$\cos 2\pi \nu t \frac{\partial^2 f(x)}{\partial x^2} = \frac{1}{c^2} (-f(x) 4\pi^2 \nu^2 \cos 2\pi \nu t)$$

$$\text{or } \frac{\partial^2 f(x)}{\partial x^2} = - \frac{4\pi^2 \nu^2}{c^2} f(x)$$

where c is the velocity of the wave, so that t has been eliminated from the wave equation.

Further, since $c = \lambda \nu$, there results $\frac{\partial^2 f(x)}{\partial x^2} = - \frac{4\pi^2}{\lambda^2} f(x)$ (2)

Now it is to be noted that not every possible solution of this equation is a physically significant and acceptable solution. To make the point clear, consider the simplest differential equation, $dy/dx=1$, the solutions of which are $y=x+a$, where a is a constant, so that y can have any value depending on the value given

for the constant a . Similarly the solution of the above eqn. (2) will involve an integration constant and hence a large number of solutions can be had viz., $f(x_1)$, $f(x_2)$, $f(x_3)$ and so on. Of these, the only acceptable ones will be those satisfying what are known as "continuity" and "boundary" conditions. They are that $f(x)$ must be *continuous*, *finite*, and *single valued* for every value of x between the boundaries.

Thus Fig. 2 represents a function which would not be an acceptable solution of the wave equation, since there is a discontinuity at $x = x'$ and also the function has an infinite value at the point x' .

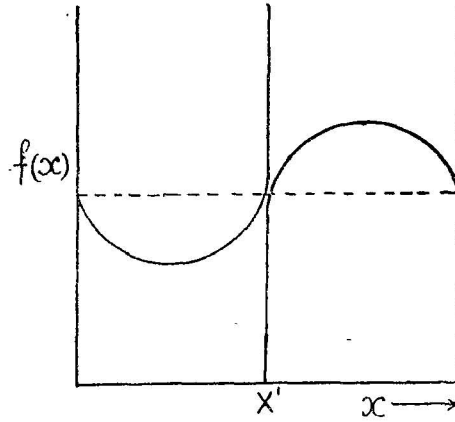


FIG. 2.

Single valued function means that the amplitude has only one value at a given position x' . The boundary conditions are imposed by the physical restraints

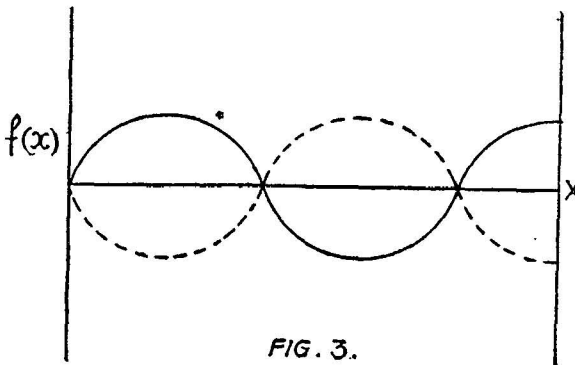


FIG. 3.

acting on the vibrating system. In the case of a stretched string, $f(x)$ must be zero at both ends of the string. This condition is not fulfilled in Fig. 3

in which $f(x)$ is not zero at the right-hand end of the string. The acceptable

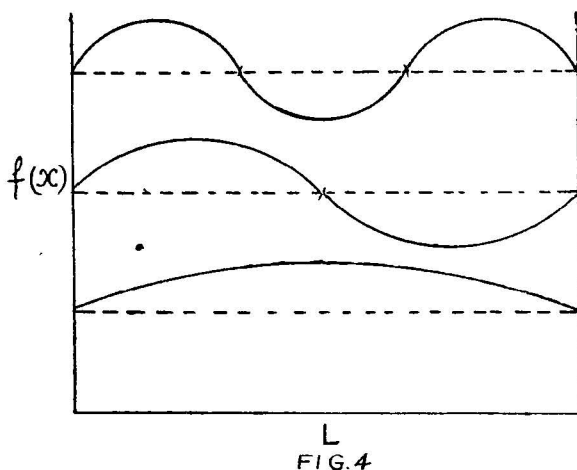


FIG. 4

solutions are represented by Fig. 4 in which $L = n \frac{\lambda}{2}$.

The values of λ are the “Eigenvalues”, and the corresponding functions are called “Eigenfunctions”.

After these introductory mathematical notions, we are in a position to deal with the main Schrodinger's equation. It may be recalled that although Bohr's theory was fairly successful in the case of a single electron such as the one in hydrogen atom, it could not be extended to two or more electron atoms. Further it was essentially based on the application of celestial classical mechanics to the Rutherford atom with superimposed arbitrary quantum conditions.

In 1923, Louis de Broglie introduced the idea of waves associated with electrons in motion, that is with periodicity. He suggested that a free electron is associated with a progressive wave, whereas a bound electron, as in the atom could be represented by a stationary or standing wave which could have only certain definite frequencies like a stretched string. By considering a photon, on the basis of relativity theory and Planck's quantum theory, the following relationships could be easily deduced :

$E = h\nu$ and $E = mc^2$ where m = mass of photon & c = velocity of light.

$$h\nu = mc^2 \quad \text{or} \quad \frac{c}{\nu} = \frac{h}{mc} = \frac{h}{p}; \quad p = \text{momentum}$$

He suggested that a similar equation could hold for the wavelength associated with a bound electron, that is,

$$\lambda = \frac{h}{mv} = \frac{h}{p}$$

in which m is the mass of the electron and v , its velocity. That the electrons have wave character was brilliantly demonstrated in 1927 by Davisson and Germer of Bell Telephone, New York, and independently by G. P. Thomson of Aberdeen University.

For the electron in a given orbit of radius r , say for hydrogen atom, the following relations can be easily deduced from the above considerations,

$$2\pi r = n\lambda = n \frac{h}{mv} \quad \text{or} \quad mvr = n \frac{h}{2\pi}$$

which naturally follows from basic principles here unlike as arbitrarily postulated by Bohr. This is one of the many achievements of wave mechanics in its justification.

Schrodinger introduced the equation which goes by his name almost by intuition, of course with the back-ground knowledge available at the time about electrons. The success of the equation was measured by its ability to account for the observable properties of hydrogen. However it is possible to deduce it systematically from the considerations which have been described earlier in this lecture.

For the motion of the electron in one direction, the appropriate equation which has already been deduced is (cf. eqn. (2)).

$$\frac{\partial^2 \psi}{\partial x^2} = - \frac{4\pi^2}{\lambda^2} \psi.$$

In three dimensions it will be

$$\frac{\partial^2 \psi}{\partial x^2} + \frac{\partial^2 \psi}{\partial y^2} + \frac{\partial^2 \psi}{\partial z^2} + \frac{4\pi^2}{\lambda^2} \psi = 0 \quad \text{or} \quad \nabla^2 \psi + \frac{4\pi^2}{\lambda^2} \psi = 0.$$

$$\text{Replacing } \lambda \text{ by } \frac{h}{mv}, \text{ we get } \nabla^2 \psi + \frac{4\pi^2 m^2 v^2}{h^2} \psi = 0 \quad (3)$$

In order to utilise this equation to calculate the energy states of a hydrogen atom with only one electron, the total energy is denoted by E and the potential energy by V , so that $(E-V)$ is equal to the kinetic energy of the electron, $1/2 \cdot mv^2$, from which it follows that $v^2 = 2(E-V)/m$

Substitution of this in eqn. (3) gives

$$\nabla^2 \psi + \frac{8\pi^2 m}{h^2} (E - V) \psi = 0 \quad (4)$$

which is Schrodinger equation.

The $\psi(x, y, z)$ function is quite similar to the $f(x)$ function which represents (cf. supra) the amplitude of the wave in the case of the stretched string and so is a sort of amplitude function. The intensity of light or electromagnetic field at any point is proportional to the square of the amplitude. If light is considered as consisting of photons, the more intense the light at a given point, more photons fall at that point. The same holds good for electrons. In view however of Heisenberg uncertainty principle, we can say that the greater the value of the amplitude function ψ , the greater the probability of finding the photon in the region in question, so that the ψ function may be called a probability, amplitude function.

Applying these considerations in the case of Schrodinger equation, if $\psi(x)$ is solution of the wave equation for an electron, then the probability of finding the electron within the region x and $x + dx$, is $\psi^2 dx$ or better still $\psi\psi^* dx$ where ψ^* is the conjugate complex of ψ that is if $\psi = e^{-ix}$ then, $\psi^* = e^{+ix}$ so that $\psi\psi^* =$ a real value.

Further more, as in the case of $f(x)$ function, ψ must be single valued, finite and continuous for all values of x . The ψ describing a single electron, in analogy with the older notion of orbits, is called an "orbital". As in the case of the stretched string, only for certain values of the total energy E , can the Schrodinger equation give the corresponding acceptable solutions of the wave function. Such functions are called the "eigenfunctions" and the corresponding energies, the "eigenvalues".

LECTURE 2

Application of Schrodinger equation to hydrogen and hydrogen like atoms. Conversion of the equation into polar co-ordinates, and separation of the variables into radial and spherical components. Solution of the equation for s , p , etc. orbitals, and their specific characteristics. Application to hydrogen molecule by valency bond (V. B.) method. The idea of spin valency.

The motion of the single electron in hydrogen atom or hydrogen like atom can be represented by the wave equation,

$$\nabla^2 \psi + \frac{8\pi^2 m}{h^2} (E - V) \psi = 0 \quad (4)$$

where ψ is the wave function, h , the Planck's constant, E the total energy, V the potential energy and m is the mass of the electron, although more exactly μ should be used for the reduced mass $Mm/(M + m)$ where M is the mass of the nucleus, but for the present m can serve as well. Now the potential energy of the electron at a distance r from the nucleus is equal to $-e^2/r$, so that (eqn) (4) becomes

$$\nabla^2 \psi + \frac{8\pi^2 m}{h^2} \left(E + \frac{e^2}{r} \right) \psi = 0 \quad (5)$$

It is found for practical purposes more convenient to replace the Cartesian co-ordinates by polar co-ordinates, namely $x = r \sin \theta \cos \phi$, $y = r \sin \theta \sin \phi$, $z = r \cos \theta$. Substitution of these values by a rather lengthy and involved manipulation, which need not be given here but which can be attempted by anyone who wishes to take the trouble, gives the following expression,

$$\begin{aligned} \frac{1}{r^2} \frac{\partial}{\partial r} \left(r^2 \frac{\partial \psi}{\partial r} \right) + \frac{1}{r^2 \sin^2 \theta} \left(\sin^2 \theta \frac{\partial^2 \psi}{\partial \phi^2} \right) + \frac{1}{r^2 \sin^2 \theta} \frac{\partial^2 \psi}{\partial \theta^2} \\ + \frac{8\pi^2 m}{h^2} \left(E + \frac{e^2}{r} \right) \psi = 0 \end{aligned}$$

The wave function, now consisting of three variables, can be separated into a product of three functions thus :

$$\psi(r, \theta, \phi) = R(r) \Theta(\theta) \Phi(\phi)$$

in which $R(r)$ is called the radial function, depending only on (r) the radial distance from the origin, $\Theta(\theta)$ depending on a sort of longitude and $\Phi(\phi)$ depending on a sort of latitude, the two latter functions being called spherical functions. Each of these functions can be separately evaluated and hence the total function. Without going into the details of the calculations, it may be stated that the final solution gives a set of discrete energy states for hydrogen atom, characterised by certain integers n , l , and m , expressed in a simple manner in the following way :

$$\psi_{nlm}(r, \theta, \phi) = R_{nl}(r) \Theta_l \Theta_m(\theta) \Phi_m(\phi)$$

in which $n = 1, 2, 3, \dots, \infty$; $l = 0, 1, 2, 3, \dots, (n-1)$ and $m = -l, -(l-1), -(l-2), \dots, -1, 0, +1, +2, +3, \dots, +(l-1), +l$. These can easily

be recognised respectively as the principal, azimuthal and magnetic quantum numbers. The principal quantum number n , determines the total number of nodes in the wave function, viz., $(n-1)$. These nodes may be present in the radial or the azimuthal function, since both these contain l . When l is equal to zero, $R(r) \cdot \Theta(\theta)$ contains no nodes. In other words, $(n-1)=0$, and the corresponding wave function is called s orbital. When $l = 1, 2$, etc, one, two nodes will appear and the corresponding orbitals are termed p, d , etc orbitals. It is to be noted that when $n = 2$, l may be zero, in which case however a node will appear $(n-1)$ even in an s orbital which will be designated as $2s$ orbital.

The following Table gives the complete eigen functions for the various orbitals.

n	l	m	state	complete function
1	0	0	1s	$\psi_{100} = \frac{1}{\sqrt{\pi}} \left(\frac{1}{a_0} \right)^{3/2} e^{-r/a_0}$
2	0	0	2s	$\psi_{200} = \frac{1}{4\sqrt{2\pi}} \left(\frac{1}{a_0} \right)^{3/2} \left(2 - \frac{r}{a_0} \right) e^{-r/2a_0}$
2	1	0	2p	$\psi_{210} = \frac{1}{4\sqrt{2\pi}} \left(\frac{1}{a_0} \right)^{5/2} e^{-r/2a_0} r \cos \theta$
2	1	± 1	2p	$\psi_{211} \rightarrow \begin{cases} \frac{1}{4\sqrt{2\pi}} \left(\frac{1}{a_0} \right)^{5/2} e^{-r/2a_0} r \sin \theta \cos \phi \\ \frac{1}{4\sqrt{2\pi}} \left(\frac{1}{a_0} \right)^{5/2} e^{-r/2a_0} r \sin \theta \sin \phi \end{cases}$

where $a_0 = \frac{h^2}{4\pi^2 m e^2} = 0.529 \text{ \AA}$ (Bohr's orbit for $n=1$)

These eigenfunctions when normalised to 4π , that is when the probability of finding the electron in a volume comprising whole of space is unity, as given by the integral $\int \psi^2 dv = 1$ evaluated for whole of space, namely, 2π in one direction and 2π in a direction perpendicular to the first, have the following simplified values :

n	l	m	symbol	normalised function value
1	0	0	1 s	1
2	1	0	2 p_z	$\sqrt{3} \cos \theta$
2	1	-1	2 p_y	$\sqrt{3} \sin \theta \sin \phi$
2	1	+1	2 p_x	$\sqrt{3} \sin \theta \cos \phi$

The charge cloud surface obtained by squaring the wave function for various orbitals will have the following appearance :

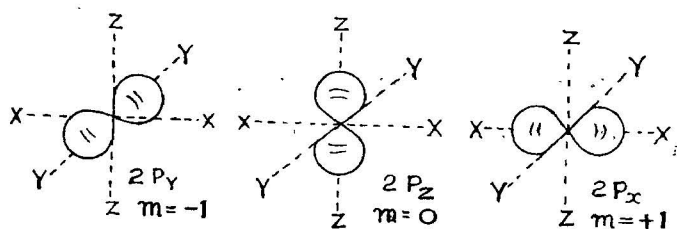


FIG. 5.

The s orbital is spherical, whereas the p orbitals are concentrated along three mutually perpendicular directions, a conclusion which was originally arrived at in organic chemistry in order to account for the structure of various molecules.

Application to Hydrogen Molecule: The problem here is to solve Schrodinger equation for a system of two electrons, as represented by

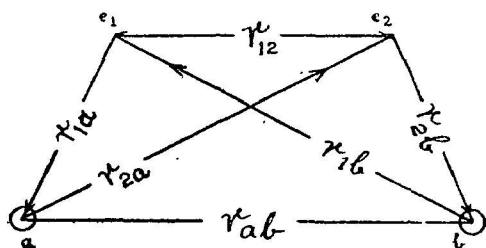


FIG. 6.

Let ψa^1 and ψb^2 represent respectively the eigenfunctions for electron (1) on nucleus a and electron (2) on nucleus b . These being probability amplitude functions, the corresponding orbits cannot be sharp but diffuse. The eigenfunction for the ground state of hydrogen has already been shown to be,

$$\psi_{100} = \frac{1}{\sqrt{\pi}} \left(\frac{1}{a_0} \right)^{3/2} e^{-r/a_0}$$

Following the so-called valency bond method (V. B.) due originally to Heitler and London and later elaborated by Slater and Pauling, as the two hydrogen atoms come together, the probability of simultaneously finding electron (1) on nucleus a and electron (2) on nucleus b , is the product of the two individual probability functions, that is, $\psi_a(1) \psi_b(2)$. Since there is no physical difference and so no possibility of distinguishing between the two systems, that is, electron (1) on a and (2) on b , and electron (2) on a and electron (1) on b , an equally probable combination is $\psi_a(2) \psi_b(1)$.

Applying the principle of superposition explained in Lecture 1, namely that if ψ_1 and ψ_2 are two solutions of the wave equation, any linear combination of the two is also an acceptable solution, one gets for H-H system two new wave functions :

$$\psi_s = \psi_a(1) \psi_b(2) + \psi_a(2) \psi_b(1)$$

$$\psi_A = \psi_a(1) \psi_b(2) - \psi_a(2) \psi_b(1)$$

The symmetrical wave function ψ_s indicates that it does not suffer any change in sign on changing the co-ordinates of the electrons, whereas this happens in the anti-symmetric function ψ_A . These are the molecular orbital functions; the square of each will give the probability of finding the electrons at any given place.

The spin property of the electrons must also be taken into account to get the correct wave functions. Electron spin s can have the allowed values $+\frac{1}{2}$ and $-\frac{1}{2}$ corresponding to the spin function α and β . For the two electrons, there are four possible complete spin functions as shown below.

Spin function	Electron (1)	Electron (2)
$\alpha(1) \alpha(2)$	$+\frac{1}{2}$	$+\frac{1}{2}$
$\alpha(1) \beta(2)$	$+\frac{1}{2}$	$-\frac{1}{2}$
$\beta(1) \alpha(2)$	$-\frac{1}{2}$	$+\frac{1}{2}$
$\beta(1) \beta(2)$	$-\frac{1}{2}$	$-\frac{1}{2}$

Since electrons are indistinguishable, one is again compelled, as in the case of the orbital functions, to choose linear combinations for the two electron systems, symmetric and anti-symmetric, thus

$$\begin{array}{ll} \text{Symmetric} & \left\{ \begin{array}{l} \alpha(1) \alpha(2) \\ \beta(1) \beta(2) \\ \alpha(1) \beta(2) + \alpha(2) \beta(1) \end{array} \right. \\ \text{Antisymmetric} & \alpha(1) \beta(2) - \alpha(2) \beta(1) \end{array}$$

In order to get the complete wave functions for the H-H system, the four spin functions are combined with the two orbital functions to give a total of 8 functions, the correct choice of which is dictated by Pauli's exclusive principle which states, "Every allowable eigenfunction for a system of two or more electrons must be anti-symmetric for the interchange of the co-ordinates of any pair of electrons". Consequently the allowable eigenfunctions are those made up

of either symmetric orbital and anti - symmetric spin, or anti-symmetric orbital and symmetric spin functions. The possible combinations are :

Orbital.	Spin.	Total spin.	Term symbol.
$\psi_a(1) \psi_b(2) + \psi_a(2) \psi_b(1)$	$\alpha(1) \beta(2) - \alpha(2) \beta(1)$	0	$^1\Sigma$
$\psi_a(1) \psi_b(2) - \psi_a(2) \psi_b(1)$	$\begin{cases} \alpha(1) \alpha(2) \\ \beta(1) \beta(2) \\ \alpha(1) \beta(2) + \alpha(2) \beta(1) \end{cases}$	1	$^3\Sigma$

The term symbol Σ indicates that the molecular state has a zero angular momentum, the two atoms being in S state. The left hand superscript denotes the multiplicity or number of eigenfunctions of the molecular state, here one for the singlet and three for the triplet state. The complete eigenfunction including the orbital and spin contributions is given by,

$$[\psi_a(1) \psi_b(2) + \psi_a(2) \psi_b(1)] [\alpha(1) \beta(2) - \alpha(2) \beta(1)]$$

The second step in the solution of the original problem is to calculate the energy corresponding to the interaction of the two hydrogen atoms using the allowed wave functions. In order to do this, the various possible electrostatic interactions between electrons, and electrons and nuclei shown in Fig. 6 are evaluated :

I.	electron	(1) with electron	(2); potential V_1 being $-e^2/r_{12}$
II.	electron	(1) with nucleus	(b) $V_2 + e^2/r_{1b}$
III.	electron	(2) with nucleus	(a) $V_3 + e^2/r_{2a}$
IV.	nucleus	(a) with nucleus	(b) $V_4 - e^2/r_{ab}$

The interaction of electron (1) with nucleus (a) and electron (2) with nucleus (b) have already been included in the two hydrogen atoms we started with. Given therefore these interaction potentials, to find the corresponding interaction energy, the potential is multiplied by the probability of finding the electron in a given element of volume and integrated over all of space, that is $E = \int V_1 \psi^2 dv$. For obtaining the total energy of interaction, the total potential of interaction of the two hydrogen atoms is included thus, $E = \int V \psi^2 dv$ (5) where $V = V_1 + V_2 + V_3 + V_4$. The energy is then calculated for both symmetric and anti-symmetric functions.

For simplicity and for our present purpose, the integral in eqn. (5) can be written as

$$E = 2C + 2A$$

where $C = \int V \psi_a^2(1) \psi_b^2(2) dv$ and $A = \int V \psi_a(1) \psi_b(2) \psi_a(2) \psi_b(1) dv$

C being the *coulombic energy* and A the *exchange energy*. In regard to the coulombic energy, resulting from the ordinary electrostatic interaction between charged particles, electrons and nuclei, at large nuclear distances C will be zero, and at very small distances, it will approach infinity due to the strong repulsion of the nuclei. At intermediate distances at which the electron clouds overlap, there is a net positive attraction. Fig. 7, curve C represents the dependence of the coulombic energy on the inter nuclear distance r , and has a minimum depth of potential energy corresponding to 0.6 ev which is much smaller compared with the actually observed value of 4.75 ev for the bond H-H. There must be some other source contributing to the strength of the bond and this comes essentially from the quantum mechanical phenomenon of the exchange energy A.

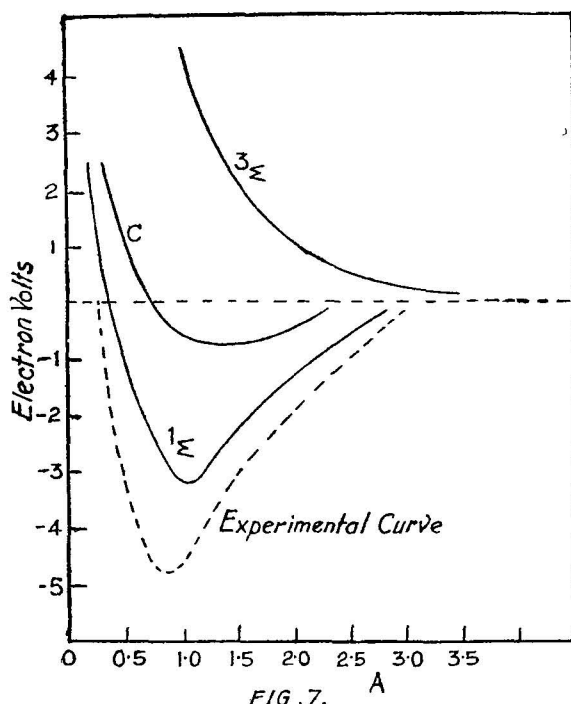


FIG. 7.

This exchange energy arises from the fact that, since the electrons are indistinguishable, there is equal probability of electron (1) being on nucleus (a) and on nucleus (b), and electron (2) being on nucleus (b) as well as on nucleus (a). In terms of wave function we must consider the interactions arising from the charge densities representing electron (1) on nuclei a and b, similarly electron (2) on b and a, which necessarily implies increase of density of electron charge around both the nuclei and hence an increase in the bond energy between the two hydrogen atoms.

As in the case of the coulombic energy, here too the exchange energy is zero at large internuclear distances, and at very small distances, leads to high potential energy of repulsion, whereas at intermediate distances to strong interaction and a minimum of potential energy. In terms of wave functions, we say the overlap of the orbitals is greatest at the distance corresponding to the minimum potential energy. On plotting the total energy of interaction $2C + 2A$, one gets two curves, Fig. 7, the one corresponding to $2C + 2A$ giving a deep minimum (singlet state) and the other giving a continuously increasing potential energy (the triplet state). The formation of the stable hydrogen molecule is represented by the symmetric orbital function and anti-symmetric spin function. In other words for a stable chemical bond, the two electrons constituting it must have opposite spins.

The actual binding energy from Heitler-London integrals as calculated by Siguria gave the binding energy 3.140 ev and a minimum distance of $0.869 \text{ \AA}$ (corresponding to 72.3 kcal). However taking into account the ionic structures, one got for the binding energy 92.0 kcal . But more refined calculations by James and by Coolidge taking into account the inter-electronic repulsions, led to a value of 108.4 kcal (compared to the experimental 108.8 kcal) or 4.75 ev and distance $0.74 \text{ \AA}$. Exchange is 90 and coulombic 10% of the total energy.

Since the covalent bond is formed between atoms that share a pair of electrons with opposite spins, covalence is also called "spin valency." The Heitler-London theory is an example of the approach of the valence-bond (V.B) method to the molecular structure.

LECTURE 3

Molecular orbital (M. O.) theory. Comparison between the M. O. and V. B. theories. Applications of the two methods.

One approach to the problem of the chemical bond is the valency bond theory which has been described in the previous lecture. Another approach to the same problem, the molecular orbital theory, developed by Hund, Mulliken, Herzberg and Lennard-Jones, also uses the same general principles as those employed to describe the electron state in an atom by wave functions, but with certain specific modifications to take into account the fact that the electrons move in the field of all the nuclei, so that here account is taken of the interaction of each electron with all the other electrons and nuclei in the molecule. This leads to the molecular orbital which is assumed to consist of

a series of superimposed atomic orbitals, obtained by a linear combination of the atomic orbitals. It may be noted that the distortion of atomic orbital by the adjacent atoms is neglected in the case of hydrogen molecule, since it does not seriously affect the final results.

To illustrate the method of molecular orbital approach, let us consider the hydrogen ion molecule H_2^+ . At large internuclear distances, the electron can be represented by the atomic orbital ψ_a . As the nuclei approach each other, the electron may be at either of the nuclei, a and b , (this being the first step in the formation of the molecular orbital)

$$\psi = \psi(a : 1s) + c \psi(b : 1s)$$

in which the relative probability of $\psi_a : \psi_b = 1^2 : c^2$. But since there is equal probability of the electron being on a and b , $c^2 = 1$. The two possible linear combinations of the functions are

$$\psi_g = \psi(a : 1s) + \psi(b : 1s)$$

$$\psi_u = \psi(a : 1s) - \psi(b : 1s)$$

The corresponding electron densities are given by,

$$\psi_g^2 = \psi^2(a:1s) + \psi^2(b:1s) + 2\psi(a:1s)\psi(b:1s)$$

$$\psi_u^2 = \psi^2(a:1s) + \psi^2(b:1s) - 2\psi(a:1s)\psi(b:1s)$$

the subscripts g and u stand for gerade (even) and ungerade (odd). In the case of the gerade function, the electron cloud density of the transition structure, $2\psi_a \psi_b$ in which the electron is in the field of the two atomic nuclei, is added to the electron clouds of the two atoms. Consequently the cloud density between the two nuclei is increased, so that the two nuclei are drawn together, leading to an increase in binding energy, and ψ_g is a *bonding orbital*. In the other case, the cloud density of the transition structure is deducted as shown by the negative sign before it, and the electron is drawn away from the region of the two nuclei so that bonding does not take place. ψ_u is an *anti-bonding orbital*.

It is to be remarked that the transfer of an electron from the atomic orbital to an anti-bonding orbital involves loss of energy and will therefore occupy such an orbital only as long as the bonding orbital is already occupied by two

electrons permitted by Pauli's principle, but it will always tend to return to an atomic orbital and so will lower the stability of the molecule

These two kinds of molecular orbital, namely, the bonding orbital in which the electron is at a lower level and the anti-bonding orbital in which it is at a higher level than in the atom, are basic to the theory of molecular orbital. Further each combination of atomic orbitals will produce two such molecular orbitals.

A second way of looking at the formation of molecular orbital is to imagine the two nuclei being brought together and coalescing into a single nucleus, or the "united atom viewpoint" originally suggested by Mulliken. This permits of characterisation of the molecular orbitals by means of quantum numbers as in the case of atomic orbitals, n , l , m and s ; the numbers n and l are the same for free atom and for the "united atom", but m assumes a slightly different significance. In a free atom, m determines the components of the orbital angular momentum of the electron along the direction of the applied magnetic field, which has the value $m (\hbar/2\pi)$. In the case of the united atom, the axis is defined by the line joining the two nuclei into which the united atom is separated, and so m is replaced by λ and the component of the angular momentum of the electron about the internuclear axis is $\lambda (\hbar/2\pi)$.

The following are the values of the various quantum numbers

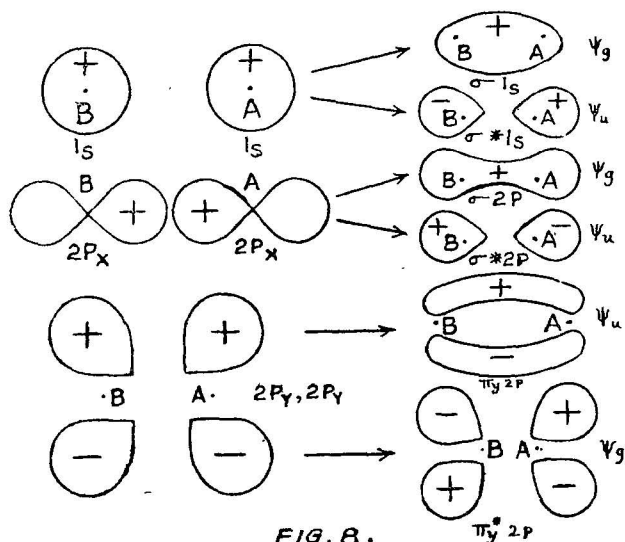
$$n=1, 2, 3, \dots; \quad l=0, 1, 2, \dots (n-1)$$

λ , like m , can take the values

$$-l, -(l-1), -(l-2), \dots, -1, 0, +1, \dots, l$$

Molecular orbitals with $\lambda=0$, are termed σ orbitals; when $\lambda = \pm 1$, π orbitals; $\lambda = \pm 2$, δ orbitals, and so on. For each value of λ , there will be a bonding and an anti-bonding orbital, designated as σ & σ^* , π & π^* orbitals. The number of electrons in each orbital cannot be more than two in accordance with Pauli principle. Thus in each σ or σ^* orbital there are only 2 electrons. In the case of π & π^* states, there will be in each state 4 electrons, that is, 2 in the orbital with $\lambda = +1$ and 2 in the orbital with $\lambda = -1$. Similarly in each δ and δ^* there are 4 electrons since λ has the values $+2$ and -2 . The molecular orbitals are formed, as explained above, by linear combination of atomic orbitals and the electronic states in the constituent atoms will determine the resultant state, that is the λ value, in the molecule.

Diagrammatic representation of formation of bonding and anti-bonding molecular orbitals



Simplified notation introduced by Mullikan for homonuclear molecules

Atomic Orbitals.	Molecular Full notation	Orbitals Abbr. not.	No. of Electrons in mol. orb.
1s, 1s	$(\sigma 1s)^2$ $(\sigma^* 1s)^2$	$\begin{array}{c} - \\ - \end{array} \left. \vphantom{\begin{array}{c} - \\ - \end{array}} \right\}$	4
2s, 2s	$(\sigma 2s)^2$ $(\sigma^* 2s)^2$	$\begin{array}{c} z\sigma \\ y\sigma \end{array} \left. \vphantom{\begin{array}{c} z\sigma \\ y\sigma \end{array}} \right\}$	4
2p _x , 2p _x	$(\sigma 2p)^2$ $(\sigma^* 2p)^2$	$\begin{array}{c} x\sigma \\ u\sigma \end{array} \left. \vphantom{\begin{array}{c} x\sigma \\ u\sigma \end{array}} \right\}$	12
2p _y , 2p _y or	$(\pi_{yz}p)^2 = (\pi_z 2p)^2$	$w\pi$	
2p _z , 2p _z	$(\pi^*_{yz}p)^2 = (\pi^*_z 2p)^2$	$v\pi$	

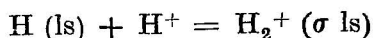
The building up of homonuclear diatomic molecules, or the *aufbau* can be achieved by feeding electrons into the various orbitals, provided the relative order of molecular orbital energies is known. This has been determined by Mulliken from a study of molecular spectra :

$$\sigma 1s < \sigma^* 1s < \sigma 2s < \sigma^* 2s < \sigma 2p < \pi y 2p = \pi z 2p < \pi y^* 2p = \pi z^* 2p < \sigma^* 2p$$

$$z\sigma < y\sigma < x\sigma < w\pi < v\pi < u\sigma$$

The distribution of electrons in homonuclear diatomic molecules can now be examined :

H₂⁺ is formed from a H atom and a H⁺ and the lowest bonding orbital is $\psi_g = \psi(a : 1s) + \psi(b : 1s)$ and represented as



H_2 of which each atom in the ground state has 1s electron and if the spins of the two electrons are anti-parallel, they occupy the same molecular orbital and the molecule is represented by

$$H(1s)\psi + H(1s)\psi = H_2(\sigma 1s)^2$$

If however the two spins are parallel, then according to Pauli principle, only one electron can exist in the lowest bonding orbital, the other electron being transferred to the higher energy anti-bonding orbital $\sigma^* 1s$ ($\psi_u = \psi(a:1s) - \psi(b:1s)$) so that this state is represented by

$$H(1s)\psi + H(1s)\psi = H_2(\sigma 1s)(\sigma^* 1s)$$

The anti-bonding character of the $\sigma^* 1s$ orbital cancels the power of the bonding $\sigma 1s$ orbital, so that effectively no bonding occurs. This corresponds to the triplet state, the former combination to the singlet state.

He_2^+ made of one helium atom with two electrons in the 1s orbital and a helium ion with one electron in the 1s orbital. In the molecule, 2 of these electrons with opposite spins will occupy the lowest bonding orbital, whereas the third electron will occupy the anti-bonding orbital in the next higher energy level, and the representation is

$$He(1s^2) He^+(1s) = He_2^+(\sigma 1s)^2(\sigma^* 1s)$$

The anti-bonding power of $\sigma^* 1s$ lowers the stability of the molecule whose presence therefore can only be detected by spectroscopic methods. He_2 has the following orbital structure :

$$2 He(1s^2) = He_2(\sigma 1s)^2(\sigma^* 1s)^2$$

Since the anti-bonding orbital completely cancels the bonding orbital, no molecular formation occurs.

Li_2 . Here only the outer electrons need be considered, namely the two valency electrons in the 2s orbital :

$$2 Li(1s^2 2s) = Li_2 [KK(z\sigma)^2]$$

where KK represent the two K shells which are filled by non-bonding electrons.

N_2 is represented using the simplified notation of Mulliken by

$$2N(1s^2 2s^2 2p^3) = N_2 [KK(z\sigma^2)(y\sigma)^2(x\sigma)^2(w\pi)^4]$$

The bonding power of $(z\sigma)^2$ may be regarded as being cancelled by the anti-bonding power of $(y\sigma)^2$ with the result that the bonding is due to the $(x\sigma)^2$ and the $(w\pi)^4$ orbitals. This corresponds to a σ bond and two π bonds at right angles to each other. As there are six electrons involved in bonding, we may speak of a triple bond, as termed by the valency bond method, or the electron pair method.

O_2 can be represented by

$$2O (1s^2 2s^2 2p^4) = O_2 [KK (z\sigma)^2 (y\sigma)^2 (x\sigma)^2 (w\pi)^4 (v\pi)^2]$$

The bonding $(z\sigma)^2$ is cancelled by the anti-bonding $(y\sigma)^2$ and the anti-bonding $(v\pi)^2$ cancels one of the two $(w\pi)^4$ orbitals, so that the two oxygen atoms are held by a σ and a π bond, comprising 4 electrons and hence by a double bond. However on account of the degeneracy of the two π_y & π_z states, this orbital can accommodate 4 electrons and so involves two anti-bonding orbitals $\pi_y^* 2p$, $\pi_z^* 2p$ each capable of holding two electrons. The two electrons in O_2 occurring in this state will, according to Hund's rule, go one each into $\pi_y^* 2p$ and $\pi_z^* 2p$ orbitals, and can have parallel spins, thus accounting for the paramagnetism of molecular oxygen. This specific property of oxygen molecule cannot so satisfactorily be explained by the valency bond method.

F_2 which includes in each of its atoms one more electron than oxygen atom and is diamagnetic, is given by

$$2F (1s^2 2s^2 2p^5) = F_2 [KK (z\sigma)^2 (y\sigma)^2 (x\sigma)^2 (w\pi)^4 (v\pi)^4]$$

Here the $(z\sigma)^2$ and $(y\sigma)^2$ orbitals cancel each other as do the $(w\pi)^4$ and $(v\pi)^4$ due to their mutual bonding and anti-bonding character, so that the bond is effectively constituted by $(x\sigma)^2$ and so is a single bond.

Ne_2

$$2Ne (1s^2 2s^2 2p^6) = Ne_2 [KK (z\sigma)^2 (y\sigma)^2 (x\sigma)^2 (w\pi)^4 (v\sigma)^4 (u\sigma)^2]$$

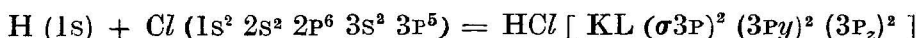
In this case the $(x\sigma)^2$ is also cancelled by $(u\sigma)^2$ orbital and so there is no molecular formation.

Heteropolar dinuclear molecules :

HCl : Hydrogen has one $1s$ electron, whereas chlorine atom has one $3p$ electron capable of forming a bond. The wave function for HCl is

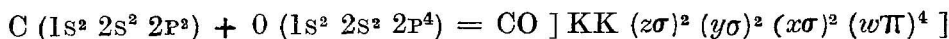
$$\psi = \psi (H : 1s) + c \psi (Cl : 3p_x)$$

Given the greater electronegativity of chlorine, $e^{\ominus} \neq 1$, and hence the polarity of the molecule. The electron configuration is



Only the $\sigma 3p$ is the molecular in character, whereas the $3s$, $3py$ and $3pz$ are essentially atomic, hence not taking part in bond formation.

CO has the following distribution :



This configuration is similar to that of nitrogen molecule and so implies a triple bond between carbon and oxygen, since the $(z\sigma)^2$ is cancelled by $(y\sigma)^2$, so that there are three bonding orbitals. However this comparison does not seem to be entirely satisfactory. On ionisation, the resulting CO^+ has a stronger bond than CO whereas the reverse is the case with N_2^+ , as shown by bond distance and vibrational frequency. This can be satisfactorily accounted if initially CO has only a double bond which is changed into a triple bond on ionisation. For this possibility, the suggestion has been made that one of the orbitals is largely atomic in character and is centralised almost entirely over the oxygen atom.

NO has one electron more than the nitrogen molecule and this electron enters the anti-bonding ($v \pi$) orbital to give the configuration,



On account of the single anti-bonding electron, the molecule is paramagnetic, and also the bonding is weaker than in nitrogen molecule. However the stability of NO molecule in spite of its unpaired electron is attributed to this electron being distributed over the whole molecule in a molecular orbital.

Comparison of the molecular-orbital and valency-bond methods.

The common features of both the methods are that the bonding electrons are associated with both nuclei, that an increase in charge density results on bond formation and both methods distinguish between σ and π bonds.

The fundamental difference consists in that the molecular orbital method regards all the electrons as belonging to the whole molecule, whereas the other method considers only the pair of electrons forming the molecular bond, and assumes that all other electron pairing is irrelevant to bond formation.

In order to bring out the essential difference between, and the basic limitation of, the two methods we may consider the simplified wave functions given by the two methods. According to the M. O. method, the wave functions for electron (1) in a diatomic molecule AB is given by the sum of the atomic wave functions $\psi_1 = \psi_a(1) + \psi_b(1)$, and similarly for electron (2), so that the overall molecular wave function is

$$\begin{aligned}\psi &= \psi_1, \psi_2 = [\psi_a(1) + \psi_b(1)] [\psi_a(2) + \psi_b(2)] \\ &= \psi_a(1) \psi_a(2) + \psi_b(1) \psi_b(2) + \psi_a(1) \psi_b(2) + \psi_a(2) \psi_b(1)\end{aligned}$$

The first term corresponds to electrons (1) and (2) being on nucleus *a*, and so to the ionic structure A^+B^- and the second term to the ionic structure A^-B^+ , and so the two terms are called the ionic terms. The last two terms correspond to electron (1) on *a* and electron (2) on *b*, and vice versa.

These last two terms are identical with the total symmetric orbital wave function for a diatomic molecule given by the V. B. method, namely,

$$\psi_s = \psi_a(1) \psi_b(2) + \psi_a(2) \psi_b(1)$$

These correspond to the structure $A:B$ in which the two electrons are equally shared by the two nuclei and so are termed homopolar terms.

It is evident from these considerations, that the V. B. method ignores the contribution from ionic terms, whereas the M. O. theory seems to give equal importance to both ionic and homopolar terms. Actually in the case of hydrogen molecule, the ionic structures' contribution is about 10%, that of the homopolar structures, nearly 90%, so that the actual structure is in between the structures suggested by the two methods. Hence both the methods are to be suitably modified to be able to give satisfactory answers even to a simple problem such as that of the structure of hydrogen molecule. We may say that each method has in itself the property of pointing out the inherent deficiency of the other, and so may be regarded as complementary to the other. Consequently it is necessary to have a correct idea of both the methods in order to appreciate the application of each to a given problem.

In spite of the limitations of each of the two methods, each introduces certain concepts which give an insight into the physical basis of chemical bonding. Thus the V. B. method introduces the concept of *resonance* which has in the hands of chemists like Pauling, become a powerful means of getting a very useful qualitative picture of the structure of a molecule in terms of Lewis' electron pair

for a single covalent bond. It is particularly useful for describing organic molecules and predicting in a qualitative manner their chemical reactions; for instance, the stability of organic molecules with conjugated double bonds and of organic free radicals, the reactivity of unsaturated molecules, the orientating effect of various substituents in aromatic rings in substitution reactions, electrophilic and nucleophilic etc.

The M. O. method on the other hand is particularly useful in picturing delocalised orbitals in aromatic ring molecules, and in describing certain inorganic molecules. Thus it readily explains the paramagnetic properties of O_2 and S_2 molecules (cf. *supra*), gives a more satisfying picture of the one-electron bond in He_2^+ and the three-electron bond in NO . Furthermore, the concept of antibonding orbital in M.O. theory is a very useful one as has been demonstrated in the description of O_2 and N_2 and other molecular structures.

Finally the idea of directed valency is better illustrated by the V.B. considerations than those of the M.O.

LECTURE 4

Hybridisation of atomic orbitals: sp^3 , sp^2 , sp , etc. Applications of V.B. and M.O. to aromatic compounds.

Allusion has already been made in Lecture 2 to the essential directional character of p -orbitals, the 3 p orbitals, p_x , p_y and p_z being mutually perpendicular to one another. Further, it has also been shown that even in the case of hydrogen molecule formation (cf. Lect. 2) the stability of the bond is greater, greater the value of the overlap integral $\int \psi_A \psi_B$ which is the case when the energies corresponding to the two atomic orbital functions are nearly equal. A very useful qualitative explanation of directed valency can be obtained if it is assumed that the strength of a covalent bond is approximately equal to the amount of overlap. In the case of the s -orbitals, since they are spherically symmetrical (cf. Lect. 2), they overlap to the same extent in all directions. On the other hand, the p -orbitals are concentrated along particular directions, for instance, p_x along the x -co-ordinate, so that two p_x orbitals will overlap to maximum extent. Now the normalised p_x orbital has the value $\sqrt{3}^{-1} r \sin \theta \cos \phi$ and so the two p_x orbitals for r equal to unity will form a bond of strength $\sqrt{3}$, whereas the normalised value of the s orbital is 1, so that two s orbitals will form a bond of strength 1 only.

On extending considerations applicable to O, S and Se, to atoms such as Be, B and C, we meet with difficulties. The ground state of Be, is $1s^2 2s^2$, so that Be would seem to have no unpaired electrons for chemical combinations. Actually, Be forms divalent compounds. To account for this, if one of the $2s$ electrons is promoted to a $2p$ state, the excited electronic state $1s^2 2s 2p_x$ results in which there are now two unpaired electrons, capable of entering into bond formation. However, Be would then form with chlorine for instance, one bond with its s orbital and another with its p_x orbital and the two Be-Cl bonds would be of unequal character. In point of fact, the two Be-Cl bonds are quite equivalent in length and in bond strength, so that a new explanation must be sought for this phenomenon.

Similarly boron's ground state is $1s^2 2s^2 2p^1$ with only one free electron and in the excited state it would have one s orbital and 2 p orbitals, but the three bonds made with three hydrogen atoms would be of unequal strength and unequal length contrary to experience.

A more striking case is that of carbon with its ground state $1s^2 2s^2 2p^2$ which becomes, on promoting a $2s$ electron to a higher level, $1s^2 2s 2p^3$ which on combination with 4 hydrogen atoms would give methane with three bonds mutually perpendicular to each other and one without any particular direction, quite contrary to the actual methane which has four exactly equivalent bonds. In all these cases, it would appear that the s and p orbitals are in some way mixed up and redistributed in order to give new equivalent, or *hybridised* orbitals. The following considerations using carbon for illustration will make the point clear.

In the case of carbon atom, the promotion of a $2s$ electron to the p level requires an energy of 65 kcals, leading to the electronic configuration $1s^2 2s 2p^3$. The additional energy supplied for this excitation is more than compensated for by the formation of four C-H bonds in methane, each of which will release 98.2 kcals. The energy difference between the $2s$ and $2p$ states is not too great. Consequently, it is possible to obtain by a suitable linear combination of the wave functions of the one $2s$ and the three $2p$ electrons, four new equivalent eigenfunctions in accordance with the principle of superposition (cf. *supra*). They are expressed in the following way :

$$\psi_i = a_i \psi_{2s} + b_i \psi_{2px} + c_i \psi_{2py} + d_i \psi_{2pz}$$

where a, b, c , & d are numerical coefficients and i takes the value 1, 2, 3 or 4. The coefficients are determined by the normalising condition,

$$\int \psi_i \psi_i^* dv = 1$$

$$\text{or } a_i^2 + b_i^2 + c_i^2 + d_i^2 = 1$$

and by the orthogonality requirement,

$$\int \psi_i \psi_k dv = 0$$

$$\text{or } a_i a_k + b_i b_k + c_i c_k + d_i d_k = 0$$

where i and k take the values 1, 2, 3, and 4 and i is not equal to k .

Let the first orbital lie along x-axis, in which case the p_y and p_z will have to lie in the same x-direction which would imply $\theta = 90$ and $\phi = 0$. Then,

$$\begin{aligned} \psi_1 &= \frac{1}{2} \psi_{2s} + \frac{1}{2} \sqrt{3} \psi_2 p_x \\ &= \frac{1}{2} \times 1 + \frac{1}{2} \sqrt{3} \cdot \sqrt{3} = 2 \end{aligned}$$

$$[\psi_{px} = \sqrt{3} \sin \theta \cos \phi = \sqrt{3} \sin 90 \cos 0 = \sqrt{3}; \psi_{2s} = 1]$$

The other three functions have to be evaluated in a similar manner, each having the value 2 and the angle between the orbitals being $108^\circ 29'$. The value of p_x orbital is $\sqrt{3} = 1.732$, whereas that of the sp^3 hybridised orbital is 2, so 2, so that the latter can make a stronger bond than the former simple p orbital.

The plot of ψ_1 in the x - z plane is given by FIG. 9.

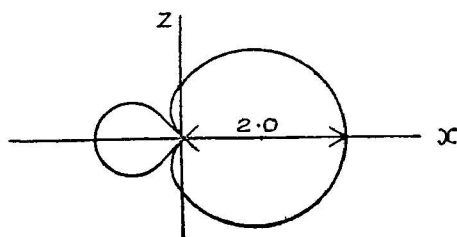


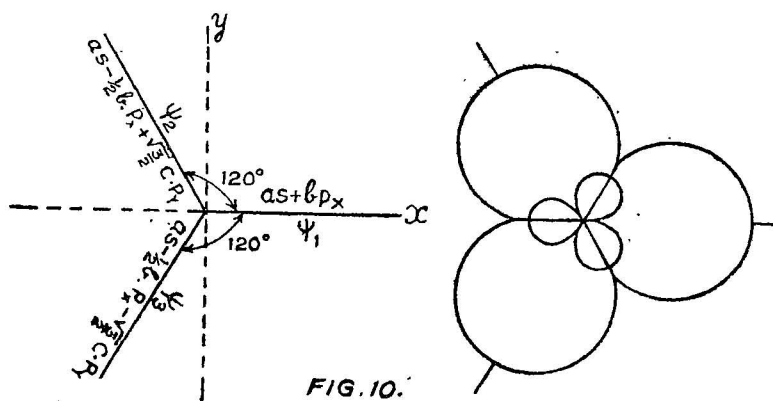
FIG. 9.

Four such hybridised bonds of carbon are present in methane molecule.

In the case of ethylene, the $2s$ $2p_x$ and $2p_y$ orbitals are hybridised to give three equivalent sp^2 orbitals, the first of which is expressed by,

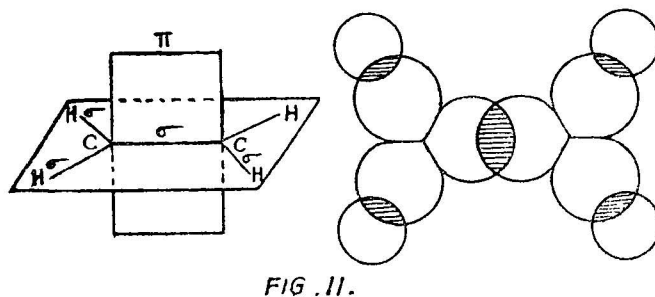
$$\begin{aligned}\psi_1 &= \frac{1}{\sqrt{3}} \psi_{2s} + \sqrt{\frac{2}{3}} \psi_{2p_x} \\ &= \frac{1}{\sqrt{3}} \times 1 + \sqrt{\frac{2}{3}} \times \sqrt{3} = \frac{1}{\sqrt{3}} + \sqrt{2} = 1.991\end{aligned}$$

The other two orbitals give a similar value. All the three orbitals lie in the same plane, at 120° to each other as shown in Fig. 10.



The remaining fourth orbital p_z is perpendicular to the plane of the paper.

The structure of ethylene is represented by Fig. 11.



The four C—H bonds with $\lambda = 0$ (cf. M. O. magnetic quantum number, Lect. 3) are σ bonds, whereas the second C—C bond is a π bond constituted by the two p_z orbitals, as shown in the Fig. 11.

The structure of acetylene in which only one s and one p orbitals are hybridised, so that they are termed the sp hybridised orbitals, and the other two are pure p orbitals, is shown in Fig. 12.

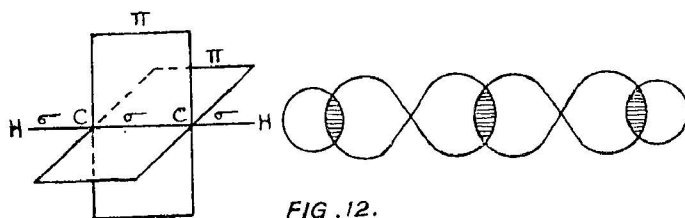


FIG. 12.

Benzene has the following structure :

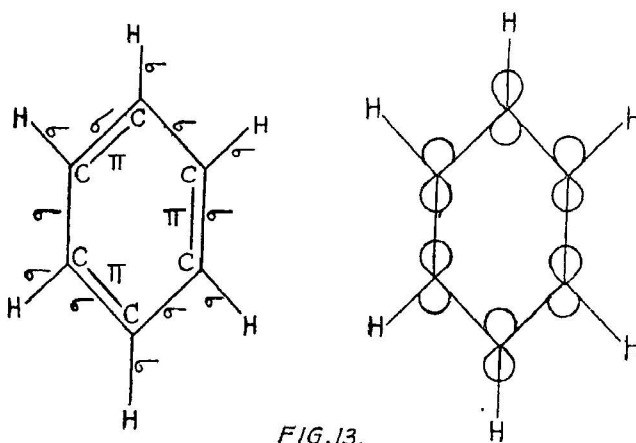


FIG. 13.

In this, the C—H and one of the C—C bonds are σ bonds but one bond of each of the three double bonds is a π bond.

According to the V. B. there will be three alternating π bonds. A little reflection shows that each p_z orbital could overlap with either of the neighbouring p_z orbitals, so that it might not be quite correct to speak of three localised π bonds. It would be more correct to speak rather of delocalised p_z orbitals. This is explicitly brought out by the M. O. method, where each electron is considered to belong equally to all the other nuclei and electrons in the molecule. This mode of regarding p orbitals in benzene leads to the following

Fig. 14 in which there is a streamer below and above the plane of the benzene ring, and the electrons are free to move about without any restriction. The benzene ring would then be similar to a loop of metal wire

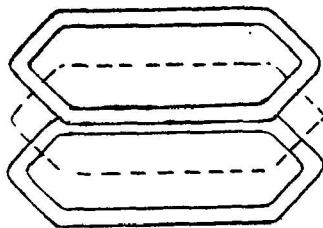


FIG. 14.

containing free electrons. In point of fact, when a magnetic field is applied normal to the plane of benzene rings in solid state, the electrons are set in motion, and an induced magnetic field is caused in opposition to the applied field, thus reducing the latter, as has been experimentally verified.

In spite of the above useful and valuable considerations of benzene from viewpoint of M.O. theory, it is, in some ways, more convenient to regard the structure of benzene and other aromatic molecules as made up of the superposition of various distinct canonical forms according to the V.B. method. The actual structure of benzene will then be a resonance hybrid of the several possible canonical forms or structures, that is the two Kekule and the three Dewar structures. The eigenfunctions describing the actual structure of benzene will be a linear combination of the eigenfunctions of the several structures, each weighted with appropriate coefficients,

$$\psi = a_1 \psi_1 + a_2 \psi_2 + a_3 \psi_3 + a_4 \psi_4 + a_5 \psi_5$$

The values of a_1 and a_2 will be of equal magnitude, because of the equivalence of the two Kekule structures, and will be much more significant than the constants for the wave functions for the Dewar structures. (The actual problem is to evaluate the constants in such a manner that the potential energy corresponding to the resultant wave function for the actual molecule is a minimum, which is usually done by the variation method). The values of a 's

are determined in such a way as to make the total energy E a minimum, and the a 's will give the relative importance of each structure.

These considerations can be applied to other molecules such as naphthalene, anthracene etc.

The same method applied to a simple molecule like HCl which can be represented by two important structures, one covalent $\text{H}:\text{Cl}$ and the other ionic H^+Cl^- will indicate the actual structure to be a resonance hybrid of the two :

$$\psi_{\text{HCl}} = a \psi_{\text{H}:\text{Cl}} + b \psi_{\text{H}^+\text{Cl}^-}$$

a and b are the values required for minimum energy, and the ratio $\{b/(a+b)\}$. 100 is the percentage ionic character of the bond. Similar calculations for the other hydrogen halides give the following results ;

Molecule	HF	HCl	HBr	HI
% of ionic character	60	17	11	5

The tendency of a pair of atoms to form an ionic bond is measured by the difference in their power to attract electrons or in their electronegativity. Thus F is the most electro-negative, whereas I the least electronegative.

General References

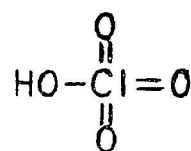
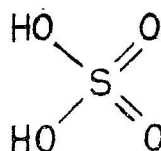
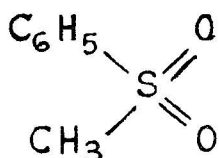
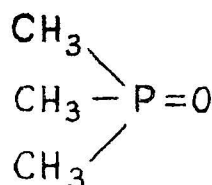
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THE NATURE OF THE SULPHUR-OXYGEN BOND IN SULPHONES AND RELATED COMPOUNDS

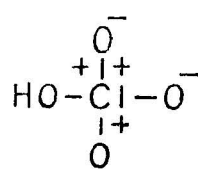
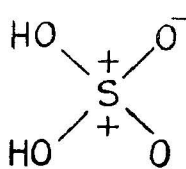
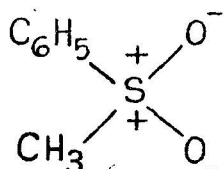
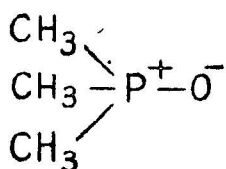
By V. BALIAH

The sulphur-oxygen bond in sulfoxides, sulphones, sulphates and related compounds can be formulated either as a double bond or as a semipolar bond. The same may be said of the phosphorus-oxygen bond and chlorine-oxygen bond in the higher oxides and oxy-acids of phosphorus and chlorine. The double bond formulation was in vogue before the advent of the electronic theory of valency. Some examples are given below :



In these compounds phosphorus was supposed to be quinquivalent, sulphur sexavalent and chlorine septavalent.

The electronic theory of valency made it possible to formulate many compounds, including the higher oxides and oxyacids, with an octet of electrons round each atom. The double bonds in such compounds were replaced by semipolar bonds (co-ordinate links) for which the central atom provides both the shared electrons.



Soon the co-ordinate bond became widely accepted because it enabled a wide group of compounds to be formulated on the basis of the octet principle.

In 1937 Pauling and Brockway¹ pointed out that the bond lengths in the common oxy-acid ions are much shorter than those of single bonds, being as short

as double bonds or even shorter. Thus it appeared that either the semipolar bonds must be shorter than single bonds or the assumption that they are semipolar bonds must be wrong. So many investigators became interested in the length of semipolar bonds.

Lister and Sutton² reported that the length of the N-O in trimethylamine oxide is $1.36 \text{ \AA}$. The length found for the N-O single link³ in O-methylhydroxylamine is $1.43 \text{ \AA}$. For a double bond it should be $1.15 \text{ \AA}$. So the actual length is nearer to that expected for a single bond rather than for a double bond. Bauer, Finlay and Laubengeyer⁴ reported that the B-O bond length in $(\text{CH}_3)_2\text{O} \cdot \text{BF}_3$ is $1.52 \text{ \AA}$ which is close to $1.54 \text{ \AA}$, the sum of the Pauling single bond radii. Schutze⁵ found the B-O bond lengths in the tetrahedrally co-ordinated boron phosphate and arsenate to be $1.47 \text{ \AA}$. Thus semipolar bonds appeared to be nearly of the same length as that of single bonds. The sulphur-oxygen bonds are, however, seen to be comparable to the double bond in their length. Sometimes they are even shorter (S-O single 1.7 ; S-O double $1.49 \text{ \AA}$).

Sulphur-Oxygen bonds.

<i>Compound.</i>	<i>Observed length.</i>	<i>Ref.</i>
CH_3SOCH_3	$1.46 \text{ \AA}$	6
$\text{CH}_3\text{SO}_2\text{CH}_3$	1.44	2
SO_2	1.43	7
SO_2Cl_2	1.43	8
SOCl_2	1.45	8
$\text{S}_2\text{O}_8^{--}$	1.50	9, 10
SO_4^{--}	1.49	11, 12
β - Isoprene sulphone	1.43	13

These data raised serious doubts regarding the nature of the S-O bonds in sulfoxides and sulphones. Some people thought that the S-O bonds cannot be semipolar. This conviction gained support with the publication of a paper by Phillips, Hunter and Sutton¹⁴ who deduced from electric dipole moment measurements that the S-O bond must have considerable double bond character.

The arguments of Phillips, Hunter, and Sutton may be stated briefly as follows: the N-O bond in trimethylamine oxide is $1.36 \text{ \AA}$ long; so if an electron is completely transferred in the formation of the bond, and if there is symmetrical sharing of the bonding electrons, the moment would be (electronic

charge) X (bond length) i.e. 6.53 D. The value derived by Linton¹⁵ and by Phillips and his co-workers is 4.22—4.37 D., i.e., 66–68% of theory. Moreover, the very large moments of certain co-ordination complexes show that they contain highly polar bonds, although in some of these the unco-ordinated molecules are themselves quite polar. Examples are: (Et₂O)₂, BeCl₂, 6.71 D; MeCN, BCl₃, 7.74 D.; Et₂O, BCl₃, 6.04 D.; EtNH₂, AlCl₃, 6.94 D.; Et₂O, AlCl₃, 6.68 D.; C₆H₅NO₂, AlCl₃, 9.25 D.; CPh₂, AlCl₃, 8.32 D.¹⁶; (Et₂S)₂, PtCl₂, 9.5 D.; (Et₃P)₂, PtCl₂, 10.7 D.¹⁷ If the S—O bond is a co-ordinate link it should be even more polar than the N—O link, because it is actually longer; the moment for full transference would be 6.86 D. The actual value ascribed is however 2.5—3.0 D. Thus it appeared that the S—O bond cannot be a co-ordinate link. Phillips and his co-workers, however, felt that a direct comparison of the moments of bonds to oxygen, formed by elements in the first and the second short period, cannot settle the point at issue, since the greater polarisability of the latter elements may affect the moments. So they determined the changes of moment which occur when sulphides form links to oxygen and boron trichloride. These changes were compared with the ones produced when amines or ethers form links to oxygen and boron trichloride. Thence they estimated $\Delta \mu_{S \rightarrow O}$ to be 3.8, whereas it was found to be 2.5—3.0.

$$\frac{\Delta \mu_{O \rightarrow O}}{\Delta \mu_{S \rightarrow O}} = \frac{\Delta \mu_{O \rightarrow BCl_3}}{\Delta \mu_{S \rightarrow BCl_3}}$$

From this simple consideration of magnitudes of moments changes they concluded that the S—O bond is not a pure co-ordinate link.

Wells¹⁸ refuted the conclusions of Phillips, Hunter, and Sutton. His words are quoted below:

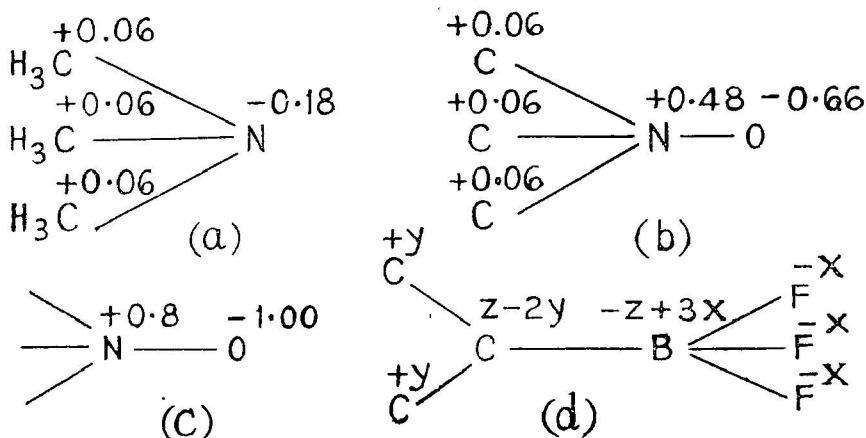
“Confusion has arisen because the term co-ordinate link has been used in two quite different senses: (1) to denote that the two electrons of the bond came from one atom, and (2) to imply that the degree of asymmetry of sharing of the two electrons is similar in all co-ordinate links. The only possible interpretation of the statement ‘If the S—O bond were a co-ordinate link it should be even more polar than the N—O link, because it is actually longer,’ is that Phillips, Hunter, and Sutton assume that there would be the same charge distribution in S→O as in N→O. This assumption is entirely without justification; without it there is clearly no necessary connection between the lengths and the μ ’s of two different bonds such as S—O and N—O. The use of the term

co-ordinate link in sense (1) is simply a convenient way of indicating the origin of the electrons. The use in sense (2) is an entirely different matter, for (2) is concerned with the final sharing of the electrons.

"From dipole moments we can deduce the resultant formal charge distributions in molecules. For $(\text{CH}_3)_3\text{N}$ and $(\text{CH}_3)_3\text{NO}$ these are approximately as shown in (a) and (b), and for complete transfer of an electron we should

$$1 + 1 - \quad \quad \quad \frac{1}{2} + \frac{1}{2} -$$

have (c). The N—O bond in $(\text{CH}_3)_3\text{NO}$ is therefore not N—O but close to N—O. Again, although the bonds in BF_3 must be highly polar, the final charge



distribution in $\text{R}_2\text{O} \rightarrow \text{BF}_3$ is the resultant of the original polarities of R_2O and BF_3 and the rearrangement of electrons which we call the formation of the co-ordinate link. The positive formal charge on B and negative formal charge on O have both decreased, so that we have (d) and a B—O bond with a dipole moment $z \times d$. The data from these compounds merely show that a bond of type (1) *can* be as long as an ordinary single covalent bond. It has *not* been shown that if a bond is abnormally short it *cannot* be of type (1). The low μ of the short S—O bond indicates that x in $\text{S}^{+x}-\text{O}^{-x}$ is less than y in $\text{N}^{+y}-\text{O}^{-y}$ (the length being similar), but this does *not* prove that they are *not* co-ordinate links in the sense (1). It is not admissible to deduce the origin (still less, the number) of the electrons in the short S—O bond from dipole moment data, and particularly to argue from the lengths of bonds such as N—O and B—O. If $\mu_{\text{S—O}}$ is greater than $4.8 \times d$ ($\sim 7\text{D.}$) then it could be argued that more than two electrons are involved. Since it is *less* than 7 D., the moment can obviously be accounted for as well by two as by four electrons, a different degree of asymmetry of sharing being assumed. "

A study of the parachors¹⁹ of compounds containing S—O bond indicated that the S—O should be a semipolar bond. The contribution of the semipolar bond to the parachor is known to be very small or negative.

<u>COMPOUND</u>	<u>S-O BOND CONTRIBUTION TO THE PARACHOR</u>
Thionyl Chloride $\text{Cl}_2\text{S} \rightarrow \overset{\text{O}}{\curvearrowright}$	-2.3
Sulphuryl Chloride $\text{Cl}_2\text{S} \begin{matrix} \nearrow \text{O} \\ \searrow \text{O} \end{matrix}$	-1.65×2
Ethyl Sulphite $(\text{Eto})_2\text{S} \rightarrow \overset{\text{O}}{\curvearrowright}$	+1.3
Methyl Sulphate $(\text{Meo})_2\text{S} \begin{matrix} \nearrow \text{O} \\ \searrow \text{O} \end{matrix}$	-0.75×2
Ethyl Sulphate $(\text{Eto})_2\text{S} \begin{matrix} \nearrow \text{O} \\ \searrow \text{O} \end{matrix}$	-2.3×2

The data on molecular refraction of sulfoxides and sulphones also tends to show that the S—O bond in these compounds is semipolar, Price and Gillis²⁰ have well discussed this point.

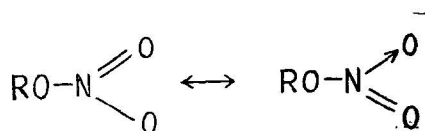
Molecular refraction of some sulfoxides and sulphones, R_2X

R_2	$\text{X} = \text{S}$	$\text{X} = \text{SO}$	$\text{X} = \text{SO}_2$
Cl_2	19.87	22.12	21.43
Me_2	19.13	20.06	20.08
Et_2	28.53	29.34	29.73
$n\text{-Pr}_2$	37.79	38.43	38.73
Me, Pr	28.38	29.22	29.24
Me, Vinyl	23.52	23.70	24.17
Me, Allyl	28.12	—	28.91
Ph, Allyl	48.46	49.3	48.72

These results strikingly illustrate the small contribution of the new oxygen atom and its bond to the sulphur. In one case the molecular refraction actually decreases upon introduction of an oxygen atom bonded to sulphur.

Vogel and his co-workers²¹ pointed out that the bond refraction for a single covalent bond is about 4.6 units. In the case of most normal covalent double bonds, the bond refraction for the double bond is more than twice that of the single bond. For example, the S-C single bond has a refraction of 4.6 units, the double bond a refraction of 11.9 units. This is understandable because the π -electrons, being mobile, are more polarisable. For a true S-O covalent double bond a bond refraction of at least 10 units would be expected. Actually the S-O bond refraction in sulphoxides is about 0.6 unit or less and the introduction of a second oxygen atom gives an even smaller increment in molecular refraction.

Vogel and his co-workers give a value of 1.78 for the bond refraction of the N-O semipolar bond, less than the value for the N-O covalent single bond (2.43). Actually the value of 1.78 was derived from the molecular refraction for nitrates. In these substances, the N-O bond will have some double bond character due to resonance.

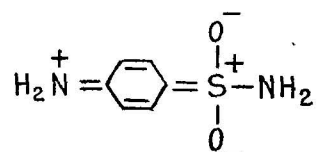


For this reason, the value given is probably higher than for a true N-O semipolar bond.

As pointed out by Price and Gillis²⁰, a better indication of the low value to be expected for the molecular refraction of bonds unquestionably semipolar is the fact that the molecular refraction for BF_3 etherate (R_D 26.63) is 1.68 units less than the sum of the molecular refraction for BF_3 (R_D 6.0) and ether (R_D 22.31). Laubengeyer and Finlay²² report the etherate to have a molecular refraction 1.83 units less than the sum of its components.

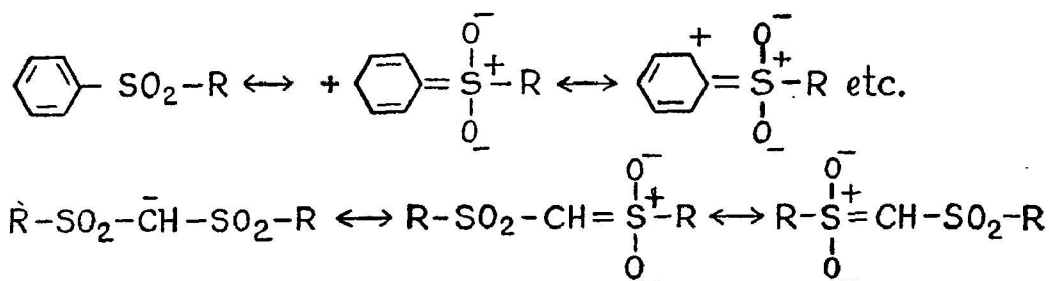
Thus the S-O bond in sulphoxides and sulphones was not considered to be a covalent double bond but a semipolar bond. Why the bond refraction for the semipolar bond should be less than for a covalent single bond is easily understood: the high charges associated with the atoms and the electric field thus created reduce the overall polarisability of the molecule to impinging electromagnetic radiation.

Kumler and Strait²³ studied the absorption spectra of sulphanilamide and related compounds. With sulphanilamide a strong resonance was found to exist between the amino and the sulphonamido group with forms of the type

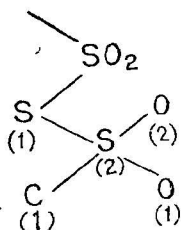


making a significant contribution. Sulphanilamide has a higher extinction coefficient than either aniline, benzene sulphonamide or metanilamide and furthermore, the character of the spectrum is quite different from that of these other compounds. When sulphanilamide is placed in acid solution both the resonance between the amino group and the ring, and that between the amino group and the sulphonamide group, are blocked. The spectrum reverts to that of benzenesulphonamide. In solvents such as water where the resonance between the amino and the sulphonamide group is not blocked, sulphanilamide has about thirty times the absorption it has when this resonance is blocked.

Fehnel and Carmack²⁴ determined the ultraviolet absorption spectra of a number of mono- and poly-sulphones, ketosulphones and carbalkoxysulphones in both neutral and alkaline solutions. No characteristic absorption bands attributable to the isolated sulphone function were observed in ethanol solutions in the near-ultraviolet region of the spectrum, although the attachment of a sulphonyl group to benzene caused shifts and intensified the benzenoid peaks in a manner similar to the carboxyl group in benzoic acid. Strong conjugative effects were observed in the anions formed by the methylene disulphones, β -ketosulphones and $\mathcal{L}$ -carbalkoxysulphones in alkaline solutions. When the central carbon atom in the latter compounds is completely alkylated so that no anion can be formed, the spectra in neutral and alkaline solutions are identical. These effects were interpreted as evidence for conjugative interaction of the sulphonyl group with attached aromatic nuclei in aryl sulphones and with unshared pair of electrons on the central carbon atom in sulphone anions.

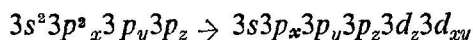


These formulae show sulphur with an expanded shell of valence electrons. It is, of course, possible to write structures in which one or both S—O bonds are double bonds, whereby the valence shell of sulphur is expanded to ten or twelve. Thus it may be noted that the spectroscopic investigations have not thrown any light on the nature of S—O bond, beyond providing strong evidence that the sulphur atom is capable of expanding its shell in the sulphone structure.



Mathieson and Robertson²⁵ made a quantitative X-ray analysis of the crystal and molecular structure of bisphenylsulphonyl sulphide. The bond angle of the central sulphur atom, S(1), is 106.5° and it is near the expected tetrahedral value. The angle S(1) — S(2) — C(1) is 101.7° and the angle O(1) — S(2) — O(2) is about 117° . Thus the angles of the sulphur atom, S(2), deviate considerably from the expected tetrahedral value. Mathieson and Robertson believe that the stereochemistry of the valence angles of sulphur in sulphone function can be based on a distorted octahedral structure.

The irregular tetrahedral nature of the valence bonds of sulphur in sulphones has been observed by many investigators, e. g., by Sorum²⁶ in $\text{CH}_3 - \text{SO}_2 - \text{S} - \text{S} - \text{SO}_2 - \text{CH}_3$; by Cox and Jeffrey¹³ in β -isoprene sulphone; by Allen and Sutton²⁷ in dimethyl sulphone; by Toussaint²⁸ in di-(*p*-bromophenyl) sulphone. The irregular tetrahedral arrangement of the valence bonds can also be explained as follows: the primary σ -bonds may arise from tetrahedral sp^3 hybridisation in the ($3s$, $3p^3$) shell of doubly ionised sulphur which can result by the transfer of one $3s$ electron and one $3p$ electron to the vacant $3d$ orbitals.



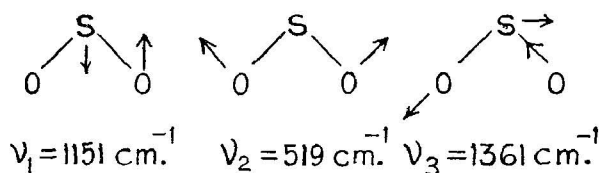
when π -bonds are formed (valency shell expansion), they will be $d-p$ π -bonds. The involvement of the d orbitals in π -bond formation may cause the observed deviations in bond angles. If the S—O bond is semipolar the large O—S—O angle readily finds an explanation from the repulsion between the oxygen atoms which bear negative formal charges.

Barnard, Fabian and Koch²⁹ studied the infra-red absorption spectra of several sulfoxides and sulphones, hoping that a systematic investigation of S—O bond-stretching vibration frequencies might throw light on the vexed problem of the electronic nature of this linkage. They observed the existence of characteristic infra-red frequencies for the sulphone and sulfoxide groups.

Characteristic frequencies (cm^{-1}) in CCl_4 solution

<i>Substituents</i>	<i>Sulphoxide</i>	<i>Sulphone</i>	
	ν_{SO}	ν_1	ν_3
Cyclohexyl methyl	1055	1144	1321
Dicyclohexyl	—	1130	1312
Phenyl methyl	1055	1160	1334
Diphenyl	1055	1164	1336
Methyl 2-methylallyl	1061	—	—
Diallyl	1047	—	—

All the sulphoxides displayed a sharp high intensity band at a remarkably constant mean frequency of 1055 cm^{-1} . The sulphones showed two sharp high intensity bands at frequencies of $1130\text{--}1164 \text{ cm}^{-1}$ and $1312\text{--}1336 \text{ cm}^{-1}$, respectively. The related molecule of sulphur dioxide is known to give rise to a total of three strong fundamental absorption bands which have been assigned to the three normal modes of vibration as follows:



The observed two frequencies in sulphones were taken as corresponding ν_1 and ν_3 in sulphur dioxide.

Barnard, Fabian and Koch found that hydrogen-bond formation with methyl alcohol or chloroform decreases the characteristic S-O bond-stretching frequencies; sulphoxides form strong hydrogen bonds than do sulphones.

They also calculated the force constant of the S-O bond in sulphones and sulphoxides. For the purpose of calculation, the mean sulphone stretching frequency $(\nu_1 + \nu_3)/2$ was taken. The resulting average value of 1238 cm^{-1} , when compared with the average sulphoxide frequency of 1055 cm^{-1} , represents a considerable increase (more than 17%) over the latter, corresponding to an increase of 35—40% in the force constant of the S-O bond. The consequent greater strength of the S-O bond in sulphones is reflected in the fact that sulphoxides, but not sulphones, are readily reducible to the corresponding sulphides under a variety of conditions.

The same workers considered the relationship of stretching frequencies and force constants with the relative bond lengths. The existence of such a relationship seemed implied by the data in the following table which suggest a slight decrease in bond lengths like the frequencies and force constants.

Bond characteristics of the S-O link.

Molecule	ν_{SO} or $(\nu_1 + \nu_3)/2$ cm^{-1}	$k \times 10^{-5} (\text{app.})$ dynes/cm.	$r \times 10^8 (\text{cm.})$
$\begin{array}{c} \text{R} \\ \diagdown \\ \text{S}=\text{O} \\ \diagup \\ \text{R} \end{array}$	1055	6.95	1.47
$\text{S}=\text{O}$	1124	7.9	1.49
$\begin{array}{c} \text{Cl} \\ \diagdown \\ \text{S}=\text{O} \\ \diagup \\ \text{Cl} \end{array}$	1229	9.4	1.45
$\begin{array}{c} \text{R} \\ \diagdown \\ \text{S}=\text{O} \\ \diagup \\ \text{R} \end{array}$	1238	9.6	1.44
$\begin{array}{c} \text{O} \\ \diagup \\ \text{S}=\text{O} \\ \diagdown \\ \text{O} \end{array}$	1256	9.97	1.43
$\begin{array}{c} \text{Cl} \\ \diagdown \\ \text{S}=\text{O} \\ \diagup \\ \text{Cl} \end{array}$	1303	10.6	1.43
$\begin{array}{c} \text{F} \\ \diagdown \\ \text{S}=\text{O} \\ \diagup \\ \text{F} \end{array}$	1312	10.8	—

The observed vibration frequencies in the above table appeared to fall in line with the view that (1) the S-O link in sulphur dioxide and sulphones is shorter than in sulphur monoxide, and (2) the strength of this link as determined from thermochemical data¹⁴ is greater than that in sulphur monoxide. Since the nature of the sulphur monoxide bond is essentially double rather than single, the even higher vibration frequencies of sulphur dioxide, the sulphones, and the thionyl and sulphonyl halides seemed to signify that in these molecules, the bond order must be

greater than it is in sulphur monoxide. Koch and his co-workers, however, thought that there is a variable contribution from the semipolar bond structure which is appreciable in the sulfoxides, less important in the sulphones, and probably negligible in sulphuryl chloride and thionyl fluoride.

If the S—O bond is largely double, conjugation might be expected to occur in the presence of adjacent phenyl or ethylenic groups, just as it occurs in the corresponding carbonyl derivatives. If conjugation does take place, it should be reflected in a lowered stretching force constant and vibration frequency of the oxy-bond; a frequency decrease of nearly 2% is observed in such molecules as benzaldehyde and acetophenone^{30,31}. Such a frequency decrease was not observed by Koch and his co-workers; the aromatic sulphones actually displayed a small frequency increase over the saturated analogues. This significant observation takes away most of the force in the argument of Koch *et al.* that the S—O bond *must be* a double bond. In fact after reading the long and excellent paper of Barnard, Fabian, and Koch one is still left with the doubt – what is the precise nature of the S—O bond?

In order to obtain information concerning the influence of sulfoxides and sulphone groups on aromatic systems, Price and Hydock³² studied the ultraviolet absorption spectra and the rates of saponification of the ethyl esters of *m*- and *p*-methyl-sulphinyl- and -methylsulphonyl-benzoic acids. The values of the Hammett constant, σ , for the sulfoxide and sulphone groups are as follows:

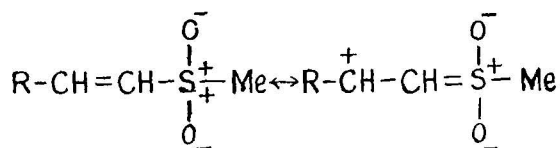
$$\text{SO } \sigma_p = 0.54 ; \quad \sigma_m = 0.52$$

$$\text{SO}_2 \sigma_p = 0.76 ; \quad \sigma_m = 0.65$$

The values indicate the high electron affinity of the two groups. They do not, however, throw light on the nature of the S—O bond though Price and Hydock suggested that the semipolar bond to oxygen, putting a positive charge on the sulphur, would greatly increase its electron affinity, thereby causing an induced positive charge on the ring. The fact that the σ_p and σ_m values are essentially the same for the sulfoxide group while σ_p is perceptibly greater than σ_m for the sulphone group proves that the sulphonyl-aryl conjugation is significant while sulphinyl-aryl conjugation is negligible.

Price and Gillis²⁰ obtained some significant data by measuring the infra-red spectra of some saturated and unsaturated sulphones. The characteristic sulphone bands at 7.65 and 8.75μ , strong and well defined in the alkyl, allyl and vinyl sulphones, show no displacement as a result of conjugation in the latter case.

This is also true in the case of phenyl alkyl and phenyl vinyl sulphones³³. The C=C bands at 6.2, 10.55, and 11.2 μ are all considerably displaced, presumably by resonance of the type :



This seems to show, more convincingly than by any other method so far considered, that the S – O bond in sulfoxides and sulphones is not a covalent double bond, but a semipolar bond.

Price and Gillis answered the argument of Amstutz, Hunsberger, and Chessick³⁴ and Barnard, Fabian, and Koch²⁹ that the stronger hydrogen-bonding tendencies of sulfoxides as compared to sulphones favour the covalent double bond structure for the S – O bond as follows: "The weaker hydrogen bonds formed to the sulphone group are not necessarily a measure of the weaker negative charge on the oxygen atom, but of the weaker negative field near the oxygen. In the sulphone the second S – O bond nearly doubles the positive charge on the sulphur atom, thereby increasing the S–O bond strength by increasing the electrical attraction between the sulphur and each oxygen atom and, at the same time, decreasing the negative field near each oxygen, thereby weakening the hydrogen-bonding capacity of the sulphone group as compared to the sulfoxide."

The low monomer reactivity of methyl vinyl sulphone was interpreted by Price and Zomlefer³⁵ as indicating that the S–O bond is semipolar and not doubly covalent. These workers believe that the dipole moments, bond lengths and bond energies of sulphones¹⁴ can be interpreted in terms of a semipolar bond with a single pair of shared electrons. Their argument may be quoted: "Because of the net positive charge on the donor atom and the net negative charge on the acceptor, it is certainly reasonable to expect this pair to be strongly polarised toward the donor atom, reducing the polarity and dipole moment of the bond. The added attraction of the net opposite charges on the donor and acceptor atoms will further result in an electrostatic force in addition to the normal covalent bond energy, accounting for shortening the bond and increasing its strength as compared to a normal non-polar covalent single bond."

The same arguments should hold good for the $N \rightarrow O$ bond also. But Price and Zomlefer did not consider this point at all.

Koch and Moffitt³⁶ investigated the possibilities of conjugation in unsaturated or aromatic sulphones on the basis of molecular orbital theory. They concluded that different kinds and degrees of conjugation arise in differently substituted compounds, depending on the number and steric arrangement of the unsaturated groups attached to the sulphur atom. When the $\mathcal{L}$, $\mathcal{L}'$ carbon atoms of a sulphone are both formally capable of conjugation with the SO_2 group, and steric conditions are not unfavourable, strong conjugation was predicted. Styryl *p*-tolyl sulphone and 3:4-dihydroxythiophene 1-dioxide are examples of this type. In these compounds the S atom and the two $C = C$ groups attached to SO_2 were considered to be in the same plane. The probable configuration of diphenyl sulphone was considered to be the one in which the planes of the two benzene rings are nonplanar and, most probably, the normals to the planes of the benzene rings are parallel to the directions of the aromatic π -orbitals. In sulphones of this type and in sulphones in which only one $C = C$ group is attached to the SO_2 (e.g. $MeSO_2 CH = CH_2$) Koch and Moffitt predicted weaker donor-acceptor type conjugation, not affecting the S-O bond.

To test these predictions Waight³⁷ determined the valence vibration frequencies of the S-O bond in several sulphones. The data assembled by him are given below :

U. V. Spectra of unsaturated sulphones

(In absolute ethanol)

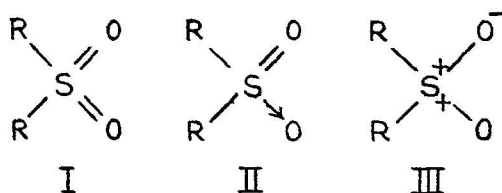
<i>Sulphone</i>	$\lambda \text{ max}(\text{\AA})$	ϵ
Diphenyl	2350	15,000
Di- <i>p</i> -bromophenyl	2330, 2530	16,000 ; 27,000
Di- <i>p</i> -aminophenyl	2610, 2950	18,000 ; 28,000
Thiaxanthene 9 : 9-dioxide	2350	8,900

Valence vibration frequencies of the sulphone group (in CCl_4) (cm^{-1})

Sulphone	ν_3	ν_1	$\nu_{\text{so}} = \frac{\nu_3 + \nu_1}{2}$	$\nu_{\text{so}} - \nu_{\text{so sat.}}$
Diphenyl	1329	1160	1245	25
Di- <i>p</i> -bromophenyl	1341	1162	1252	32
Thioxanthene 9 : 9-di-oxide	1321	1167	1244	24
Dicyclohexyl	1305	1134	1220	—
Divinyl	1332	1138	1235	4
Diethyl	1323	1138	1231	—

The predicted conjugation, involving the sulphur-oxygen bonds, is not detectable in thioxanthene 9 : 9-dioxide. In fact the S-O bond frequency does not seem to be affected in any of the unsaturated sulphones. Though Waight tried to support the theory of Koch and Moffitt, the lack of strength in his argument is quite apparent.

An interesting suggestion has been made for the structure of the sulphone group by Szmant and his co-workers^{38, 39}. These workers proposed that the electronic structures range from those in which both sulphur-oxygen bonds are doubly covalent to those in which both bonds are semipolar (I-III).

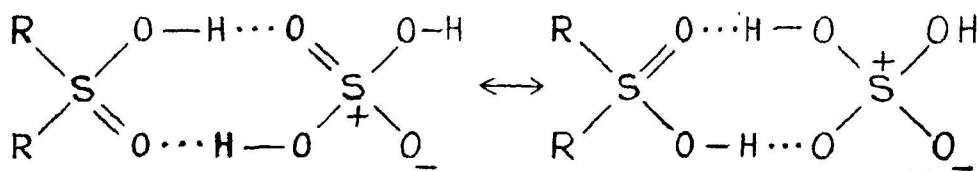


The actual structure of sulphones is considered as a hybrid of the resonant structures (I to III), the relative contribution of the individual forms depending on the structural features present in a given molecule. Nitro and similar electron-withdrawing groups were considered to increase contribution to the double bond

structure (I) to the ground state of the molecule. These conclusions were drawn from the cryoscopic behaviour of a number of sulphones in sulphuric acid. The i values obtained for a number of sulphones are given below :

<i>Sulphone.</i>		<i>i-value.</i>
1. Diphenyl	...	1.3
2. <i>p</i> -Nitrophenyl phenyl	...	1.5
3. Di-(<i>p</i> -nitrophenyl)	...	2.0
4. Di-(<i>p</i> -nitrobenzyl)	...	1.0
5. Di-(<i>m</i> -nitrophenyl)	...	1.3
6. Di-(3-nitro-4-chlorophenyl)	...	1.2
7. Di-(<i>p</i> -chlorophenyl)	...	1.0
8. <i>o</i> -Nitrophenyl phenyl	...	1.1
9. 2 : 4-Dinitrophenyl phenyl	...	1.4
10. 2 : 4-Dinitrophenyl 4-chlorophenyl	...	1.4
11. Di-(<i>p</i> -aminophenyl)	...	3.5
12. <i>p</i> -Nitrophenyl <i>p</i> -tolyl	...	1.35

It was postulated that the negative electromeric effect of the nitro group causes an electron deficiency near the sulphone group, thus increasing the basicity of the sulphone group. A corollary of this postulate is that the basicity of the sulphone function depends more on the resonance stabilisation of the protonated structure than on the fractional negative charge present initially on the oxygen atom. The protonated sulphone complex was represented as follows :



The marked lowering of the i factor by an *o*-nitro group was ascribed to steric effects.

Recently Baliah and Shanmuganathan⁴⁰ made a novel approach to the study of the nature of the sulphur-oxygen bond by determining the ultraviolet absorption

spectra of conjugated sulphones and ketones in cyclohexane and ethanol. The observed spectral changes due to the solvent effect are given below :

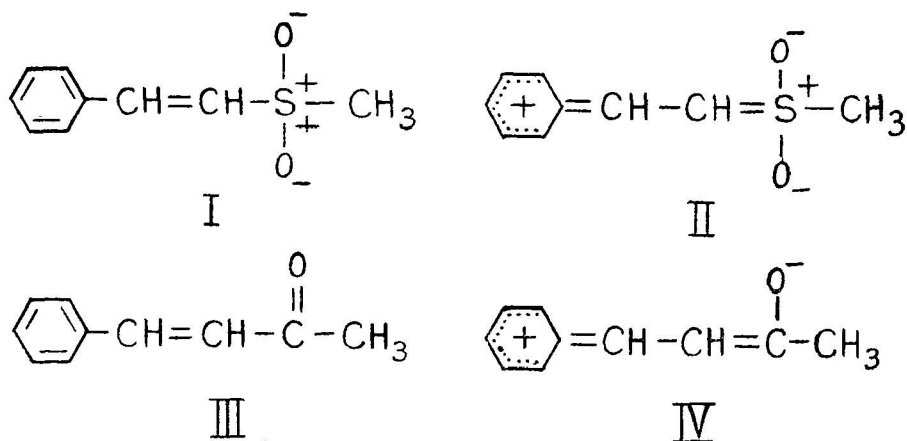
Absorption spectra of sulphones and ketones

(K-bands only are given. Wavelengths are in $m\mu$)

	Cyclohexane		Ethanol (95%)	
	λ_{max}	ϵ	λ_{max}	ϵ
$C_6H_5SO_2CH_3$	217	7,000	217	6,800
$p-CH_3OC_6H_4SO_2CH_3$	238	17,500	240	16,500
$C_6H_5SO_2C_6H_5$	235	17,600	235	17,400
$C_6H_5CH=CHSO_2CH_3$	263	20,200	264	20,700
$C_6H_5CH=CHSO_2C_6H_5$	275	24,600	275	26,000
$C_6H_5COCH_3$	239	12,000	243	13,200
$p-CH_3OC_6H_4COCH_3$	264	18,000	274	17,100
$C_6H_5COC_6H_5$	249	18,900	253	17,500
$C_6H_5CH=CHCOCH_3$	280	26,500	285	22,100
$C_6H_5CH=CHCOC_6H_5$	300	20,000	310	19,000

There is little or no change in the λ_{max} of sulphones with change of solvent from cyclohexane to ethanol. A significant bathochromic shift is seen to occur in the case of ketones on passing from cyclohexane to ethanol. It may, therefore, be stated that the difference in the energies of the ground and excited states in non-polar and polar solvents is about the same for sulphones, whereas this energy difference in polar solvents is less than that in non-polar solvents for ketones. This means that the stabilisation of the excited state relative to the ground state is greater for ketones in ethanol.

These facts were explained on the basis of semipolar bond formulation of the S - O bonds in sulphones. For example, methyl styryl sulphone would then



chiefly be I in its ground state but derives a significant contribution from II in its excited state. Both I and II are zwitterionic, the magnitude of the ionic charge being unaffected during the transition (the total number of positive or negative charges was taken as the magnitude of the ionic charge). Hence the solvation energy in a polar solvent for both states will very nearly be the same. Any change in the difference in energy of the two states on changing the solvent from non-polar to polar will be due to the dipole moment and solvent refractive index effects. In the case of benzalacetophenone it is III which contributes chiefly to its ground state though the contribution of IV to the excited state will be significant. Here structure IV alone is zwitterionic. Thus there will be a significant stabilisation of the excited state in a polar solvent. This lowers the energy difference between the ground and excited states in a polar solvent, leading to a bathochromic shift of the absorption maximum. If the S—O bond is doubly covalent, the excited state alone will be zwitterionic and the solvent effect observed in the case of conjugated ketones should also be observable in the case of conjugated sulphones.

Similar studies of the solvent effect on the ultraviolet absorption spectra of phosphine oxides and sulphides indicated that the P—O and P—S bonds are also semipolar.⁴¹

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INSTRUMENTATION IN SCIENCE AND INDUSTRIES *

Professor I. RAMAKRISHNA RAO, M. A., Ph. D., D. Sc. (Lond.)

LECTURE No. 2

INDUSTRIAL INSTRUMENTATION

The majority of industrial processes are of the mechanical and chemical engineering type. The products mainly comprise consumer goods, the demand for which is increasing on a world scale. Manual operation of these processes is both slow and unreliable. Hence control instrument engineering is resorted to, by which production is rapid, reliable and uniform. It is impossible for me, during the course of a single lecture, to describe the mode of application of control instrumentation in the various categories of industries; nor is it possible for me to go into the details of the control mechanism even in the case of a single industrial process. I shall only outline the general principles of the subject, which will enable you to visualise the basis of application of controls for various types of industrial processes.

The basic components of any automatically controlled industry are :

1. The Process and
2. The Automatic Control.

The process is the combination of various operations by which certain raw materials are converted to finished goods. Such operations may be in a single stage or in a series of stages. It may also be by a series of separate batch operations or a continuous process in which the batch material is fed at one end and the finished product received at the other. In the majority of cases the process is brought about by application of heat. Thus in the case of a single batch operation, the material is first raised to a certain temperature. It is then maintained at that temperature for a specified time period, during which the process is completed, and finally the batch is cooled for removal of the finished product. The factor that enable the completion of the process, viz. temperature in this case, is what is called the process variable. For different types of processes there are different process variables. The more important of these variables are : (1) Temperature, (2) Pressure, (3) Humidity, (4) Flow, (5) Liquid level, (6) pH.

These form Special Lectures 2 and 3 delivered by Prof. I. Ramakrishna Rao, Professor of Instrument Technology, M. I. T., Madras, in the Department of Physics, Annamalai University in February 1959. First Lecture of this Science has been Published in Part C. Engineering and Technology Section of the University Journal—1960, pp. 50-58.

Every industrial process involves the maintenance of one or more of the above process variables at a certain rate of increase or decrease or at a constant value. This maintenance can be achieved either by manual operation or by automatic controls. Manual operation is, however tedious, inconvenient, uneconomical, and very often unreliable owing to personal factors that may result in non-uniformity in the manufactured product. The modern tendency is therefore for the adoption of automatic controls which eliminate all these defects.

The most important of the process variables is temperature, and control of temperature is a factor that is common to most of the chemical industrial operations. During this lecture, I shall take up this variable and describe the basic principles involved.

The process is observed by a measuring thermometer or temperature recorder which is coupled to a control instrument that operates a valve that controls the fuel input to the process. The fuel may be steam, gas, oil or electricity, when the temperature rises above the specified value, the thermometer or recorder transmits the fact to the control which immediately operates the control valve to diminish the fuel input so that the temperature is brought back to the normal. The reverse operation takes place when there is a fall of temperature in the process.

A typical practical system of hot water supply is an example of a dynamic process in which rate of out flow of hot water determines the temperature which is controlled for a definite value.

A static process in which milk is pasteurised by keeping it at a certain temperature for a specified time is another simple example of a controlled process.

This process, on account of its simplicity, will be described in detail. The operations for this process are, (1) letting in of steam at high pressure into the jacket to raise the temperature of milk, (2) diminution of this pressure to a value just enough to maintain the temperature constant for a specified time and (3) cut of completely the steam supply after this. The operation can be achieved (a) entirely manual (b) semiautomatic, (c) fully automatic.

In the case of manual operation, a person opens the steam valve fully and lets the temperature rise to the sterilisation value, then leaves it partially open to maintain the temperature at the same time continuously opening or closing the valve to allow for fluctuation of temperature at the maximum value and to compensate for heat losses. After the time for sterilisation is complete he cuts off the steam entirely to allow the milk to cool for actual use.

In the semi-automatic case, the steam valve is opened manually. As soon as the maximum temperature is reached, the thermometer sets the controller into action, which in its turn opens or closes the valve according as the temperature falls or rises. After the specified time, the entire system is put out of action again manually.

The fully automatic control, however runs on a motor with a cam arrangement and a time switch.

The system is electrically operated by a motor with a cam coupled to a time switch. The only manual part of the operation is in setting the temperature limit in the thermometer and the time duration in the clock. The main switch is set on. Immediately the steam valve is fully open. As soon as the temperature reaches the maximum value, the motor with the cam is switched on and the temperature controller put in action and also the time switch. Fluctuations in temperature are transmitted electrically to the motor which runs in either direction for opening or closing the valve to compensate for these fluctuations. Along with this the time clock works and as soon as the stipulated time for sterilisation is reached, the entire system is automatically stopped when the steam valve is completely closed.

The electrical part of the control mechanism is as follows: By suitable connections to the controlling motor, it can be made to such as a two-position (on-off) control in which the steam valve is fully open or fully closed alternately when the temperature of the kettle falls or rises. The time interval during which the valve is open or closed is controlled by the temperature controller which regulates the motor. In the continuous type of motor control, however, the amount of steam let into the jacket is continuously regulated so that the temperature of the kettle is maintained steady with small fluctuations about the specified mean value.

The above two examples indicate also the two different types of controls,

- (a) the discontinuous two-position or on-off control, and
- (b) the continuous floating or proportional control.

In both cases the power line is in the on position and the electric motor which runs on this power is switched on or off by the mercury switch which is operated by the temperature controller. When the temperature is too high, the mercury switch is tilted to the high position and the motor is made to rotate in such a direction that the steam valve is completely closed in case (a) or partially closed in case (b). The reverse happens when the temperature of the

kettle goes below the required value. In this case, the mercury switch is tilted to the side to operate the motor such that the steam valve is fully opened in case (a) or more steam is allowed in case (b).

In a typical two-position (on-off) electrical controller, the pointer of the temperature indicating instrument has a vane, made of soft iron sheet, attached to it. It serves two functions, (1) to indicate the temperature on the scale and (2) to introduce more or less of magnetic flux linkage between the pair of coils. The increased current that is induced in the secondary of this pair is amplified and then fed to an electric relay which controls the current from the mains to a solenoid valve. This in turn opens or closes the valve through which the fuel is supplied and thus the temperature of the process is brought back to the operating value.

Another arrangement is made where the controller automatically adjusts the percentage of time that the electric load contact is made during one minute period. The process is electrically heated. The full load current is at first on. Soon after the specified temperature of the process is reached, the controller commences functioning. The controller controls the time intervals for which the heating current is on or off depending upon the fluctuations in the process temperature. A constantly rotating motor determines the basic period of on or off of the controller. A reversible motor moves only when the temperature is above or below the neutral. The resulting action of a power relay supplies electric power to the furnace at a variable rate.

The same functional controls can be operated by pneumatic devices. In a common type of a pneumatic on-off controller. The pressure of the fuel transmitted through the fuel line depends upon the balance between the supply and leakage of air. The baffle or flapper positioned by the pointer of the measuring instrument pointer is above the control point, indicating a rise of temperature, the flapper covers the nozzle opening, the pressure of air supplied increases, and the valve passing the fuel to the process closes. When, however, the pointer is below the operating value of temperature, the flapper uncovers the nozzle, the pressure of air is reduced and the valve opens permitting more of the fuel to raise the temperature.

The functioning of a proportional pneumatic control is however different. The only change from the above is the addition of the feed-back bellows to which the output pressure of the pilot is connected. The bellows makes the work of the pilot continuous and not intermittent as in the case of the on-off control. It serves the same purpose as a feed-back mechanism in an electronic circuit.

Mechanical details of a pneumatic controller are: A two-position pneumatic controller applies either full air pressure or zero pressure with no intermediate, on the control valve when the controlled variable (temperature as indicated by the pen-pointer in this instance) deviates a very small amount from the set point (of specified temperature). The air supply is a line leading from a compressor with a filter and pressure regulator to provide a clean, constant air pressure. The bleed is a small nozzle, covered or uncovered by the flapper, which in turn is moved by the instrument pointer-pen to raise the air-to-valve pressure to a maximum or lower it to a minimum in response to the pointer-pen movement about the extremely narrow neutral zone at the set point.

Other control elements are of the electrical type, with a bridge circuit operating on the differential principle and hence of a more sensitive character.

In a balanced bridge type electric proportional controller, when the instrument pointer-pen rises a small amount, the resistance of one side of the bridge becomes greater than the other. This causes a small current to flow between the controller and motor slide wire contactors. The controller balancing unit detects the unbalance and drives the valve motor in a direction to rebalance the bridge. This operation provides a given motor position for each deviation of the pointer-pen from the control point, and the motor in turn determines the corresponding position of the fuel valve to control the supply of fuel to restore the process temperature to the neutral value.

The electrical proportional controller is, now-a-days, a common feature in furnace installations.

In this, a potentiometer controller working through a proportional control relay operates a motor-driven valve, which controls the pressure of the fuel that is fed for heating the furnace. The furnace load is fairly constant and the fuel pressure is sometimes separately controlled with a self-operated regulator. Another feature that is usually common to such installations is an additional fuel-to-air ratio control. However, a pneumatic proportional controller is comparatively smoother in its operation.

Yet another application of temperature control is in fractionating columns.

The problem of temperature control in such fractionating columns is different in that different sections of the column are at different temperatures. Location of the feed of the raw material, the feed of the fuel (usually steam in such cases) the temperature indicator or recorder are all factors that have to be carefully designed to enable the controller to function properly so that the

operation is continuous with the least possible manual attention. Multiple columns require multiple controls, one for each column since the operating temperatures are different for different stages of fractionation.

The complicated nature of a control panel for an oil refinery, which comprises a series of fractionating columns will be evident to any one visiting the control room of the refinery. The operation of the refinery is fully automatic from the rate of feed of the crude oil to the final receptacle for the refined petroleum, in addition to the various byproducts from the different stages of fractionation.

The problems confronting the control engineer in the installation of control panels are very many. One of the most important factors that is to be considered is the thermal capacitance of the process.

I shall explain examples of two processes in which the thermal capacitances are widely different. The process is one of heating a liquid to a specified temperature and allow it to flow at that temperature. The time lag between fuel input and temperature rise is very large in the case of the tank type supply compared to that for a simple flow pipe. In all processes where temperature is controlled, the thermometer takes sometime to respond to the change in the process. Hence there is always a time lag between the actual temperature of the process and that indicated by the thermometer. Fluctuations of process temperature are not instantaneously indicated by the measuring instrument. This time lag plays an important role in the design of the control mechanism.

The quicker the response of the instrument to variations of temperature, the smaller is the time lag. The thermal capacitance of the batch determines the time period of the fluctuations. For baths of large capacitance the period is large and the reverse is the case for a process with small capacitance. For the latter, fluctuations in temperatures are so rapid that a thermometer with slow response may show practically a constant value for the temperature of the process, though in actuality, there are rapid variations of this value about the specified mean.

Control instruments and automation are playing an increasing role in machine tool operations. An example of a fully automatic factory is one designed and run by W. F. and John Barnes and Co. of U. S. A. for manufacture of shells in millions during the last war. Not only was there shortage of manual labour, but machine tools themselves were in short supply. An automatic plant was therefore a dire necessity. This plant may well be termed an automatic mass

production factory. Here, heavy parts, weighing in excess of 125 lbs. are handled mechanically from the time the billets enter the heating furnaces until the completed shell, after having passed through all machining, heat-treating, and other operations, is ready for inspection. By manipulating push buttons on an electric control board, all operations such as turning, boring and threading are completed. The estimate of production by this factory was ten times what would have been possible by the same number of operators following the routine production methods.

Another example of a complete automatic mass-production plant is that of the Ford Motor Co. in Highland Park. This plant has a daily production capacity of 10,000 bushings for intake and exhaust value guides in the internal combustion engines of cars. The feeding of raw materials, handling of work, its transfer from one machine to another for a subsequent operation are all done automatically. Though the limits of tolerance in the bushings are as close as 0.00025 inch., the machining is so precisely done that there are practically no rejects. Manual labour is employed merely for set-up, maintenance and other supervisory work.

I have described only the most elementary aspects of control instrumentation in industrial processes. I have not even mentioned the more complicated aspects like the programme control in which a material is subjected continuously to different processes to obtain the final product. Nor have I taken up the subject of cascade control in which the material is subjected to different processes in different stages. The varied problems in control engineering are too many to be dealt with in a single lecture of this type. I shall consider my purpose fully served, if by my lecture, I have created in you interest in the subject and impressed on you the importance of controls in the future industrial development of India.

The foregoing are only a few instances of application of instrumentation for automation in industry. Examples are also given of applications in heavy industries. Automatic control is not a dream as in the past, but an accomplishment. Already, the skill in mechanical operations has passed from the Mechanic to the Instrument Engineer. The next stage of development involves the transfer of this work to the personnel who will design and maintain these instruments.

It appears from the above that we are at the beginning of a new era when instrumentation will, in a continuously increasing proportion, replace manual labour. In the office, the new devices of calculating and computing instruments are enabling cutting down of clerical staff. In the factory, automatic instruments

are displacing skilled labour of different categories. The latest scientific and technological developments in our basic industries are having profound but imperceptible effect on our lives and the lives of our succeeding generations, in which instrumentation may play a predominant role.

LECTURE 3

The latest in modern Physics is the study and application of fundamental particles. If the 19th century was the age of atoms, molecules and waves, the first six decades of the 20th century form the age of fundamental particles, known as nucleons and quanta otherwise called photons. In the last century, matter, supposed to be constituted of 92 different elements of the periodic classification and energy radiated in the form of waves of different wavelengths formed the two entirely different basic entities of the physical world. With the enunciation of the revolutionary concept of equivalence of matter and energy, as given by the equation.

Energy of a mass at rest $E_0 = M_0 c^2$ where M_0 is the rest mass and c is the velocity of light, a new source of prodigious energy potentially conserved in matter itself is revealed to man. The spontaneous release of high energy particles like the α and β and γ radiations from radioactive substances confirmed the reality of this concept. Intensive studies of these new types of particles on the one hand and of high energy radiations on the other, were therefore carried out with a purely academic outlook in the initial stages and latter with a view to produce energy out of matter which we now call atomic energy.

All these studies were carried on with a wide variety of modern instruments which are progressively being developed, modified and new instruments designed. This third lecture will be devoted to a description of the design and use of these instruments intended for investigations on the properties and applications of the fundamental particles and photons.

The foundations of particle instrumentation were laid with the invention of the discharge tube. When a high voltage of the order of some thousands of volts is applied to the two electrodes of a partially evacuated discharge tube, the residual gas gets ionised into positive and negative ions. The positive ions move towards the cathode and the negative ions to the anode thus establishing flow of current in the circuit. By subjecting these ions to crossed or parallel magnetic and electro fields, the negative ions are identified as electrons. Both the velocity v and specific charge e/m of these fundamental particles are determined. These electrons are independently produced in thermionic emission from heated

filaments, and by application of high potentials, they are accelerated to high velocities in vacuum tubes evacuated to what is called the hard stage. This has resulted in the development of all electronic instruments.

By suitable set up of the instrumental technique of the simple discharge tubes, positive ions of different elements were produced by J. J. Thomson in his positive ray parabolas resulting in the design of the mass - spectrograph by which masses of individual atoms are determined to a remarkable degree of accuracy. Not only were the masses of the atoms of most of the different elements compared by this instrument, but several isotopes of each of the elements were discovered, whose relative abundance, as revealed by the intensities of the mass-spectral lines corresponding to these isotopes established the integral character of stomic weights of elements compared to oxygen 16. Increased precision in this instrument revealed the small but definite deviations from the above integral or whole - number rule of atomic weights. This led, in co-ordination with other lines of evidence, to the concept of the mass defect and the confirmation of Einstein's postulate of the equivalence of matter and energy. Improvements in instrumental designs and technique have thus led to experimental discoveries of a fundamental nature.

Spontaneous emanation of fundamental particles and photons from radioactive substances was another aspect of scientific investigations which necessitated the invention of a wide variety of modern scientific instruments. Of these, the most important are Millikan's Oil Drop apparatus and Wilson's Cloud Chamber. The former was designed for the successful determination of the electric charge e on individual electrons to a remarkable degree of accuracy.

Applications of the Cloud Chamber are many and varied. It is used for the detection and measurements of the characteristics of α , β and γ rays. The underlying principle of this instrument is the ionisation produced by these radioactive emanations along their tracks in air. The ions thus produced form nuclei for the condensation of water-vapour in the super saturated condition formed when the air within the chamber is expanded and consequently cooled. Along the tracks of these particles, therefore, are formed a large number of waterdrops which become visible when illuminated by a separate source of light. While the formation of these tracks is an indication of the emanation of these radiations, the length of the tracks measure their energies.

The Cloud Chamber has, in addition, resulted in discoveries of fundamental importance. Firstly, it revealed among the tracks of α -particles, a few that had sudden changes in direction. This led to the postulate of collisions of these

particles with nuclei of atoms, which formed the beginning of artificial disintegration of atoms. This chamber was also responsible for the discovery of the neutron which is a fundamental particle of profound importance.

A similar instrument of equal usefulness in detection of individual particles is the ionisation chamber. It possesses two electrodes, one of which is the metal chamber itself and another insulated from it. Under normal conditions no current passes between the electrodes, when a high potential is applied to them. If, however, high speed α or β rays pass through it, the gas in the chamber gets ionised and a current passes through. The ionisation chamber, enables not only detection of the particles, but also a measure of their number and energies. This instrument was extensively used in radioactive investigations. While single particles are clearly revealed by their tracks in Wilson's Cloud Chamber, they are not so easily detected by the ionisation chamber. The current produced in the latter due to passage of a single particle is too feeble to be detected. It therefore requires an electronic amplifier in conjunction and a cathode ray oscillograph also.

For the accurate determination of the activity of radioactive substances, the number and rate of emission of the radiations require measurement. The larger the number of particles radiated from a specified weight of a radioactive element, the greater is its activity. Counting of particles has therefore become a necessity. Hence particle counters have been designed and constructed, which have contributed immensely to our knowledge of radioactive emanations.

On account of their importance in nuclear physics, these counters will be described in some what detail of the wide variety of counters in use, only two will be dealt with in detail on account of their greater usefulness and convenience. These are Geiger Counters and scintillation counters.

The Geiger counter is a remarkable and ingenious improvement on the ionisation chamber. It is in fact a modification of the latter to work at higher voltages at which it functions as a self contained high gain amplifier. It consists of a cylindrical cathode and a thin anode wire, usually tungsten, stretched along the axis of the cylinder. The two electrodes are enclosed in a cylindrical vacuum tight container of glass. It is at first evacuated and then filled with argon mixed with a 10% vapour of ethyl alcohol. The total internal pressure is maintained at 10 cm of mercury. The cylindrical cathode is kept at the potential of the earth, and the anode wire is raised to a potential of the order of 800 to 1500 volts depending upon the design of the counter.

An ionising particle, α or β in passing through a thin window at one end of the Geiger Counter, collides with the atoms of argon, then leaving behind it a trail of positive ions and free electrons. It is found by earlier experiments, that each β -particle of energy 1 MeV, for example, produces about 10 pairs of ions per cm of its path in the gas. A proton of the same energy forms about 10^3 ion pairs for the same path of 1 cm. α -particles, however, are the most powerful in the property of ionisation, as it produces the maximum number, about 10^4 pairs per cm. path.

At very low potential, most of the electrons recombine with their positive counter parts with the result that very little current passes between the electrodes. Application of a potential ranging from about 10 to 70 volts, will enable the ions to separate and acquire velocities enough to make them collect at the respective opposite electrodes. The behaviour of the counter, in this region, corresponds to that of an ordinary ionisation chamber, and the current between the electrodes is proportional to the number of ions produced at a given potential, but the number of ion pairs is independent of the applied potential.

At potentials of the order of 80 volts, some of the electrons produced by ionisation acquire enough energy to produce further ionisation resulting in the formation of one further pair of ions, besides the original electron. Both electrons are now accelerated towards the central anode. with further increase in potential, the secondary electrons themselves acquire energy, before they reach the anode, enough to act as ionising particles. The effect is cumulative and the result is an avalanche of electrons, secondary and tertiary. Thus, if each electron, on an average, makes n ionising collisions, the final number of ions produced both positive and negative will be 2^n times the number originally formed. Between 80 and 600 or 700 volts the number n of ionising collisions depends only on the applied potential. There is thus an amplification factor corresponding to each applied potential, and the number of ion pairs collected at the electrodes is proportional to the original number formed by the passage of the first particle. In this range, the counter is therefore said to operate as a proportional counter. This region is important for distinguishing between the α and β particles and protons.

At this stage, the number of electrons and positive ions moving in opposite directions is so large that they form space electric charges enough to produce their own potential gradient.

Ionisation in this range is the result of the combined effect of the applied potential and the potential arising out of the space charge. The proportionality

in the previous range becomes limited. In addition, the electrons which impinge on the anode produce ultra-violet radiations due to photoelectric effect, which are also effective in producing ionisation. This effect of limited proportionality continues till about 1000 volts, when a state of complete saturation is reached, and further increase in voltage does not any longer enhance the ionisation in the chamber.

The original ion pair produced by a single fundamental particle, produces the full number of ion pairs that it is capable of i.e. about 10^8 pairs per cm. The number of ions finally collected at the electrodes is independent of the number of original ions pairs formed by the fundamental particle provided there is initially this particle entering the chamber. The ions are completely discharged at the electrodes and a pulse of current passes through the meter or recorder connected in it. The chamber is now free of ions and is ready for the entry of the next particle which produces another pulse of current. Thus the entry of each particle results in a pulse of current and the rate of pulses as recorded in the electric recorder directly counts the rate of entry of particles into the chamber from the radioactive source. The Geiger Counter thus enables a direct determination of the rate of emanation of fundamental particles from radioactive materials.

Another instrument of equal importance and efficiency in counting of particles is the scintillation counter. The physical principles involved in the design and development of this instrument are primarily three. The first is the scintillation or light pulse that is produced when a fundamental particle impinges on a fluorescent substance like zinc sulphide. The second principle is the production of a photoelectron when this light pulse falls on a photoelectric metal like calcium. The third phenomenon known as secondary electron emission is the production of multiple electrons when a single photoelectron like the above impinges on a polished surface like that of a sheet of beryllium copper. The number of secondary electrons for a single primary having energy about 100 eV will be about 3 to 4. By arranging a series of multiple electron reflectors, it is possible to multiply the original single electron current exponentially. Such a series is contained in the photomultiplier tube. This tube consists of a photoelectric cathode (the primary source of electrons formed by the incidence of the feeble scintillation radiation) and a series of secondary electrodes, known as dynodes, which are good emitters of secondary electrons. The series of dynodes are made progressively more positive in potential with respect to the cathode. The final anode is made positive with respect to the last dynode which emits the final multiplied array of electrons. Suppose 10 scintillation protons fall upon the photoelectric cathode producing a single electron. This electron impinges upon

the first dynode producing, say about m secondary electrons. Each of these m electrons falling upon the second dynode produces again m electrons. Thus the total number of electrons emitted from the second dynode is m^2 . This number thus exponentially increases with increasing number of dynodes with a final value of m^n for total of n dynodes. Thus if m , the number of secondary electrons produced by each primary is 5, and the number of dynodes 11, the final beam of electrons impinging upon the anode is 5^{11} or 5×10^7 electrons.

The whole process, commencing from the production of scintillation by a fundamental particle to the creation of a photoelectron which multiplies in the photomultiplier as described above, resulting finally in the discharge of the avalanche of electrons at the anode as indicated by a pulse of current in an indicator or recorder, takes place in less than $\frac{1}{100}$ th of one microsecond. Each fundamental particle is thus detected by a strong pulse of current, and emission rate of as many as 10^8 particles per second can be measured.

The Geiger and the scintillation counters are examples of simple physical devices which are applied to investigations of high importance in detection and counting of elementary particles. Modern instruments employing the above principles, but modified to suit different types of researches are too many to be mentioned. But they are an indication of the role of highly developed instrumentation in modern nuclear science.

On the one hand, instruments enable discoveries of basic new scientific phenomena and these phenomena are in their turn applied to design and develop new instruments which help to further our knowledge of science and through that of the physical world. Thus instrumentation and science are progressing together to enable man to achieve the goal of fully knowing Nature and of its final conquest.

The latest in technological achievements are the sputniks and man-made planets. The contents of these units are nothing but instruments of a wide variety including mechanical, optical, electrical and electronic devices to transmit information of profound importance regarding outer space.

During this course of lectures, I have just touched on the fringes of the science of instrumentation. The variety and applications of instruments has now become so vast that the subject has become an independent branch of engineering. In applications of physical principles, it is a science. In design and development it is technology. In development and manufacture it is as industry.

Electronic instrumentation has so rapidly developed of late that it has crept into the domain of mathematics. Electronic computers are quickly replacing manual calculations which are too slow to keep pace with the modern requirements in technology. They enable not merely elaborate additions, subtractions, multiplications and divisions, but solve differential equations of a complicated problems in X-ray crystallography etc. Analog computers are widely applied in the understanding the effects of complicated electrical circuit systems. Different branches of science and technology are developing on independent lines with very little of overlapping. But the one, science or technology, by whatever name it may be identified, that is all pervading and indispensable for all aspects of science, engineering, technology and industry is instrumentation. In conclusion it may be asserted that "Except for atomic energy, the development and application of instrumentation have far greater potential material significance for our age and civilization, than any other factor on the contemporary scene".

ON TWO RECIPROCAL SYSTEMS OF CIRCLES

By K. RANGASWAMI AIYAR

Department of Statistics.

1. *Introduction:* It is well known that two systems of circles which are reciprocals of each other are represented in a three-dimensional space by two surfaces Σ and $\bar{\Sigma}$ which are reciprocal with respect to the absolute quadric Q representing the point circles of the plane. A familiar example of two such circle systems is furnished by the family of Lemoyne circles of the lines of a plane, with respect to a triangle, constituting a system Σ and represented in the three-space by a Steiner-Quartic surface and the family of pedal circles of pairs of isogonal conjugates on the lines, constituting the reciprocal family $\bar{\Sigma}$ and represented in [3] by a quadrinodal cubic surface (1). In this paper we propose to study two such reciprocal circle systems defined with respect to a base conic Γ , viz., the system of ∞^2 circles S described on chords of the conic as diameters, constituting a family Σ and its reciprocal system of circles $\bar{S}$ constituting the family $\bar{\Sigma}$. It will be shown in the investigation that, as in the case of Lemoyne-Pedal circle systems, the family of circles S is represented in [3] by a Steiner Quartic surface Σ and the reciprocal system of circles is represented by a Quadrinodal cubic surface $\bar{\Sigma}$. This feature of the circle system adds, therefore, not only to the interest regarding the investigation of the circle systems but further helps to derive a number of interesting properties relating to the two systems.

2. Let P_1, P_2 be any two points on a base conic Γ , centre C . Then the circles S on chords like P_1P_2 as diameters generate a family of ∞^2 circles, say, Σ . Now taking the familiar mode of representing circles in the plane by points of a projective three-space wherein the point circles are represented by the points on a quadric surface Q , called the absolute, the system of circles S will be represented by a surface Σ . Since two orthogonal circles in the plane are represented by two points conjugate with respect to the absolute quadric Q in [3], the system of circles reciprocal to Σ will be represented in [3] by the points which are the poles with respect to Q of tangent planes to Σ .

Consider any circle $\mathcal{L}$ in the plane. Then the envelope of lines cutting the circle $\mathcal{L}$ and the conic Γ in harmonic pairs of points is the ϕ -conic say $\phi_{\mathcal{L}}$ of $\mathcal{L}$ and Γ . Now, if any tangent t to $\phi_{\mathcal{L}}$ cuts Γ in P_1, P_2 and $\mathcal{L}$ in Q_1, Q_2 then the circle on P_1P_2 as diameter, say S , cuts orthogonally the circle $\mathcal{L}$. As there will be one circle like S , corresponding to each tangent of $\phi_{\mathcal{L}}$, there will be ∞^1 circles S all

cutting orthogonally circle $\mathcal{L}$. Thus, in the representative three-space, these circles are represented by a curve σ in the polar plane of $\mathcal{L}$ with respect to Q ; that is, the curve of intersection of the surface Σ and the polar plane of $\mathcal{L}$. Further, if β be any other circle, and $\phi\beta$ be the corresponding ϕ -conic, there will be four common tangents of $\phi\mathcal{L}$ and $\phi\beta$; these four chords of Γ give four circles S_1, S_2, S_3, S_4 which cut both $\mathcal{L}$ and β orthogonally. These four circles correspond to the points of intersection of the surface Σ and the polar line of $\mathcal{L}\beta$ with respect to Q . As $\mathcal{L}$ and β are arbitrary circles it follows that any line in [3] cuts Σ in four points. Thus we see that :

(2.1) *The surface Σ in [3] representing the circles S described on chords of Γ as diameters is a quartic surface.*

Since a coaxal system of circles pass through two common points, it follows that there are four circles of the system S , say, S_1, S_2, S_3, S_4 all passing through two given points.

It is easily seen that the ϕ -conics of Γ and a coaxal system of circles $\mathcal{L}$ is a four-line system, in which there are three degenerate members each consisting of a point pair. Thus, it is seen that there are three circles in a coaxal system whose corresponding ϕ -conics with Γ degenerate into point pairs. As a coaxal system of circles is represented by a straight line in [3] it follows that :

(2.2) *The totality of circles in the plane whose ϕ -conics with Γ degenerate into a pair of points is a cubic surface.*

We now prove that this cubic surface is the reciprocal surface of Σ with respect to the absolute quadric Q .

Now, the totality of ϕ -conics of the conics Γ and the circles of a plane form a linear ∞^3 -system of conic envelopes and are, therefore, all inpolar to the conics of a pencil. To determine this pencil of conics, we observe, that if CR be a tangent from the centre C to $\phi\mathcal{L}$ cutting Γ in P_1, P_2 the circle S on $P_1 P_2$ as diameter cuts orthogonally the circle α and meets Γ again at the extremities of the diameter $Q_1 Q_2$ which are the reflections of P_1, P_2 in either axes of Γ . Thus Q_1, Q_2 are the extremities of a diameter of S harmonic with respect to α ; hence, the diameter $Q_1 Q_2$, say CR' which is the reflections of CR in either of the axis of Γ is other tangent from C to $\phi\mathcal{L}$. We thus see that :

(2.3) *the tangents from the centre C of Γ to the ϕ -conic of Γ and any circle of the plane are equally inclined to the axes of Γ .*

Further it will be seen that :

- (2.4) *the conic Γ confocal with Γ and having for asymptotes the equiconjugate diameters of Γ is also outpolar to the ϕ -conic of Γ and any circle a .*

Let T be any point and $TP_1 P_2$ any chord of Γ . Let the polar of T meet Γ in U, V and let a be the circle through UV cutting orthogonally the circle on $P_1 P_2$, as diameter. We now prove that a cuts orthogonally the circle on every chord through T as diameter. Let $TQ_1 Q_2$ be any other chord through T and let $P_1 Q_1, P_2 Q_2$ meet in Y and $P_1 Q_2, P_2 Q_1$ meet in Z . Now $P_1, P_2; Q_1, Q_2; Y, Z$ are the three pairs of opposite vertices of a quadrilateral. Hence the circles on these pairs as diameters are coaxial. Further since P_1, P_2, Q_1, Q_2 lie on Γ , YZ is the polar of T and cuts Γ in U and V . Since U, V are harmonic with respect to Y, Z the circle $\mathcal{L}$ is orthogonal to the circle on YZ . Further since $\mathcal{L}$ is orthogonal to the circle on $P_1 P_2$ it follows that it is orthogonal to the circle on $Q_1 Q_2$ also.

Consider the four points of intersection of this circle $\mathcal{L}$ and Γ ; two of these points are U and V . Let U', V' , be the other two points of intersection and T' , the pole of $U' V'$ with respect to Γ and let TT' cut Γ in $R_1 R_2$. As $R_1 R_2$ is a chord through T , $\mathcal{L}$ cuts orthogonally the circle on $R_1 R_2$. Thus $\mathcal{L}$ is a circle through $U' V'$ and cutting orthogonally the circle on one chord through T . Hence $\mathcal{L}$ cuts orthogonally the circles on all chords through T' as diameter. Hence, by the definition of the ϕ -conic it follows that the ϕ -conic of Γ and the circle $\mathcal{L}$ degenerates into the point-pair T, T' . Thus by (2.3) we have :

- If the ϕ -conic of Γ and the circle $\mathcal{L}$ degenerates into a point pair T, T'*
 (2.5) *then T and T' are conjugate pairs in the Desargue's involution defined by Γ , and the axes of T .*

Now the circles on chords of Γ as diameters which cut a given circle orthogonally correspond to the points on the quartic curve σ viz., the curve of intersection of the surface Σ and the polar plane of $\mathcal{L}$. In the case when $\phi\mathcal{L}$ degenerates into a point pair the family of circles corresponding to points on σ break up into two systems consisting of the circles on the chords through T and T' as diameters. Hence the quartic curve σ breaks up into two conics γ_1 and γ_2 in the polar plane of $\mathcal{L}$. This plane is tangent to the surface Σ , the reciprocal to the cubic surface corresponding to the circle $\mathcal{L}$ when $\phi\mathcal{L}$ degenerates. We thus see that the tangent plane to Σ at a point S on it breaks up into two conic sections. The circle S is evidently the circle on the chord R_1, R_2 as diameter where R_1, R_2 is the chord through T and T' . To find the other three intersections of γ_1 and γ_2 we note that if $TC, T'C$ cut Γ in K_1, K_2 and L_1, L_2 these chords are

equally inclined to the axes by (2.3). Hence the circle on K_1, K_2 as diameter has L_1, L_2 also for a diameter. This circle therefore belongs to the two conics γ_1 and γ_2 on Σ . Again, let A_∞ and B_∞ be the points at infinity on the conic Γ and let TA_∞ meet Γ again in G . The circle on GA_∞ as diameter is the line through G perpendicular to GA_∞ . If this line meets Γ again in H , HG is perpendicular to GA_∞ and is therefore the circle on GA_∞ as diameter. Thus GA_∞ passes through T' . Hence the line circle GH belongs to the two systems γ_1 and γ_2 . Similarly if $TB_\infty, T'B_\infty$ meet Γ in G', H' ; $G'H'$ is a line circle also belonging to γ_1 , and γ_2 .

Now, the three lines representing the coaxal systems of circles viz., the concentric system of circles with centre C , the two systems of concurrent lines perpendicular respectively to the directions of the asymptotes of Γ all lie on Σ and have for their common member the circle point at infinity. These three coaxal systems correspond in [3] to the three concurrent double lines on Σ (2). The tangent plane at any point S on Σ , corresponding to the circle on $R_1 R_2$ as diameter cuts Σ in two conics γ_1 and γ_2 having for common points the point of contact of the tangent plane viz., the point S and the three points where the plane meets the double lines on Σ . This is a familiar property of the Steiner Quartic surface. We have thus the result :

(2.6) *The circles S described on chords of Γ as diameters correspond to points on a Steiner Quartic surface in [3].*

References

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A NOTE ON THE EFFECT OF SOUND VIBRATIONS OF
TUNING FORK ON THE MITOSIS IN IPOMAEA BATATAS
(SWEET POTATO) AND URGINEA INDICA KUNTH.
(INDIAN SQUILL)

By K. RANGASWAMI AYYANGAR

Of late, work has been in progress in this laboratory on the effect of sound vibrations on the growth and reproductive phases of plants like *Mimosa*, *Desmodium*, *Cosmos*, *Tagetes*, *Impatiens*, *Angelonia*, *Allium*, *Manihot*, *Saccharum*, *Ipomaea* etc. The observations so far made have revealed the fact that both vegetative and reproductive developments are far better in the sound-treated plants than in the corresponding controls (3, 5). Further it has been seen that in plants like *Mimosa*, *Impatiens*, *Desmodium*, *Ipomaea* and others, some perceptible histological changes take place as a result of excitation by sound. For example, the size of the epidermal cells and palisade cells has been found to be larger in the experimental plants than in the controls. Similarly, the frequency of stomata has been observed to be greater in the experimental plants. In the case of Sweet potato, the number and lumina of the xylem vessels in the root of the sound-treated plant was larger than in that of the non-treated (5, 6). It was, therefore, thought that the sound might have some influence on the cell division also. So, two sets of *Ipomaea* plants of identical size were grown in pots maintaining other factors like soil and water also in an identical manner. Near one set of potted plants (at a distance of 3 feet) an electrically run Tuning Fork was set to produce sound vibrations at a frequency of 100. The other set of potted plants (the control) was kept far enough not to be affected by the sound of the Tuning Fork. Daily, the Tuning Fork treatment was given for 30 minutes and the growth was watched from time to time in both the experimental and control sets. As has been pointed out earlier, the general growth and morphology of the experimental plants were superior to those of the control (3, 4, 5, 6). Now, root tips from both the experimental and control plants were taken out and acetocarmine squashes were made according to the technique developed here (1). The squashes were made at different times of the day and it was found that mitosis is at its maximum at about 2 p. m. In the fore-noon, however the cells were comparatively quiescent, only 5% of the cells revealing nuclear division. When in fore-noon such relatively quiescent cells were excited by sound, the

percentage of cells undergoing division went up from 5% to 43% as the following table shows :

<i>Ipomaea. batatas</i>	Total No. of cells examined	No. of cells undergoing mitosis	Percentage
Control	133	7	5%
Experimental	141	61	43%

Similar experiments were conducted on *Urginea indica* Kunth., the Indian Squill, a bulbous plant commonly growing in this locality in clayey soil. As in the case of *Ipomaea*, in this plant also, the frequency of mitotically dividing cells in the experimental plants has been found to be higher than the frequency in the control. The experimental plants on an average registered a mitotic frequency of 31% whereas the control showed on an average only 12%. The following Table (Table-2) gives details of observation in *Urginea indica* Kunth.

TABLE-2

CONTROL				EXPERIMENTAL				(d ²)
S. No.	Total No. of cells Exa- mined	No. of cells under- going mitosis	Frequ- ency per- centage	Total No. of cells Exa- mined	No. of cells under- going mitosis	Frequ- ency per- centage	Differen- ce bet- ween column 4 & 7 (d)	
1	2	3	4	5	6	7	8	9
1	138	12	8.69	145	45	31.03	22.34	499.07
2	142	18	12.67	140	41	29.28	16.61	275.89
3	135	16	11.85	136	38	27.94	16.09	258.88
4	146	15	10.27	152	46	30.26	19.99	399.60
5	155	28	18.06	148	50	33.78	15.72	247.11
6	132	13	9.84	138	46	33.33	23.49	551.78
Average frequency			11.89%	Average frequency		30.93%	114.24	2232.33

It may be pointed out that at 6 A.M. when the sound treatment was given, mitosis was normally at a very low ebb. Nevertheless, in the experimental plants the rate of mitosis went up. This reveals that the augmented rate of mitosis in the experimental as contrasted with the control plant, is obviously due to the activation of nuclear division by sound.

The foregoing data were subjected to statistical analysis in order to see if the frequency percentage of mitosis in the experimental plant as compared with the control is of statistical significance. The analysis is as follows :

Mean frequency of the control (mC) = 11.89 %

Mean frequency of the experimental (mE) = 30.93 %

Mean observed difference ($mE - mC$) 30.93 % - 11.89 %
= 19.04 %

$$\begin{aligned}\text{Standard Deviation } (\sigma) &= \sqrt{\frac{\sum fd^2}{n-1} - \frac{(\sum fd)^2}{n(n-1)}} \\ &= \sqrt{\frac{2232.33}{6-1} - \frac{114.24^2}{6(6-1)}} \\ &= \sqrt{\frac{2232.33}{5} - \frac{13050.77}{30}} \\ &= \sqrt{446.46 - 435.02} \\ &= \sqrt{11.44} \\ &= 3.38\end{aligned}$$

$$\text{Standard Error (S.E.)} = \frac{\sigma}{\sqrt{n}} = \frac{3.38}{\sqrt{6}} = \frac{3.38}{2.44} = 1.38$$

$$\text{Critical Difference (cd)} = t \times \text{S.E.}$$

$$\text{Critical Difference at 5\% level} = 2.45 \times 1.38 = 3.38$$

$$\text{Critical Difference at 1\% level} = 3.71 \times 1.38 = 5.12$$

At both these levels, the observed mean difference (19.04) is very much higher than the critical difference. Hence, the observations in respect of mitosis frequency of the experimental plant are of statistical significance.

The foregoing observations show that sound vibrations impinging on the protoplasm stimulate the otherwise quiescent nuclei to mitotic activity. As a matter of fact, in the *Hydrilla verticillata* Presl., it was definitely demonstrated that sound vibrations caused more rapid streaming movement of the protoplasm of the cells (2). The phenomena of more vigorous growth already reported in the various plants which were bombarded by sound waves, is to be attributed to the stimulation of the cell protoplasm into greater activity which results in more

rapid and more frequent nuclear divisions and the consequent increased growth rate and augmented size of the plants concerned. It is common knowledge that other forms of energy like U. V. rays, Infra Red Rays, X-rays, influence nuclear division and even cause chromosomal aberrations. In a similar way, sound waves would appear to have the effect of accelerating mitosis in plants

I am very much grateful to Professor T. C. N. Singh, M.Sc., D. Sc., D. Ph., F.B.S. for having suggested this line of work and for his encouragement. I am also indebted to the Botany Department Research Club for its helpful discussion.

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STUDIES ON THE INFLUENCE OF VERNALIZATION ON THE MITOTIC BEHAVIOUR OF *ALLIUM CEPA* LINN. (BELLARY ONION) AND *ALLIUM SATIVUM* LINN. (GARLIC)

By K. RANGASWAMI AYYANGAR,
Department of Botany, Annamalai University.

(Communicated by Professor T. C. N. Singh, Annamalai University)

INTRODUCTION

During the course of a number of investigations now being carried out in this Botanical Laboratory on vernalization and its effects on the growth phenomena of a variety of vegetable crops, the idea that vernalization may affect also the cytological behaviour of plants was kindly suggested by Dr. T. C. N. Singh, Professor and Head of the Department of Botany, for critical inquiry. Already, it has been established by experiments in this laboratory that *Allium cepa* Linn. (Bellary Onion) and *Allium sativum* Linn. (Garlic) could be successfully vernalized. (Pannirselvam, 1954). The results obtained were striking: there was larger yield and a conspicuous increase both in the size and number of bulbs was also noted.

MATERIALS AND METHODS

Bulbs of Bellary onion and Garlic are being grown in the Botanic Garden. Before being planted in the soil or in pots, the bulbs were vernalized by keeping them for 25 days in a kelvinator (Refrigerator) thus subjecting them to a low temperature. The temperature was maintained at 7°C. Root-tips were ready in about a week's time. They were fixed in Karpechenko's modification of Nawaschin's chrome-acetic formalin. The best time for fixation was found to be between 10 and 11 A.M. when the mitotic activity was at its zenith. Paraffin sections were cut 10-12 microns thick and the preparations were stained in Newton's Iodine-gentian Violet. Drawings were made at table level with Abbe Camera-Lucida Apparatus and their respective magnifications were recorded.

OBSERVATIONS

The low temperature has greatly affected the course of mitosis in the root-tip cells of both the species of *Allium*. One of the conspicuous results of cold treatment is the occurrence of supernumerary chromosomes in a comparatively large number of cells of the root-tip as seen both in the transverse and longitudinal sections. The following table shows, in a given area of longitudinal section, the ratio between cells containing the normal chromosome numbers and those containing the changed chromosome numbers.

TABLE I

Name of the plant	No. of cells in 441 sq. microns with normal chro. No. average of 20 observations, $2n=16$	No. of cells in 441 sq. microns with super numerary chro. No. average of 20 observations	Percentage of abnormal cells
<i>Allium cepa</i>	25	119	82.6
<i>Allium sativum</i>	55	89	61.8

The changed chromosome numbers range from 10 to 32. Thus the lowest number observed was a hypoploid (aneuploid) containing 6 chromosomes less than the normal diploid ($2n=16$) while the highest was a tetraploid ($2n+16$ or 32). Of the 50 cases that were examined in a particular section of the root-tip of *Allium cepa* Linn. three cells contained the tetraploid number while other cells showed varying chromosome numbers. Table II contains these observations.

TABLE II
Allium cepa Linn.

S. No.	No. of chromosomes in Metaphase plates	Difference from the normal + or -	No. of cases
1	10	-6	5
2	11	-5	6
3	12	-4	8
4	18	+2	5
5	20	+4	7
6	21	+5	5
7	24	+8	4
8	26	+10	4
9	28	+12	3
10	32	+16	3
			Total 50

DISCUSSION

(a) *Effects of low temperature on cell division*

The foregoing observations clearly indicate that low temperature like other extraneous agents such as chemicals, ultraviolet rays and X-rays affects the normal course of mitosis.

The various mitotic aberrations caused by the low temperature treatment are: (1) differential chromosome numbers in an appreciable percentage of the cells of the root-tip; (2) irregular scattering of the divided chromosomes in the cell; (3) unequal apportionment of chromatin material between the daughter nuclei; and (4) precocious organisation of an amorphous kind of nucleus through the formation of a nuclear membrane enclosing the scattered chromosomes. All these phenomena would appear to be the immediate result of a seriously disturbed or totally impaired spindle mechanism accompanying the initial and prolonged refrigeration of the cells.

(b) *Economic significance*

The most conspicuous sequel of subjecting the plants under investigation to low temperature is the increase in their chromosome numbers. It is now common knowledge that increase in the number of chromosomes over the normal number tends to bring about an increase in the size of the plants, which again eventually result in higher yield. Artificial increase in the chromosome numbers, resulting in triploidy, tetraploidy and higher euploidy by the application of chemicals or irradiation has been brought about in various plants. (Sharp, 1934 ; Dugger, 1936 ; Goodspeed and Uber, 1939). Furthermore such cases of higher polyploids are also known to breed true by the stabilisation of their chromosomal mechanism. In a few cases high temperature has been known to bring about similar results. Likewise the present investigation has shown that vernalization may exercise such a profound and far reaching influence on mitosis in plants as to produce true breeding stable polyploids, as evidenced by the considerable increase in the size of the bulbs after vernalization. Further studies in this line are being pursued.

ACKNOWLEDGMENT

It gives me great pleasure to express my grateful thanks to Dr. T. C. N. Singh, M.Sc., D.Sc., D.Ph., F.B.S., Professor and Head of the Department of Botany for having initiated me in this line of investigation and helped me with his valuable suggestions and criticism from time to time. I am also much indebted to the Botany Department Research Club for its periodical and helpful discussions during the progress of this work.

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ON THE VERNALIZATION OF BULBS OF EUCOMIS

By S. PANNIRSELVAM

Research Scholar, Annamalai University.

(Communicated by Professor T. C. N. Singh, Annamalai University)

INTRODUCTION

There is a good deal of work on the vernalization of seeds and grains (1,1948), but there is hardly any work on the vernalization of perennating organs like bulbs, rhizomes etc. In 1924 (2) Blaauw and his co-workers of the Agriculture College, Wageningen (Netherlands) have reported the effect of low temperature, on bulbs of Tulip, Hyacinth and Onion. In the case of onion and Tulip they have shown that there is an increase in size and in Hyacinth there is an increase in the number of roots but there is no observation at all on the reproductive phase of these plants. Recently Singh (3) (1953) has shown that the root tubers of *Cyperus rotundus* kept at 7°C. for a period of 30 days get vernalized with the result that they germinated quicker and their vegetative growth was much better and they entered into the reproductive phase a month earlier than the control.

It was on the suggestion of Professor T. C. N. Singh, Head of the department of Botany, Annamalai University that a systematic extensive work has been taken up of vernalization in relation to perennating organs of the plants.

The author (4) (*Proc. Ind. Sci. Cong. Assoc.* 1955 p.255) has shown that onion and garlic bulbs on vernalization, produce more bulbs and enter into reproductive phase much earlier than the control bulbs.

In the present communication observations have been presented on the bulbs of *Eucomis punctata* L'Her.

MATERIAL AND METHOD

Bulbs of *Eucomis punctata* L'Her. were obtained from the Fern House of the Botanic Garden, Annamalainagar. The bulbs of average size were carefully selected. They were kept in the kelvinator at a temperature of 7°C for a period of 25 days. After the expiry of the scheduled period of vernalization they were sown in pots with proper controls. The control bulbs were taken from the Fern

House of the Botanic Garden at the time of sowing the experimental bulbs. The pots were of the same size containing the soil having the same composition. Interculture and irrigation were done uniformly to all the experimental and control pots.

EXPERIMENTAL OBSERVATIONS

Six bulbs of vernalized *Eucomis punctata* L'Her. were planted in pots with six control bulbs on 5—12—54. In the initial stages, the vernalized bulbs germinated earlier. The vegetative growth of the vernalized *Eucomis punctata* L'Her. plants was better than the control *Eucomis punctata* L'Her. plants.

The vernalized *Eucomis punctata* L'Her. plants produced inflorescences on 17—3—55 i. e. after 100 days of planting of the bulbs whereas the control plants produced their inflorescences between 13—4—55 and 22—4—55 i. e. after 127 to 136 days of planting of the bulbs. The vernalized plants finished their life history much earlier (30 days) than the control plants.

DISCUSSION

In the present study advantage has been taken of low temperature to the extent of 7°C coupled with darkness to effect vernalization in *Eucomis punctata* L'Her. The vernalized plants entered into reproductive phase much earlier i. e. 27 to 36 days than the control plants. The vegetative performance was much superior to vernalized plants.

As *Eucomis punctata* L'Her. is an ornamental plant the vernalization of *Eucomis* bulbs can be used to force them into flowering at any season.

SUMMARY

Bulbs of *Eucomis punctata* L'Her. were vernalized in kelvinator for continuous period of 25 days at a uniform temperature of 7°C. in darkness. After the expiry of this scheduled period they were sown in pots with proper controls. It was observed that the vernalized plants matured earlier (i.e. 27 to 36 days) and their vegetative performance was much better than the control plants.

ACKNOWLEDGMENT

I am deeply indebted to Dr. T. C.N. Singh, D.Sc., D.Ph., F.B.S., Professor and Head, Department of Botany, Annamalai University for suggesting the problem and his keen interest and valuable guidance and encouragement throughout the work. My thanks are also due to the members of the Botany Department.

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SOME SMALLER FORAMINIFERA FROM AN UPPER CRETACEOUS MARL NEAR PONDICHERRY-SOUTH INDIA

By N. RAJAGOPALAN

Department of Geology, Annamalai University, Annamalai Nagar.

Abstract

This paper records the occurrence of some smaller foraminifera from an upper cretaceous marl collected from a well section near Pondicherry.

Introduction

In the course of his field work in the cretaceous area of Pondicherry during the summer months of 1960, the author came across a new well section near Papanchavadi (Topographic sheet No. 57 P/16; $12^{\circ} 0' 24''$ N : $79^{\circ} 46' 12''$ E) which exposes a good section of the upper cretaceous. The present study is based on the material collected at a depth of 34 feet. The material contains a rich and varied foraminiferal fauna. An account of some of the smaller foraminiferal species is given in this paper.

Previous Work

The cretaceous rocks of Pondicherry which occupy an area of nearly 30 sq. miles N. W. of Pondicherry were first studied and described by Blanford¹. Later Warth¹⁴ investigated the area and recognised six lithological divisions. Kossmat⁹ who studied the fossils of this area classified the rocks into three faunal divisions viz : the lower Anisoceras beds, the middle Trigonarca beds and the upper Nerinea beds – all belonging to upper cretaceous. Rama Rao¹⁰ who made a study of certain limestones from near Valudavur came across abundant Nummulites together with Discocyclina. This discovery made him suggest that there must be an eocene horizon in this area. His later finding in 1953¹¹ of *Distichoplax biserialis* Diet. in this area further confirmed the existence of an eocene bed overlying the upper cretaceous. So far no study on the smaller foraminifera of this area has been undertaken.

Material and Method

The rock is a highly friable yellow marl. The material was loosened by hand and then boiled in a weak solution of washing soda for about one hour. Then the sample was washed clean, dried and sieved through 60, 85 and 100

mesh screens. The samples retained in 85 and 100 mesh screens were taken for microscopical examination.

Systematic Description

Only a few of the more easily recognisable species are described here. A more detailed systematic study of the several species of foraminifera and other micro fossils is under progress.

Order : FORAMINIFERA

Family : LAGENIDAE

Subfamily : NODOSARIINAE

Genus : *Dentalina* d'Orbigny 1826

Dentalina obliquesuturata Stache

Plate—FIG. 1

Dentalina obliquesuturata Stache, 1864, *Novara. Exped. Geol.* Thiel, Bd. 1, Abt. 2, p. 207. Pl. 22, fig. 36. (Eocene, New Zealand)

Dentalina obliquesuturata Cushman and Dusenbury 1934, Cushman Lab. Foram. Research Contr. Vol. 10, p. 54, pl. 7, figs. 22—25 (Middle Eocene, California)

Dentalina communis (?) Cushman and Ponton (part), 1932, Cushman Lab. Foram. Research Contr., Vol. 8, p. 55, pl. 7, fig. 12. (Wilcox group, Ozark, Alabama)

Dentalina obliquesuturata Toulmin 1941, *Jour. Pal.* vol. 15, p. 586, pl. 79 fig. 18 (Eocene Alabama)

This species is well represented in our material.

Dimensions : Length : 0.72 mm. Breadth : 0.24 mm.

Genus : *Marginulina* d'Orbigny 1926

Marginulina sp. 1

Plate—FIG. 5

Test elongate, slightly compressed, later chambers highly inflated than earlier ones, sutures of later portion of the test more distinct, aperture radiate and produced.

This species has close affinities with *Marginulina* sp. A. described by Beck².

This species is sparingly present in our material.

Dimensions: Length: 0.70 mm. Breadth: 0.27 (in the mid portion of the test.)

Marginulina sp. 2

Plate—Fig. 2

Test elongate, cylindrical, periphery rounded, circular in cross section, chambers 4 or 5 increasing slightly in size as added, sutures horizontal and distinct; aperture radiate and strongly produced.

This species differs from *Marginulina* sp. B described by Beck³ in having only a moderately inflated last chamber.

This is of frequent occurrence in our material.

Dimensions: Length: 0.60 mm. Breadth: 0.18 mm.

Marginulina sp. 3

Plate—Fig. 4

Test small, cross section circular, chambers 4, last chamber quite big; sutures distinct, flush with the surface; wall smooth, polished; aperture radiate, strongly produced.

This species resembles *Marginulina* sp. C described by Beck⁴ in all respects and in the opinion of the author both appear to be identical.

Quite a large number of specimens of this species are available in our material.

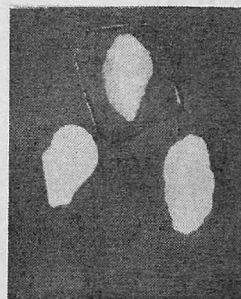
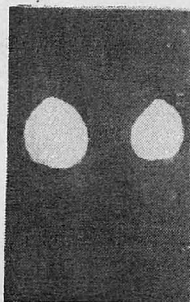
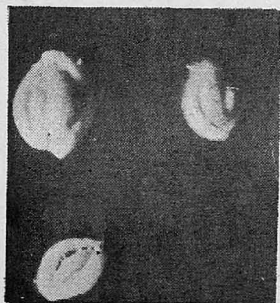
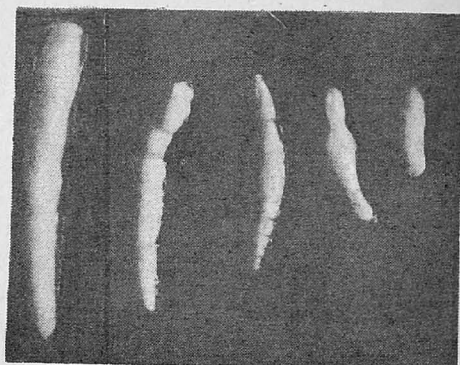
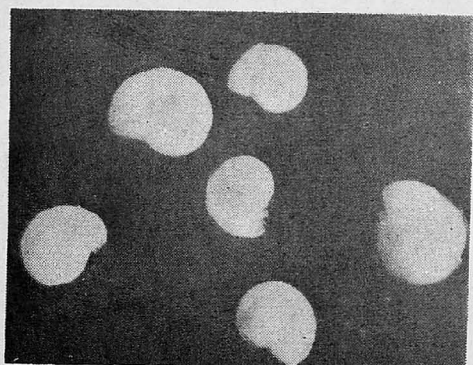
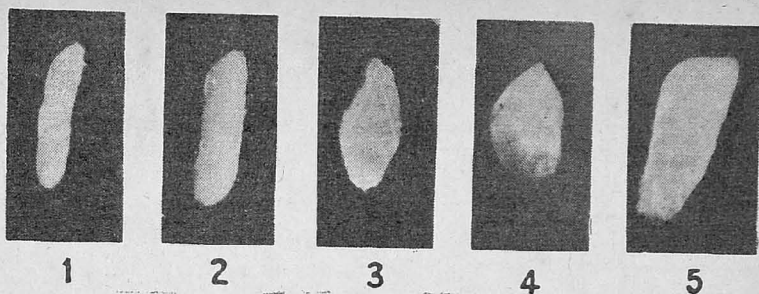
Dimensions: Length: 0.44 mm. Breadth: 0.30 mm.

Genus: *Robulus* Montfort, 1808

Robulus sp. indet.

A few specimens of this species are available.

Test lenticular, involute, periphery sharp, aperture rounded. More specimens are required for proper identification.



EXPLANATION OF FIGURES IN THE PLATE

Fig. 1. *Dentalina obliquesuturata*

Stache $\times 30$

„ 2. *Marginulina* sp. 2 $\times 40$

„ 3. *Frondicularia* sp. indet $\times 30$

„ 4. *Marginulina* sp. 3 $\times 40$

„ 5. *Marginulina* sp. 1 $\times 40$

Fig. 6. *Gyroidina* sp.

$\times 40$

„ 7. *Stilostomella* sp.

$\times 30$

„ 8. *Quinqueloculina* sp.

$\times 40$

„ 9. *Globulina* sp.

$\times 40$

„ 10. *Chrysalidinella?* sp. indet. $\times 30$

Dimensions : Diameter : 0·3 mm.

Genus : *Frondicularia* Defrance, 1824

Frondicularia sp. indet.

Plate—FIG. 3

Only a single specimen is available in our material. Specific determination is not possible for want of more specimens.

Test arrow shaped ; proloculus is clearly below the other chambers and possessing a number of costae ; sutures slightly limbate.

This species is similar in almost all respects to *Frondicularia goldfussi* Reuss sketched by Cushman and Deaderick (Jour. Pal. vol. 18. plate 52, fig. 12).

Dimensions : Length : 0·71 mm. Breadth : 0·34 mm.

Family : ELLIPSOIDINIDAE

Genus : *Stilostomella* Guppy, 1894

Stilostomella sp.

Plate—FIG. 7

This species is abundantly found in a wide variety of shapes. Test elongate, tapering ; surface smooth. In most of the individuals the proloculus is cup shaped and ends in a small sharp spinose projection. Number of chambers vary from 6 to 12. While most of the tests have an arcuate outline some are straight. In a few specimens there is a sharp bend in the beginning or middle or about the end of the test. Sutures straight, either flush with the surface or slightly constricted. Cross section circular ; aperture terminal, rounded.

This species very closely resembles *Ellipsonodosaria verneuili* emaciata Palmer and Bermudez, from the middle Oligocene (Cushman and Ellisor 1945, Jour. Pal. pl. 76. Fig. 17-19).

Hofker⁸ describes this species as *Stilostomella verneuili* (d'Orbigny). The present species differs from *S. verneuili* in having more elongated chambers and a spine in the initial chamber.

Dimensions : Length varies from 0·68 to 1·83 mm.
 Width of the initial chamber 0·1 mm.
 Width of the last chamber 0·2 mm.

Family : MILIOLIDAE
 Genus : *Quinqueloculina* d' Orbigny 1826
Quinqueloculina sp.

Plate—Fig 8.

Test more or less globular, slightly longer than broad. This species is found in abundance in our material.

Quinqueloculina vulgaris d' Orbigny described by Toulmin¹² from the eocene of Alabama compares well with the present species.

Dimensions : Length : 0·40 mm. Breadth : 0·29 mm. (biggest in the plate.)

Family : ROTALIIDAE
 Subfamily : DISCORBINAE
 Genus : *Gyroidina* d' Orbigny, 1826.
Gyroidina sp.

Plate—Fig. 6.

Test trochoid, dorsal surface flat, made up of two or three whorls, ventral portion highly vaulted ; aperture slit like along the basal suture on the ventral side of the last chamber ; umbilicus small and deep. Sutures are more distinct in the last whorl.

This species is present in abundance in our material and among the specimens there are both right and left handed forms.

Dimensions : Diameter : 0·26 mm.

Family : VERNEUILINIDAE
 Subfamily : REUSSELLINAE
 Genus : *Chrysalidinella* ? Schubert 1907.
Chrysalidinella ? sp. indet.

Plate—Fig. 10.

Test tapering, triangular in transverse section, slightly twisted in the early portion in some forms ; early chambers triserial, the nature of the later chambers is not clear, edges carinate, sides depressed or bulged out ; aperture rounded.

As the arrangement of the chambers is not clear this genus is doubtfully referred to *Chrysalidinella*.

This species is well represented in our material.

Dimensions : Length : 0.53 mm. Breadth : 0.28 mm.

Family : POLYMORPHINIDAE

Subfamily : POLYMORPHININAE

Genus : *Globulina* d'Orbigny

Globulina sp.

Plate—Fig. 9

Good number of specimens referable to a species of this genus are available in our material.

Test globular, rounded, chambers overlapping, sutures flush with the surface, surface smooth and polished ; aperture radiate and produced.

Dimensions : Diameter 0.32 mm.

ACKNOWLEDGEMENT

The presentation of this paper was not only inspired but made possible by the kindly interest taken by Professor T. N. Muthuswami, Professor of Geology. Thanks are due to Sri R. Gnanasekaran, Lecturer in Geology for the help rendered in the progress of the work and to Sri Sriramulu of the Zoology department who kindly prepared the microphotographs.

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AGE AND GROWTH OF THE YELLOW PERCH, *PERCA FLAVESCENS* (MITCHILL) OF GRAND TRAVERSE BAY

By P. GOVINDAN

Department of Zoology, Annamalai University, Annamalai Nagar.

The yellow perch, *Perca flavescens* (Mitchill), occurring in the shallow waters of the Great Lakes is of considerable importance to both commercial fishermen and anglers in the Great Lakes region. Numerous studies have been made of the age and growth of perch in small inland lakes; but only a few studies deal with the growth of this species in Great Lakes waters. Harkness (1922) investigated the rate of growth of yellow perch in Lake Erie. Jobes (1933) made a preliminary study on the age and growth of this species as determined from its scales. Hile and Jobes have made extensive and excellent studies on the age and growth of yellow perch of Saginaw Bay (1941) and in the Wisconsin waters of Green Bay and northern Lake Michigan (1942).

This paper is an attempt to furnish further information on the age and growth history of yellow perch of Grand Traverse Bay, a region where commercial fishing operations are prohibited, and to compare them with those made by previous workers in other waters of the Great Lakes.

Material and Methods

The investigation of the age and growth of the Grand Traverse Bay yellow perch has been based on the examination and measurements of scales from 88 fish taken during October 2nd to 4th 1947 by experimental gill nets with meshes ranging from 2½ to 4 inches. Scales were taken from all specimens from the left side of the body below the dorsal fin and above the lateral line.

Four scales from each fish were mounted in gelatin-glycerine medium and the one readily readable was used for age and growth determinations. The scales were projected on a scale viewing machine described by Van Oosten et al (1934) using a 32 mm. objective which yielded a magnification of 40·5 diameters. Each scale length was read along the greatest antero-lateral radius.

The terms, age groups and year classes, used in this study are explained as follows. An age group includes those individuals in a collection of fish which have completed a given number of winter marks based on which the fish are classified as age group I if they show one winter mark, age group II when there are two annuli and so on. A year class refers to those fish which have hatched

out in a particular year. For instance, in a catch of 1947, when we denote a group of fish as year class 1943, it means that the members in that group were all hatched out in 1943 and caught four years after hatching. It should be further noted that a catch may have different year classes i. e., groups that were hatched in different years. As an example, in our collection of Grand Traverse Bay sample age group I may be referred as year class 1946, age group II as year class 1945, age group III as year class 1944 and age group IV as year class 1943.

Length-frequency distribution and Age composition

Table I shows the length-frequency distribution of the sample under study. The fishes in each age group are grouped into 10 millimeter length intervals. The total number of fish for each age group, their mean standard length, standard deviation and standard error of the mean are recorded in the bottom rows of the table. At the extreme right column of the table the total number of fish for the corresponding length interval irrespective of the age groups is shown.

TABLE I
*Length-frequency distribution of 88
Grand Traverse Bay yellow perch collected in 1947*

Class Interval mm	Age class frequencies				Total
	I	II	III	IV	
110 — 119	8				8
120 — 129	9				9
130 — 139		4			4
140 — 149		4	1		5
150 — 159		3	1		4
160 — 169		12	8		20
170 — 179		5	5		10
180 — 189		1	3		4
190 — 199			7	1	8
200 — 209			2	3	5
210 — 219			3	2	5
220 — 229			3	2	5
230 — 239				1	1
Total	17	29	33	9	88
Mean Length	119.79	158.98	185.71	213.39	
Standard deviation	5.14	14.05	21.75	12.69	
Standard error of mean	0.88	1.84	2.68	2.99	

From the table it is seen that the 1947 sample falls within the 110 - 239 millimeter range and the 160 - 169 millimeter size class is dominant with 20 individuals or about 23 per cent of the total catch. The age group III represents the dominant group with 33 individuals. Following this dominant age group the number of individuals in age group IV drops sharply to 9. Hile and Jobes (1941 and 1942) and Harkness (1922) have recorded that the age groups in their yellow perch samples have fallen between II and VII (Saginaw Bay), I to XI (Green Bay) and between 0 and VII (Lake Erie) respectively. On the other hand the Grand Traverse Bay sample used here shows an age composition I to IV only. Whether this condition is due to migration or natural mortality of age group V and succeeding groups or to any other factor cannot be predicted due to the smallness of the sample.

Sex Ratio

Of the 88 specimens examined, 53 and 35 were the males and females respectively. The distribution of the sexes in the different age groups is given in table 2. It is seen from the table that there is a great variation of the sex ratio with age. It is apparent, however, that the males outnumber the females in the age groups I to III and fall down slightly in age group IV. Hile and Jobes (1941) had observed in their Saginaw Bay sample that the females predominated in every age group ; and explained that this situation lent support to the belief that the females predominated in the population toward the close of the spawning run since most of the samples were taken late in the spawning season. Carlander (1950) had also observed in his yellow perch sample from Lake of the Woods that the females were much more abundant than the males at least in the older age classes and that the 0 age group showed a slight dominance of males.

TABLE 2

Sex ratio of the different age groups of Grand Traverse Bay yellow Perch, 1947 Collection

Sex	Number of individuals			
	I	II	III	IV
Males	11	20	18	4
Females	6	9	15	5
Sex ratio (M/F)	1.8	2.2	1.2	0.8

Cahn (1927) found in his studies on Lake Mendota cisco that the males outnumber the females and that the males migrated into the shallows earlier than the females when the water temperature was 4.3°C . The females arrived a few days later when the water temperature dropped to 3.8°C . Whether the greater abundance of males in the I, II and III age groups of the Grand Traverse Bay yellow perch under study is due to a similar condition is difficult to judge since there are no data on the water temperature at the time of capture of samples.

Van Oosten (1938) observed in the fall collection of the common white-fish of Lake Huron in 1924 that the males exceeded the females in number indicating the male white-fish migrated to the spawning grounds earlier than females. It is true that the yellow perch sample under study also shows an outnumbering of males in the matured II and III age groups; however, there are not sufficient data in different seasons so as to warrant any comparison. Until more data are collected in different seasons of the year and compared the 1947 collection may not be reliable to state that the male yellow perch behaves like the common white-fish in visiting the breeding grounds earlier than the females.

Among the factors that might cause differential sex ratio in adult fish, two alternative ones are put forth by Geiser (1924): "(a) a possible differential death rate of the sexes during the embryonic, juvenile and adult period, coupled with a normal sex ratio at fertilization, and (b) an atypical primary sex ratio, due to an atypical distribution of sex determining chromosomes to the two daughter cells in the maturation divisions of the germ cells." His studies on the spermatogenesis of *Gambusia* failed to show any special chromosomes that would explain the differential sex ratios. Moreover, the *Gambusia* raised by him in the aquaria showed approximately equal numbers of males and females at the time of birth. These evidences led Geiser to believe that the males had an inherent character for higher death rate than females thus resulting in the differential sex ratios in the adult population. Hile (1936 and 1941) believed that the differences in the sex ratios of the cisco and rock bass in the Wisconsin lakes were due to the greater stability or survival value of the females. Geiser (1923) in his general discussion on the sex ratios in various animals, after quoting many cases, observed that the females had greater inherent viability than the males. If the observations of Geiser and Hile are accepted then, some other possible explanation for the greater abundance of the males in the age groups of I, II and III of the sample under study has to be given.

Eschmeyer (1938) in his perch populations in Michigan and Hile (1936) and (1941) in his cisco and rock bass populations have pointed out that gill nets

are highly selective with respect to sexes. If such selectivity has occurred for the Grand Traverse Bay yellow perch, then, the 1947 collection by gill nets may not be a reliable basis for any such discussion.

Though the pattern in the sex ratio of the Grand Traverse Bay yellow perch under study may not at present be compared to any one of the observations made by the earlier workers in their samples, the persistent occurrence of more males in the I to III age groups might probably indicate certain significance in the behaviour of the males of these age groups.

Body-scale length relationship

The body-scale relationship has been shown to be very close to a straight line regression in a considerable number of fish populations (Lewis and English (1949), Tate (1949), Scott (1949), Perlmutter and Clarke (1949), Beckman (1948), Wright (1929), Van Oosten (1942), Hile and Jobes (1941 and 1942), Segerstrale (1933), Parsons (1950), Schneberger (1935) and several other workers).

Hile (1941) in the rock bass sample of Nebish and Muskellunge Lakes, Wisconsin, established a body-scale length relationship that was expressed by a weak third order parabola. Carlander (1945a and 1945b) in his yellow pike perch and tullibee populations showed that the relationship between the scale radius and standard length was not a straight line, but could be described by a third degree parabola.

In this study the body-scale length relationship was assumed to be a linear regression since the L/Sc (L =Standard length, Sc =scale radius) ratio in the sample did not indicate any trend towards a parabolic relationship. Moreover, plotting the observed standard lengths against the anterior scale radii indicated a relationship very close to a straight line.

The straight line equation is $Y=a+bX$ where Y is the standard length in millimeters and X is the scale radius and, a and b are constants.

Fig. 1 represents the equation : $Y=29.32206 + 0.80465 X$

This straight line having an intercept on the Y axis of 29.32 millimeters and a slope of 0.80 gave a satisfactory fit. Consequently, growth calculations were made with the aid of a nomograph on a direct proportion basis using 29 millimeters as a base rather than zero as computed by Carlander and Smith (1944). For this population it is presumed that the scale is formed when the fish is about 29 millimeters in standard length.

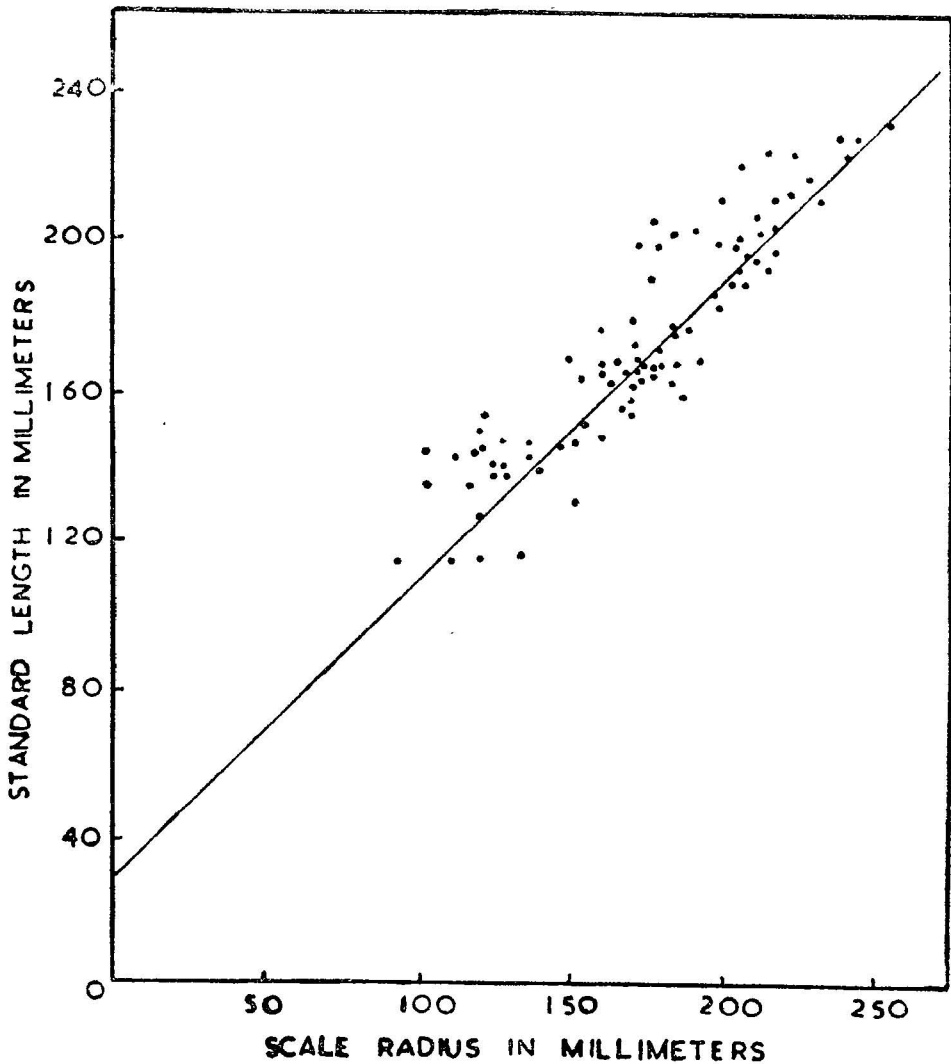


Fig. 1. *Linear relationship of the anterior scale radius to the standard length of 88 yellow perch taken in the eastern arm of the Grand Traverse Bay, Michigan from October 2 to 4, 1947. The straight line equation for the data is $Y = 29.32206 + 0.80465 X$*

Growth in length

Table 3 presents the data for the calculated growth in length for the yellow perch sample used in this investigation. A preliminary analysis showed that the differences in the calculated lengths of the two sexes were not significantly large enough to warrant separate growth curves for males and females.

Figure 2 was made to illustrate the growth curves of the age groups of the sample where the sexes were combined. The figures in the table are the average calculated lengths at the end of the respective years. The average lengths of the combined sexes are weighted means. An inspection of the figures in the table suggests that the females had grown longer than the males in all the years of age groups excepting (a) age group I and (b) the first year of age group II where the males exceed the females by a small length which is practically negligible.

TABLE 3

Calculated average lengths and increments of growth for each year of life of Grand Traverse Bay yellow perch, 1947 collection

Age Group			Average Length mm				Average increment mm				No. of fish
			I	II	III	IV	I	II	III	IV	
I	Females	...	69				69				6
	Males	...	70				70				11
	Sexes combined	...	69				69				17
II	Females	...	61	116			61	56			9
	Males	...	62	108			62	47			20
	Sexes combined	...	61	111			61	49			29
III	Females	...	64	116	163		64	53	46		15
	Males	...	60	100	140		60	40	41		18
	Sexes combined	...	62	107	151		62	46	43		33
IV	Females	...	58	102	140	184	58	44	38	44	5
	Males	...	57	99	140	171	57	43	41	30	4
	Sexes combined	...	57	101	140	178	57	43	39	38	9

Hile and Jobes (1942) have recorded that the calculated growth histories of the age groups indicated some rather large discrepancies in the corresponding computed lengths of yellow perch of the same and different ages and explained that some of those disagreements were doubtless the result of the small numbers of specimens in certain age groups. Hile and Jobes (1941) have observed in their yellow perch sample of Saginaw Bay that the females grew more rapidly than did the males and the greatest growth in length of both sexes occurred in the first year of life. They have also noted that the annual growth increments decreased in the second year and increased in the third; and beyond the third year of life the annual length increments decreased continuously for the males and irregularly for the females.

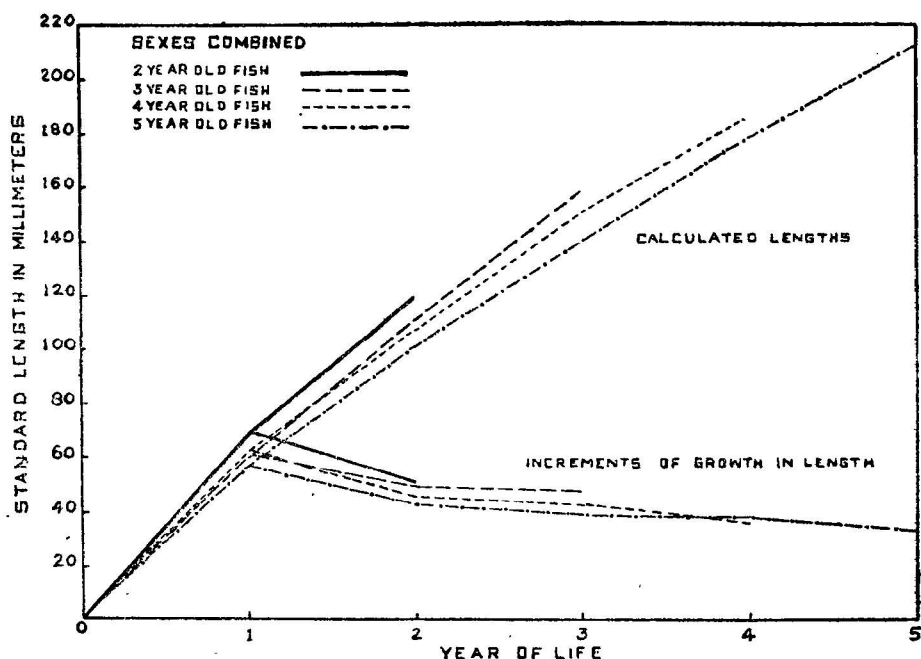


Fig. 2. *Calculated lengths and increments of growth at the end of each year of life of the Grand Traverse Bay yellow perch collected in 1947. Sexes combined.*

Lee's Phenomenon

The "phenomenon of apparent change in growth rates" has been questioned and much discussed by fisheries biologists ever since it was proposed by Lee (1912). Lee defines this phenomenon as "a tendency by which with increasing age the groups of fish all show a decreasing rate of growth in the calculated values for *each* year of their lives, that is that as we compare the present with former years the amount of growth at corresponding ages is increasing regularly. For convenience and shortness this tendency will be referred to in this paper as phenomenon of apparent change in growth rate." It was originally believed by many workers that this phenomenon was the result of the error made in assessing growth by scale method or of the selective effect in size during sampling. The results of the detailed investigations by the improved methods of calculating growth from scales had led Van Oosten (1929) and Hile (1936) to confirm that Lee's phenomenon was real and that it existed in their Lake herring populations.

Scott (1949) explains that the Lee's phenomenon "is produced by a selective mortality which eliminates the faster growing members of a year class early in life, thus allowing the slower growing fish to live to a greater age and to comprise the bulk of the older fish in a population." The two primary factors resulting in the selective mortality of the fast growing individuals of a year class

are: (1) the growth of the rapidly growing fish to such a catchable size as they are eliminated earlier than the slow growing fish; and (2) a physiological correlation between growth rate and longevity of fish. In reviewing the relationship between the rate of growth and the span of life within a given species, McCay (1933) presents the evidence obtained in his feeding experiments on the brook trout, namely, that in the experimental trout fed on the same diet the faster growing fish died earlier than the slower growing fish. It is seen that Lee's phenomenon is distinctly applicable to the Grand Traverse Bay yellow perch for all age groups (Table 3, Fig. 2). There is a clear tendency for the decreasing rate of growth in the calculated values of length for each year of life as the perch increases in age. Hile and Jobes (1942) have observed a distinct Lee's phenomenon occurring in the first three or four years of life of yellow perch in the Wisconsin waters of Green Bay and northern Lake Michigan; and in the later years of life these fish did not give any indication of the presence of this phenomenon.

Length-weight Relationship

The application of Herbert Spencer's 'Cube Law' equation to fish measurements has been carried out by many investigators. If form and specific gravity were constant throughout life, the relationship between weight and length is described by the 'Cube Law' in the equation,

$$W=KL^3,$$

where W =weight, L =length and K =constant.

The observations of Keys (1928), Hile (1936 and 1941) and others indicate that the 'Cube Law' is an incorrect formulation of the relationship between weight and length and that a true relation can be much more accurately described by the equation,

$$W=cL^n \quad \text{where } W=\text{weight, } L=\text{length,}$$

c =constant dependant on the units
employed and the general species
form and n =the rate of change of
weight with length.

In this study the sexes and all age groups of the eighty eight fish were combined in the determination of length-weight relationship. Each fish was treated as a separate unit in deriving the constants c and n in the formula.

The equation $W=cL^n$ when expressed in logarithmic form becomes a straight line. The logarithmic equation is,

$$\log W = \log c + n \log L$$

The values of $\log c$ and n were determined from the following normal equations :

$$\log c = \frac{\sum \log W \cdot \sum (\log L)^2 - \sum \log L [\sum \log L \cdot \log W]}{N \cdot \sum (\log L)^2 - (\sum \log L)^2}$$

$$\text{and } n = \frac{\sum \log W - N \cdot \log c}{\sum \log L}$$

Fig. 3 is the graph of the equation : $\log W = -4.85570 + 3.06774 \log L$

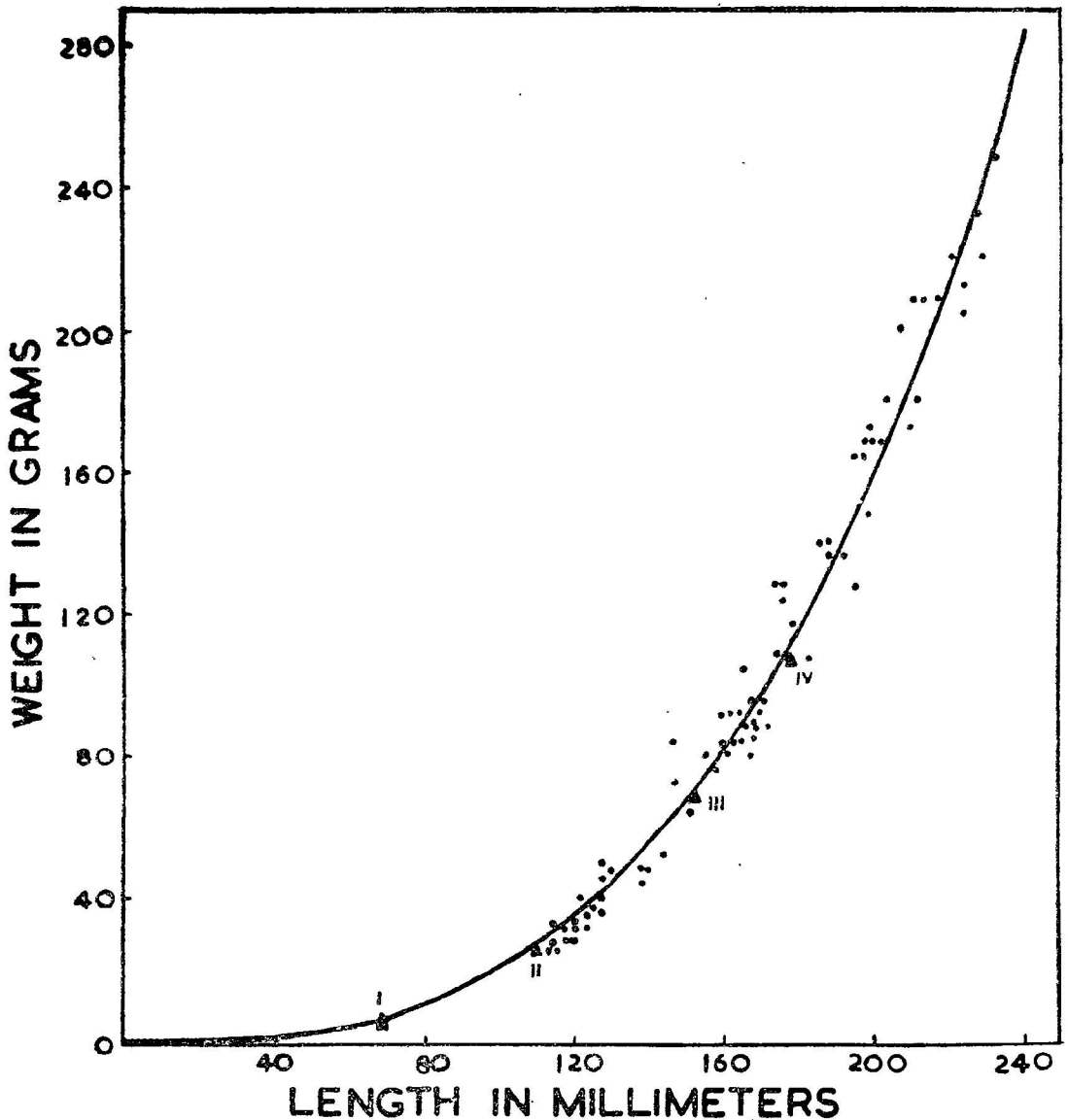


Fig. 3. Length-weight relationship of 88 Grand Traverse Bay yellow perch of 1947 collection ; the equation used is $\log W = -4.85570 + 3.06774 \log L$. The mark $\triangle$ indicates the weighted mean weight against weighted mean length of the respective age group.

It is seen that the averages of lengths and weights at last winter mark of the age groups fit closely the curve. It is interesting to note that the n value is greater than 3 indicating that the weight increasing more rapidly than the cube of the length, a condition identical with the observations of Hile and Jobes (1941 and 1942) in Green Bay and Saginaw Bay yellow perch respectively, and of Carlander (1950) in the Lake of the Woods yellow perch. Hile and Jobes (1942) have shown a different length-weight relationship for the northern Lake Michigan yellow perch as $W=5.8405 \times 10^{-5} L^{2.811}$, the weight increasing less than the cube of the length.

Growth in weight

Table 4 presents averages of the calculated weights of the yellow perch under study. Curve based on these data is shown in Fig. 4. The averages for the sexes combined groups are the weighted means. It is seen that the growth in weight follows the same trend as the growth in length for each sex, as well as when the sexes are combined. The annual increment in weight is found to increase from year to year in the age groups II to IV of both sexes. On the contrary, Hile and Jobes (1941 and 1942) have observed wide variation in the annual increment in weight in their yellow perch samples.

TABLE 4

Calculated average weights and increments of growth for each year of life of Grand Traverse Bay yellow perch, 1947 collection

Age Group	Average weight gms.				Average increment gms.				No. of fish
	1	2	3	4	1	2	3	4	
I Females ..	7				7				6
Males ..	6				6				11
Sexes combined ..	6				6				17
II Females ..	4	31			4	26			9
Males ..	4	25			4	20			20
Sexes combined ..	4	27			4	22			29
III Females ..	5	31	85		5	26	54		15
Males ..	4	19	56		4	15	37		18
Sexes combined ..	5	25	70		5	20	45		33
IV Females ..	4	20	57	126	4	17	36	69	5
Males ..	4	20	47	95	4	16	28	48	4
Sexes combined ..	4	20	52	112	4	16	32	60	9

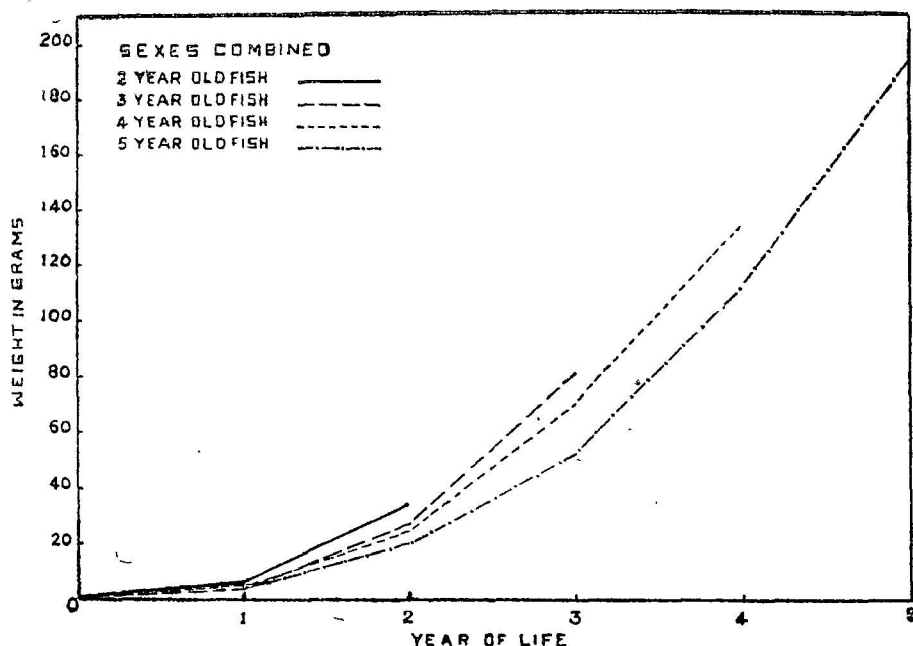


Fig. 4. Calculated growth in weight for each year of life of Grand Traverse Bay yellow perch of 1947 collection, determined from the calculated lengths. Sexes combined.

Summary

1. This paper presents the age and growth history of Grand Traverse Bay yellow perch, *Perca flavescens* Mitchell, based on 88 specimens caught by experimental gill nets with meshes ranging from 2½ to 4 inches.
2. The age group III represents the dominant group, and the 160–169 millimeter size class being dominant among the other classes.
3. The greater abundance of males in the first three age groups could not be attributed to any distinctive factor.
4. The body-scale length relationship is shown to be very close to a linear regression. The interception of the straight line on the length axis at 29 mm is taken as the length before scale formation of the fish.
5. The females had grown longer than the males in all the years of age groups, excepting the group I.
6. Lee's phenomenon is distinctly evident in this sample.

7. The length-weight relationship is described by the formula;
 $\log W = -4.85570 + 3.06774 \log L$.

8. Generally the growth in weight follows a trend similar to the growth in length for each sex, as well as when the sexes are combined.

Acknowledgment

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STUDIES ON THE GROWTH CHARACTERS OF SHOOT AND ROOT OF THREE VARIETIES OF GUAVA (*Psidium guajava* L.)

by

V. R. BALASUBRAMANYAM

Department of Agriculture, Annamalai University.

INTRODUCTION

Guava is one of the most common and relatively cheap fruits in India. Guava yields heavily, responding well for the application of manure, irrigation etc. In order to reap the maximum one should understand the optimum conditions for each of the treatments to be given to the plants. The knowledge of shoot growth is much useful to predict the cropping behaviour of fruit trees. It is a measure of the vigour of trees. A knowledge of root activity in relation to different seasonal conditions is essential to adjust the cultural practices like manuring, weeding etc. in accordance with the growth habit.

Although detailed studies on the growth habits of various fruit trees have been made, little work seems to have been attempted so far on the growth habits of guava either in India or in other countries. In the present studies the root and shoot growths of guava were examined.

Material and Methods

The studies were carried out at the Annamalai University Experimental Orchard, Annamalainagar. The following important commercial varieties, belonging to the species *Psidium guajava* L. were selected for the studies.

1. Allahabad Round
2. Chittidar
3. Lucknow

The plants selected for the study were three year old and arose originally from air-layers. Three trees of approximately equal in size, in each variety, were selected for studying the shoot and root growth. Three main branches and one secondary shoot on each branch were selected at random and tagged. The extension growth of the current season shoots was recorded in centimeters at weekly intervals. From the recorded values the mean shoot length and the growth rate were obtained for each variety.

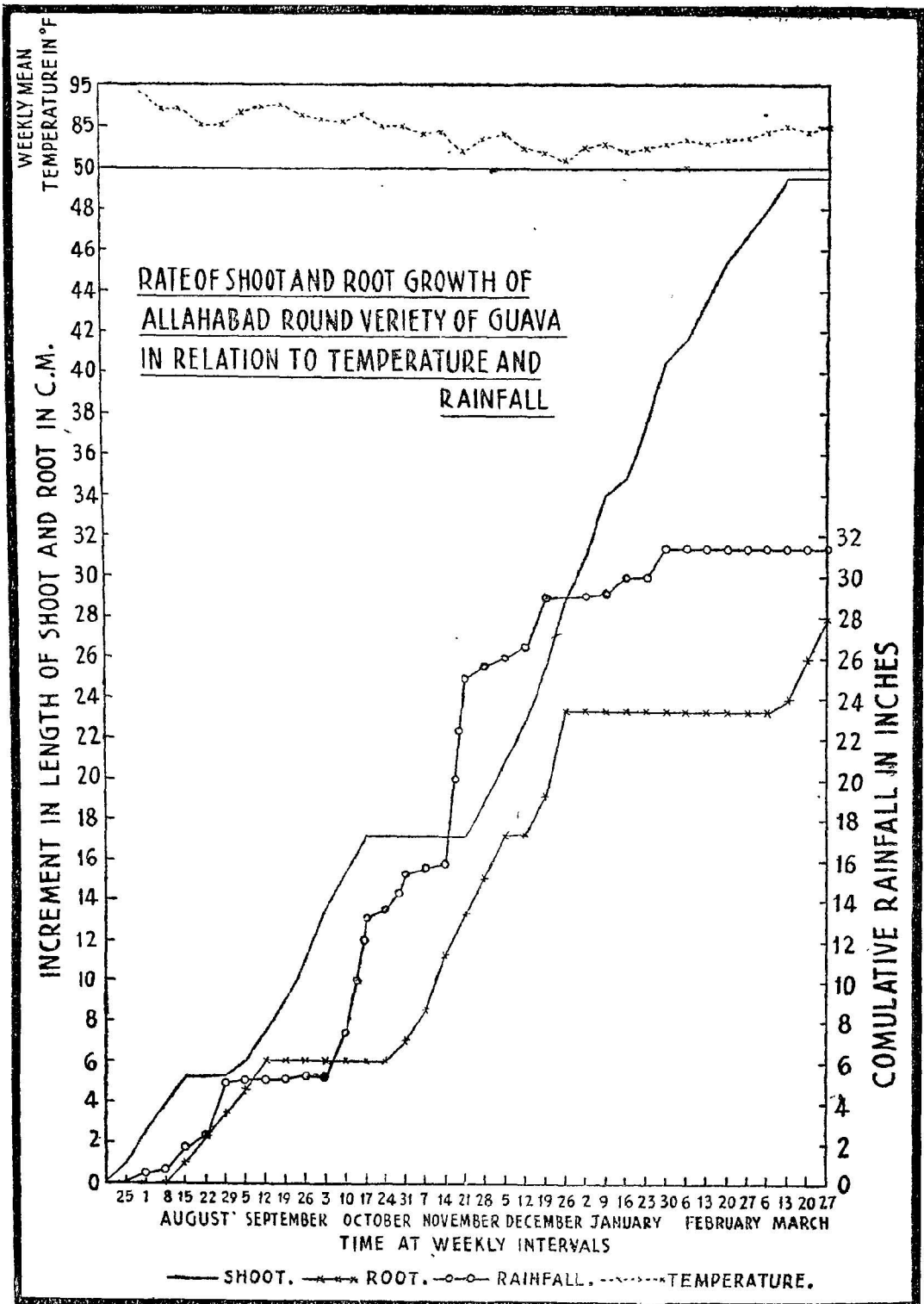


FIG. 1

The same three trees in each variety, selected for shoot growth studies, were taken up for studying the root growth also. The roots were traced by digging a pit at a distance beyond the tree spread. The roots were exposed by excavating the soil inch by inch from the pit towards the trunk of the tree and by washing down the soil particles gradually with water sprays. Three roots in three different directions from the trunk were selected at random at a depth of 15 to 20 cm. below the ground level. They were then tagged with galvanised wire loops with serial numbers affixed for identity. The wire tags were loosely tied to the trunk of the tree. The selected roots were placed in rectangular galvanised iron trays opened at one end. The sides and bottom of the trays were

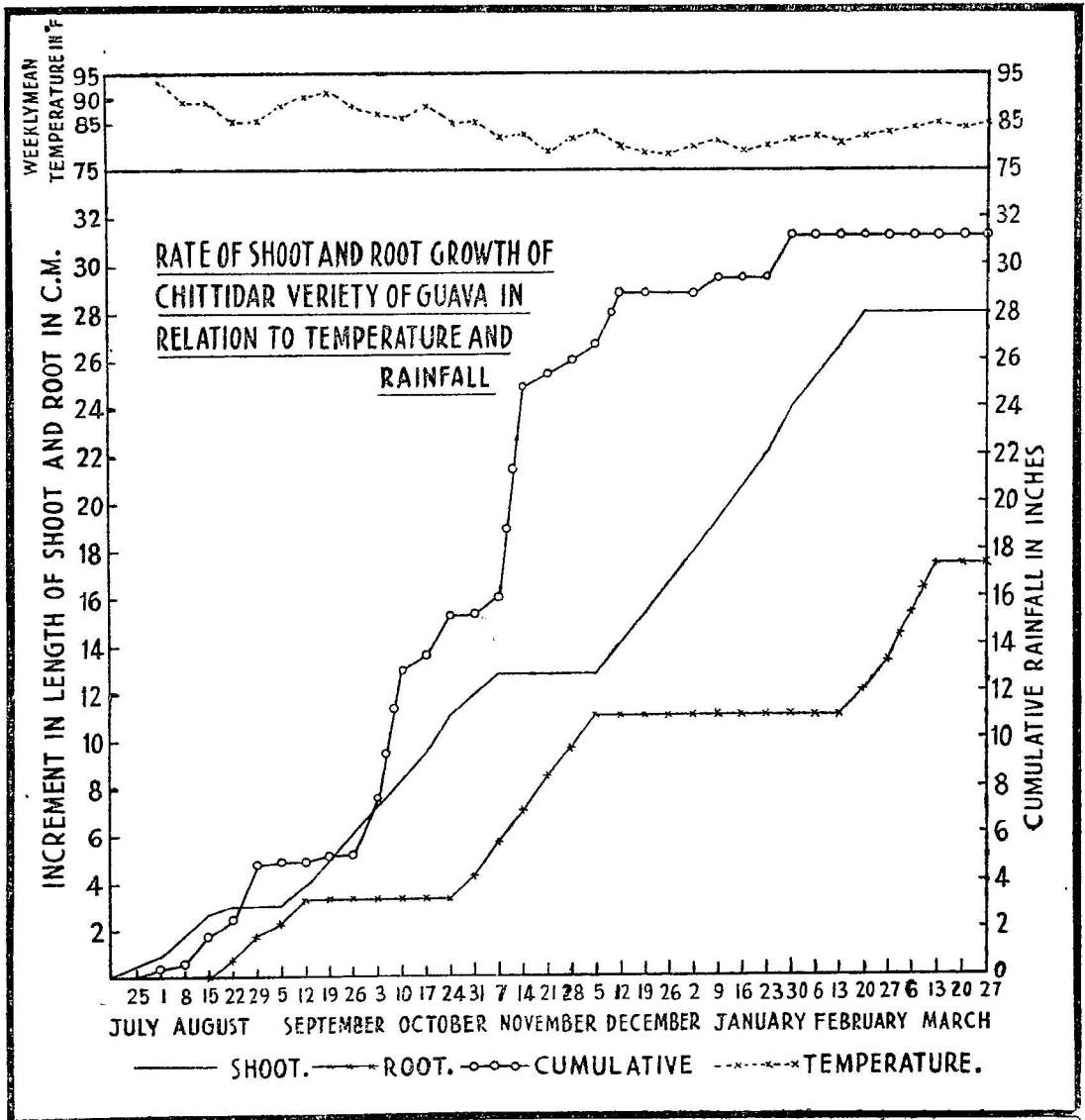


FIG. 2

perforated to facilitate easy drainage. The linear growth of root was recorded at weekly intervals by excavating the soil bit by bit washing with water sprays and measuring with scale. Then the roots were replaced in the tray and covered with sand-leafmould mixture. From the reading obtained, the mean values of the root growth and the growth rate for each variety were calculated.

Meteorological observations on the daily maximum and minimum temperatures and rainfall were recorded. The weekly averages of the maximum and minimum temperature and the rainfall are given in Figs. 1, 2 and 3.

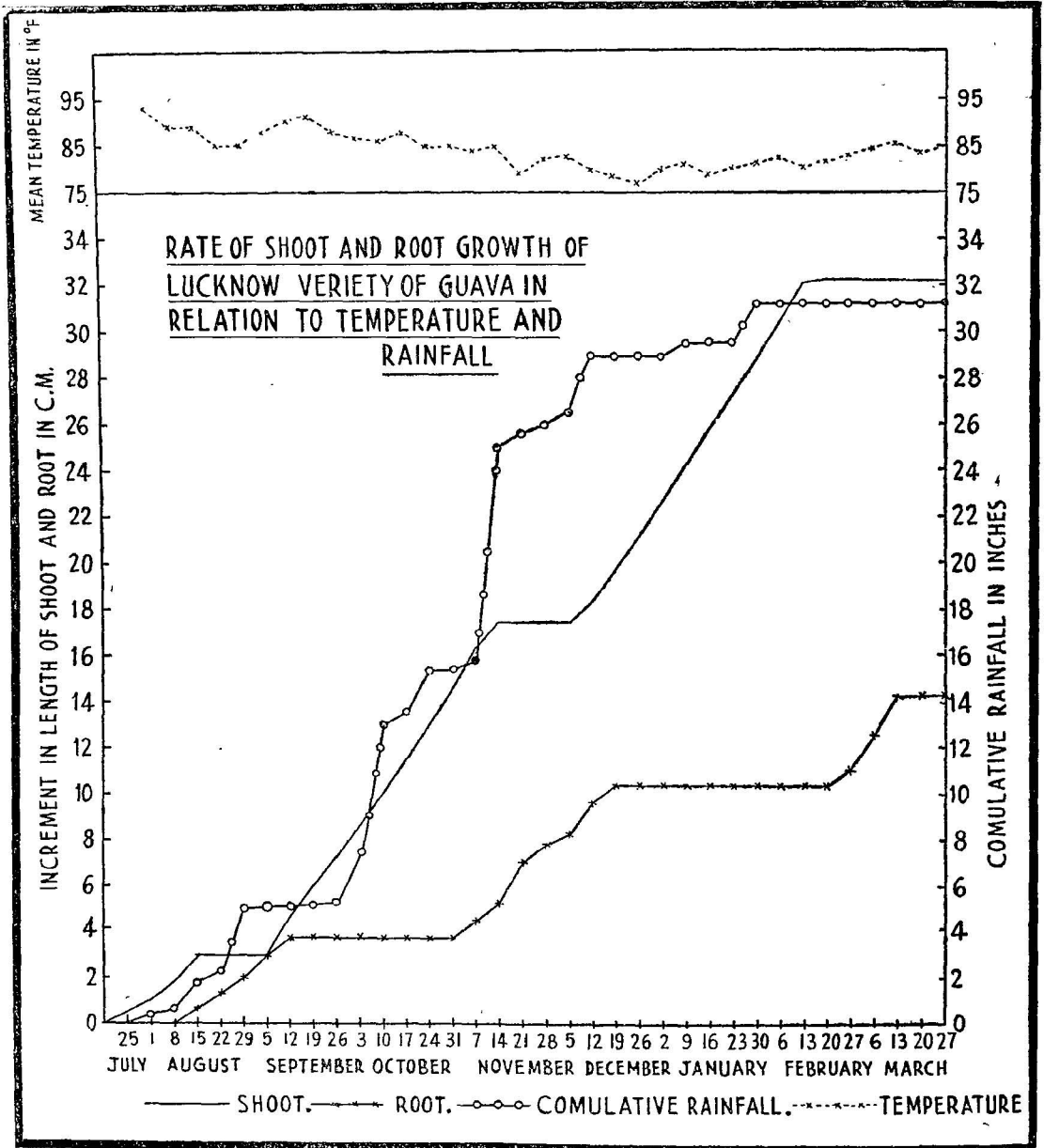


FIG. 3

Experimental Results

The first measurement of shoots and roots of the three guava varieties commenced on 25th July, 1958 and the last one was made on 27th March, 1959. The growth rates of shoot and root in relation to temperature and rainfall are given in Figs 1, 2 and 3. The most conspicuous feature revealed in the present work is that in all the three varieties there were continuous periods of growth alternated with periods of no growth. Individual variations in the duration of periods of growth and no growth among the varieties, however, have been observed.

Discussion

In the present studies in all the three guava varieties three cycles of shoot growth were recorded within a period of eight months; the first cycle was in July–August, the second in September–November and the third and the longest one during December–February. But, with regard to the time of occurrence of the cycles of growth, the duration of each cycle, and comparative increments of growth in these cycles, there are indications for wide differences among the varieties. The quiescent period between the first two growth periods in the varieties ranged from 15 to 21 days and between the second and third growth periods varied from 21 to 35 days. The results obtained in the present investigations seem to confirm the observations made by Hayes (1953) and Cheema *et al* (1954), except for slight changes in the dates and durations of the seasons. They have reported three flushes viz., June–July, September–October, and January–February. The three cycles recorded in the present study were more or less during the same seasons as recorded by them except that the duration of each cycle extended by a fortnight to a month. The second growth cycle in October recorded in this tract is in quite consonance with Hayes' (1953) statement that it is common only in Bombay and Madras.

Among the three varieties, 'Allahabad Round' ranked first in shoot growth with a mean length of 49.6 cm, 'Lucknow' was the next with a mean shoot extension of 32.3 cm. and 'Chittidar' the last with 28.1 cm. Since the shoot growth is a measure of vigour of plants (Hodgson, 1948) it can be said that "Allahabad Round" is the most vigorous of the three varieties under the conditions of the present studies.

As in the case of shoots, roots of the three varieties of guava under study, have shown periods of active growth alternating with periods of no growth.

Under the conditions of this experiment three cycles of root growth were noticed in varieties 'Chittidar' and 'Lucknow' whereas in 'Allahabad Round' four

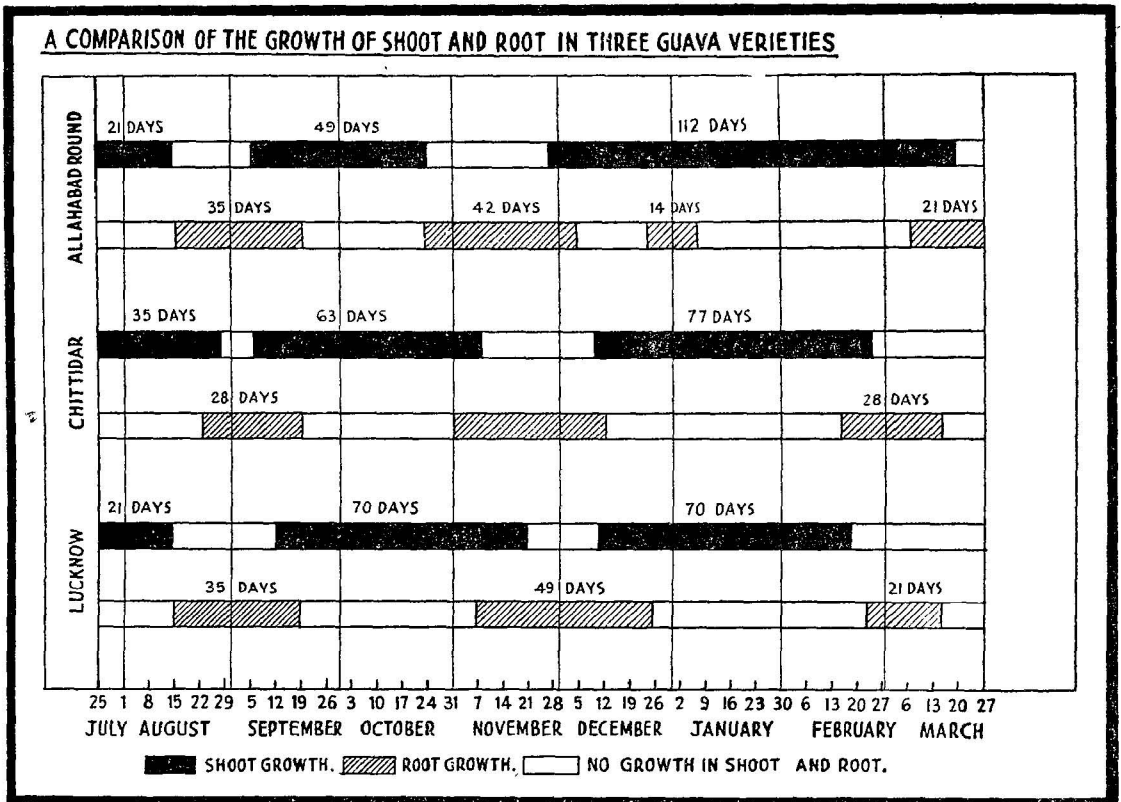


FIG. 4

growth periods were observed (Fig. 4). The first growth period occurred during August-September and the second during October-December in all the three varieties. The third and fourth growth periods in 'Allahabad Round' occurred in December-January and February-March. The third growth period in 'Chittidar' and 'Lucknow' was during February - March. The duration of the cycle was more in 'Allahabad Round', 'Lucknow' being the next and 'Chittidar' was last. Furthermore, in all the three varieties the third cycle, irrespective of the time of occurrence, recorded a greater amount of growth rate per day than the other cycles. Among the varieties studied 'Allahabad Round' recorded the greatest amount of mean root length, 'Chittidar' being second and 'Lucknow' the last.

There seems to be certain correlation between cumulative rainfall and the growths of shoot and root in all the three varieties but there is no direct

correlation between the growths and mean temperatures in any of the varieties. However, studies extending over a number of years are required to arrive at any definite conclusions.

Summary

Observations on the extension growth of shoot and root of the three guava varieties viz., 'Allahabad Round', 'Chittidar' and 'Lucknow' at the Annamalai University Experimental Orchard, Annamalainagar, were made during the period from July, 1958 to March, 1959.

There were distinct periods of growth of the roots and shoots of the three varieties. There was no distinct cyclic growth of shoot and root but there was overlapping in the growth of shoot and root in all the three varieties almost during every season.

There were indications to show that the sum-total of shoot and root growths in all the three varieties increased with the accumulated rainfall.

Acknowledgements

The author wishes to express his sincere thanks and deep sense of gratitude to Dr. G. Rangaswami, B. Sc. Ag., Assoc. I. A. R. I., Ph. D. (Rutgers), F. A. Sc., Professor and Head of the Department of Agriculture, Annamalai University, Annamalainagar for his guidance and helpful criticism during the course of these investigations.

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INFLUENCE OF CLIMATIC FACTORS ON THE INCIDENCE OF ALTERNARIA LEAFSPOT OF BRINJAL

G. RANGASWAMI AND C. N. SAMBANDAM

Department of Agriculture, Annamalai University.

IT is well known that favourable temperature and humidity are essential for the onset and spread of plant diseases incited by microorganisms. As early as in 1892 Behrens observed that excessive humidity of the soil and air weakened the tobacco seedlings markedly so that they succumbed to damping off caused by *Alternaria tenuis* Nees. Butler (1918) from India reported that *A. solani* (Ell. & Mart.) Jones & Grout does not depend on atmospheric humidity so much as the blight (*Phytophthora infestans*) and that it spreads rapidly under relatively dry conditions and was checked only by severe drought. Sherbakoff (1918) reported that early blight of tomato was more severe in the low lands of Florida, U. S. A., where the plants make a dense growth and where heavy dews occur and cause high atmospheric humidity. Tisdale and Wadkins (1931) reported that the minimum temperature for infection of *A. longipes* (Ell. & Ev.) Mason on tobacco was about 20 to 22°C and that moderate infection occurred at 23 to 25°C, while severe infection took place at and above 26.5°C. Leyendecker (1954) stated that internal mould of chilli fruits caused by *Alternaria* spp. developed mainly after the first-killing frost, since after such a frost, the pod wall at the calyx-end pulled away from the seed mass, thereby creating a space for air-borne spores to enter the pod cavity, wherein they germinated and established. Rangaswami *et al* (1957) reported that humidity percentage played a decisive role in the onset and spread of leafspot of cotton caused by *A. macrospora* Zimm.; the temperature range throughout the season was quite conducive for the growth of the pathogen but there was no disease in the first few weeks of the crop growth on account of the low atmospheric humidity, but the disease set in and spread steadily with the setting-in of the monsoonic rains, which resulted in the maintenance of high humidity levels. Bakthavathsalu and Balasubramanian (1958) correlated the weather conditions and early blight incidence of potato at Nanjanad, the Nilgiris, during the main season (May to August) for the period 1927-'55 and found that

the daily mean temperature during blight years was mostly above 60°C and weekly average rainfall was 1.69 inches and these factors were very favourable for the disease. Louvet (1958) from France reported the epidemic of *A. brassicae* (Berk.) Sacc. on turnip pods was preceded by prolonged sunshine and high wind, which helped in sporulation and dispersal of the spores, respectively; a relative humidity over 80% and temperature between 15 and 22°C were found to promote germination of the spores. Wheeler (1958) reported that spore production of *A. longipes* on tobacco was favoured by high humidity, while dispersal was helped by dry sunny conditions.

Thus it would appear that for the *Alternaria* diseases of crop plants certain climatic factors are conducive for multiplication and spread. With a view to examine the influence of climatic factors on the onset and spread of leafspot disease of brinjal caused by *Alternaria melongenae* Rang. & Sam., one of the severe diseases of the crop in this tract, studies were undertaken in the Annamalai University Experimental Farm, Annamalainagar, during 1958-59 and the results are reported here.

Materials and Methods

Long white variety of brinjal (*Solanum melongena* L.), which was found to be one of the most susceptible varieties under field conditions, was selected for the purpose. Seedlings were raised in the nursery beds in the usual manner and transplanted in the main field after a month. The spacing between plants was 2½ feet in both directions. Irrigation and interculture operations were done in the usual manner. The plants were examined carefully for disease symptoms and bi-weekly counts on the number of infected plants, the number of leaves infected and the total number of leafspots on each plant were taken. The average number of spots per plant was calculated and the results correlated with meteorological data.

Results

In all 28 plants, selected at random in a 10 cent plot, were examined at fortnightly intervals. The crop was in the field from July 26 to December 12, 1958. The data on the relative humidity percentage, maximum and minimum temperatures and the rainfall received were obtained from the Meteorological

Observatory of the Farm and the weekly averages worked out. The results are presented in Fig. 1.

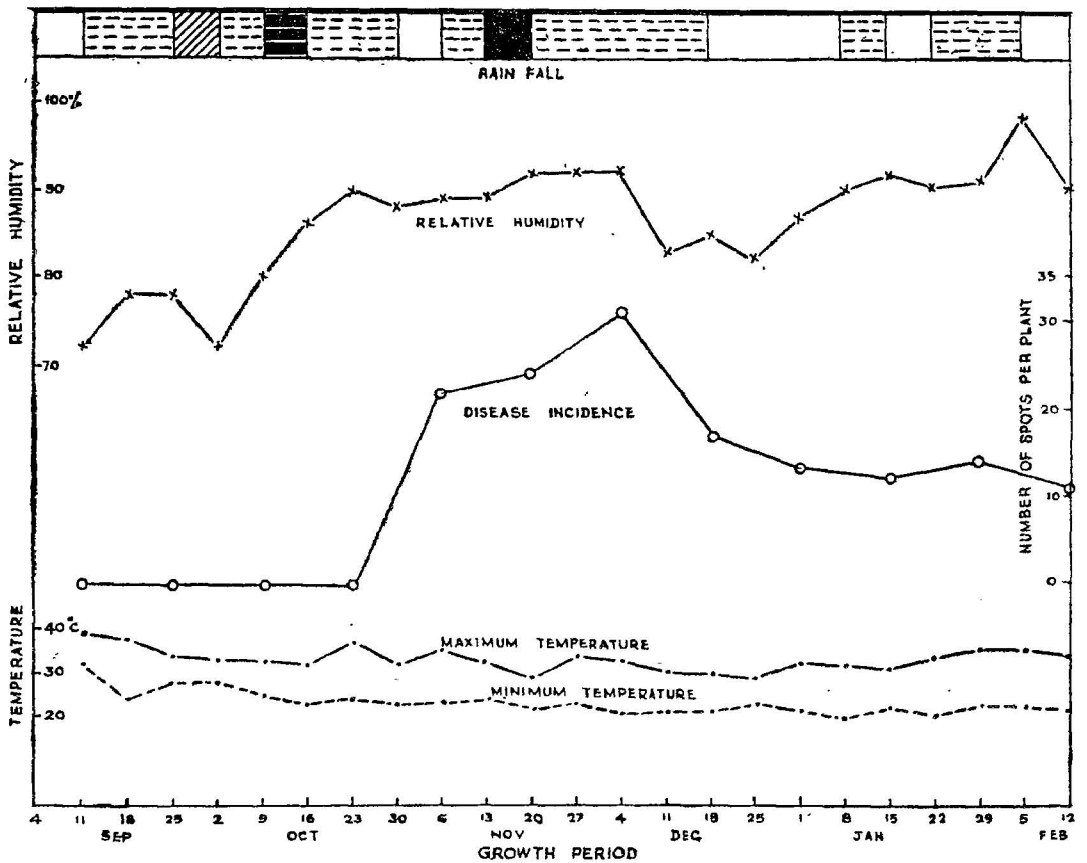


FIG. 1

The influence of climatic factors on the onset and spread of *Alternaria melongenae* Rang. & Samb. causing leaf spots on Long White variety of brinjal under field conditions in the Annamalai University Experimental Farm during 1958—'59.

There was no tangential change in the minimum and maximum temperatures that prevailed during the crop season. But there were marked changes in the humidity levels, starting from the beginning of October. There has been well distributed rainfall for the first four months. With the onset of early showers in September and subsequent heavy rains in the second and third weeks of October there was a rapid increase in the humidity percentage and subsequently there has also been an increase in the disease incidence. With the reduction in humidity percentage by the end of November there was a sudden decline in the

disease incidence. The decline rate was gradual, starting from the fourth month of the crop until it was pulled out in February, i.e., after about 7 months.

Discussion

In the present studies it is indicated, that since there has been no drastic change in the maximum and minimum temperatures during the crop season, the relative humidity percentage, as caused by the frequent showers and rains during the season, plays a decisive role on the onset and spread of the disease. In the early stages of crop growth, upto two months after transplanting, there were no disease symptoms, which might be due to the low humidity conditions that prevailed during the period. With the onset of Monsoon and the receipt of frequent showers in October the humidity rapidly increased and there was subsequent increase in the disease intensity. There was, however, a belated appearance of disease symptoms with a difference of nearly two weeks between the increase in humidity level and the increase in disease intensity. This difference may be due to the time interval (incubation period) required by the organism to enter the host tissues, establish there, and cause the disease symptoms. After the fifth month of crop growth there was steady decline in the disease intensity. To some extent this may be attributed to reductions in the humidity level, but it might also be due to the dropping off of the affected and old leaves with the age of the crop and there being not too many fresh leaves on the plants for any new infections by the fungus. After five months, the crop is usually on a decline and is maintained mainly for the fruits on the plants to mature.

The results indicate the close relationship between humidity and disease incidence rather than the temperatures and disease, as existed in the season under the conditions of experiment. Similar results were reported in the case of *Alternaria* leafspots of cotton (Rangaswami *et al* 1957) and in the case of early blight of potato caused by *A. solani* in the Nilgiris (Bakthavathsalu and Balasubramanian 1958). Further detailed studies, extending over several years to correlate the micro-climate with the disease onset and spread would help in formulating a scheme for the forecast of the disease and in taking timely preventive measures to control the same.

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A STUDY OF THE CHROMOSOMES OF *CHRYSOCORIS PURPUREUS* WESTW. DURING SPERMATOGENESIS

By VR. MUTHUKKARUPPAN AND JOSEPH L. NEDUNGADAN,
Department of Zoology, Annamalai University.

Introduction

Insects belonging to most of the families of Orthoptera and Heteroptera have been the subject of intensive cytological investigation than any other comparable group. Schrader (1941) Manna (1951) and Banerjee (1958) have remarked that the chromosomal behaviour in the families of Heteroptera is strikingly uniform. In India, an extensive study of the chromosomes in 43 species of Heteroptera has been made by Manna (1951) who, later in 1956, also pointed out the interrelationship among different families of Heteroptera from a cytological point of view. Banerjee (1958) studied the chromosomes of 22 more species of Heteroptera and suggested some modifications to the cytotaxonomy of this sub-order, proposed earlier by Manna (1956). Parshad (1957a) has studied the chromosome number and sex mechanisms in Indian heteropteran families and the same author (1957b) investigated the chromosome complement and meiosis in a few families of heteroptera with a consideration of the cytological bearing on the status of the superfamilies. Rao (1954) made studies on the chromosomal behaviour during meiosis in three species of Heteroptera. Das (1956) investigated the chromosomal cytology of *Gerris nepalensis* Distart.

The chromosomes of only 3 species namely *Chrysocoris stollii*, *Scutellera perplexa* and *Cantao ocellatus* belonging to the tribe Scutellerini of the family Scutelleridae have so far been studied (Das Gupta, 1950 ; Manna, 1951 and Banerjee, 1958). The present paper which deals with the chromosomes of *Chrysocoris purpureus* Westw. (Tribe : Scutellerini, Family : Scutelleridae) during spermatogenesis supplements the works of the above investigators.

Material and Methods

The nymphs and adult males of *Chrysocoris purpureus* were collected at Annamalainagar. The specimens occur in abundance during April to September and in other months they are sparsely distributed.

The testes which are bright red in colour were dissected out from live specimens and fixed immediately in Sanfelice or carnoy's fluid. The material

embedded in paraffin was sectioned at 10 and 12 microns in thickness. Heidenhain's iron haematoxylin and Schiff's reagent after Feulgen hydrolysis were used for staining. Acetocarmine squashes of the testes were also made and proved to be of great help for the study of various stages.

Observations

The Spermatogonial metaphase plate shows 12 chromosomes all of which stain with same intensity. All the chromosomes, though rod shaped during spermatogonial prometaphase (Fig. 1) appear as highly condensed and deep-staining bodies at metaphase (Fig. 2). It is not possible to make out the sex chromosomes from the autosomes at this stage.

The behaviour of the chromosomes during earlier meiotic prophase stages in this form is identical with the corresponding stages of many species of Pentatomidae and Scutelleridae previously described by Heizer (1950, 1951), Schrader (1941), Manna (1951) and Banerjee (1958). From the leptotene onwards the sex chromosomes show positive heteropycnosis, and seem to be clearly approximated appearing as a single bilobed mass. However, the tendency of these chromosomes to get separated during pachytene stage is completed at early diakinesis (Fig. 3).

During late diakinesis the sex chromosomes (X and Y) and the five autosomal bivalents show their individuality clearly. At I metaphase the five well condensed autosomal bivalents are usually arranged in the form of a ring, and the X and Y chromosomes which are comparatively smaller than the autosomes take a central position (Fig. 5). The bivalent nature of autosomes and the univalent nature of sex chromosomes are well seen from the side view of the late metaphase (Fig. 4). It is further seen there is a slight inequality in size between the sex chromosomes, the Y being smaller than X.

At I anaphase the sex chromosomes divide equationally (Fig. 4) while the autosomes segregate to opposite poles.

In the side view of second metaphase (Fig. 7) the sex chromosomes are found to be in an 'end-to-end' pairing condition thus forming a pseudobivalent (*i.e.*, 'touch-and-go-pairing' as given by Schrader, 1941). In a polar view the autosomes are arranged in the form of a ring while the pseudobivalent (sex chromosomes) is usually placed at the centre of the spindle (Fig. 6). During II

anaphase the five autosomes divide equationally and the sex chromosomes segregate to opposite poles. Thus two kinds of spermatids result, one with 5 autosomes plus X and the other with 5 plus Y.

General Remarks

The chromosome number, behaviour and sex determining mechanism of *Chrysocoris purpureus* studied presently do not show any variation from the observations reported previously on three other species of the same tribe of the family Scutelleridae. The similarities in the behaviour of chromosomes in the families Scutelleridae and Pentatomidae excepting their number, led Manna (1956) and Banerjee (1958) to opine that these two families are closely related to each other. The present finding on the chromosomes of the scutellerid, *Chrysocoris purpureus* further supports the view of the above authors.

Summary

The chromosomes of *Chrysocoris purpureus* Westw. of the tribe Scutellerini and family Scutelleridae has been studied.

The chromosome number and the sex determining mechanism in this species are as follows :

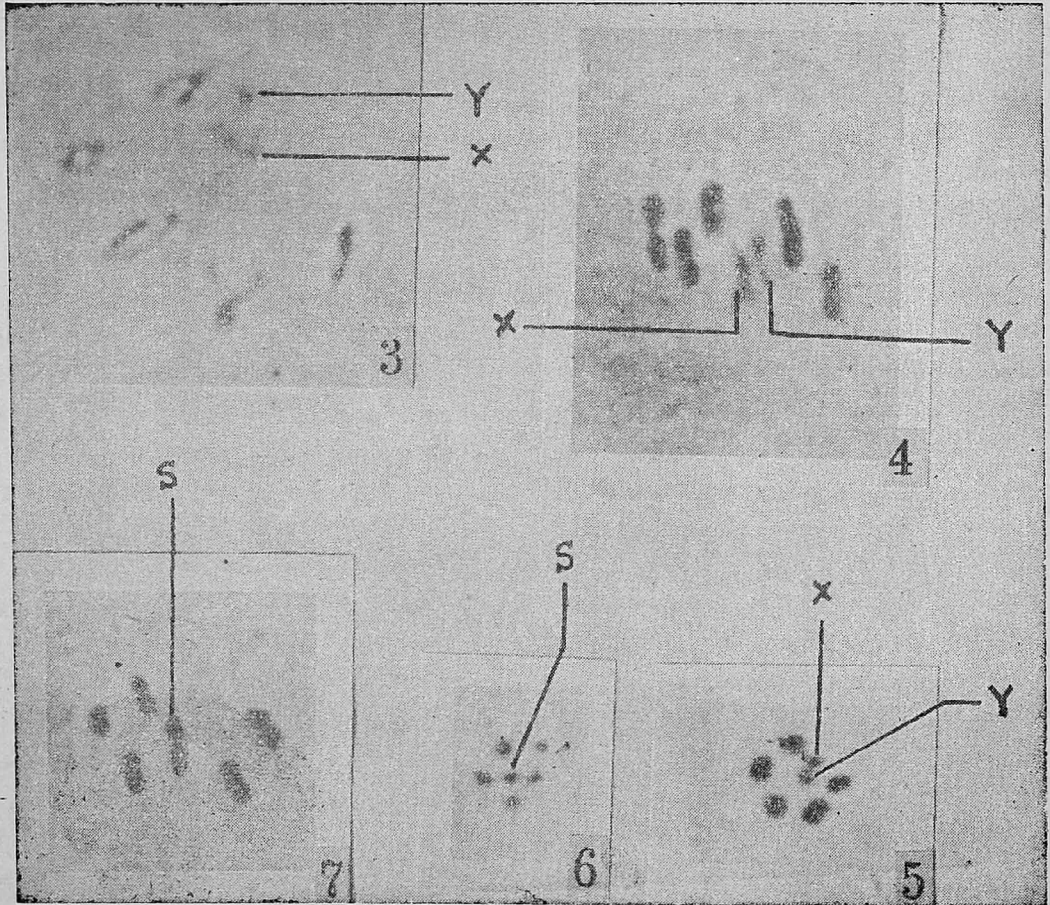
The chromosomal numbers during :

- i. Spermatogonial metaphase : $10A + X + Y = 12$
- ii. Metaphase I : $5A + X + Y = 7$
- Metaphase II : $5A + X Y \text{ (pseudobivalent)} = 6.$

The sex chromosomes (XY) show positive heteropycnosis during earlier stages of meiosis. They divide equationally in the first and reductionally in the second spermatocyte division. During the second division the X and Y always show a special type of pairing (touch-and-go).

Acknowledgement

We are indebted to Dr. P. Govindan, Professor and Head of the Department of Zoology, Annamalai University for his encouragement and helpful criticism. Our thanks are also due to Mr. R. Natarajan for his assistance in the preparation of this paper.



Explanation to Figures

Fig. 1. Polar view of spermatogonial prometaphase - Acetocarmine squash - camera lucida drawing: X ca. 1500.

Fig. 2. Polar view of spermatogonial metaphase - Acetocarmine squash - camera lucida drawing: X ca. 1500.

- Fig. 3. Early diakinesis showing the separated X and Y chromosomes – acetocarmine squash. Photomicrograph X ca. 2000.
- Fig. 4. Side view of late Metaphase – Sex chromosome seen dividing equationally – acetocarmine squash. Photomicrograph X ca. 1500.
- Fig. 5. Polar view of I metaphase – section – Sanfelice – Heidenhain's iron haematoxylin. Photomicrograph X ca. 1500.
- Fig. 6. II metaphase polar view – section – Sanfelice – Feulgen – (S.– pseudobivalent). Photomicrograph X ca. 1500.
- Fig. 7. II metaphase – side view – acetocarmine squash – (S.– pseudobivalent). Photomicrograph X ca. 1500.

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FURTHER STUDIES ON BACTERIAL GUMMOSIS AND RED-STRIPE DISEASES OF SUGARCANE

G. RANGASWAMI.

Head of the Department of Agriculture, Annamalai University.

AMONG the many pathogens affecting sugarcane, bacteria are not of less importance as they are known to cause severe damage to the crop in several countries (Cook 1928, Lee and Pierce 1928, Ashby 1929, Edgerton 1955). McRae (1933) was the first to report on the occurrence of red-stripe disease of sugarcane caused by *Xanthomonas rubrilineans* (Lee *et al*) Dowson in some parts of northern India. Desai (1935) described a severe incidence of 'Stinking rot' of sugarcane caused by *Bacillus pyocyaneus-saccharum* Desai (Syn.: *Pseudomonas desaiana* (Burkholder) Savul.). Padwick (1940) reported on the incidence of red-stripe disease in the United Provinces during 1938-'39. According to Chona (1956) redstripe disease appeared in an epidemic form on Co. 312 in Kalai near Aligarh and Risalewala, Lyallpur, during 1938-'39 and also in some areas of Phalton Sugar Factory Estate in Bombay-Deccan during 1956. Albuquerque and Arakeri (1956) reported on the incidence of red-stripe disease on Co. 419 for the first time in Padegoan, Bombay State. They isolated the causal bacterium and by inoculating on 25 sugarcane varieties found 11 of them to be susceptible. Besides these no detailed investigations on the occurrence and on the characters of bacterial pathogens seem to have been carried out so far in India. Chona (1958) has rightly pointed out that little work has been done in India on red-stripe disease and the taxonomy of the casual organism requires careful reinvestigation.

During a recent tour of the sugarcane areas of Cuddalore, Nellikuppam and Chidambaram of South Arcot District, Madras State, the author encountered some serious incidence of bacterial diseases of the crop. The chief characters of these diseases and the identity of the casual organisms were briefly reported by the author (Rangaswami 1960).

OCCURRENCE AND SYMPTOMS: The following are the main types of disease symptoms observed in the field :

(i) *Gummosis*: In the Nellikuppam Sugar Factory area the varieties Co. 449 and Co. 527 were found affected by this disease, nearly 25 per cent of the clumps in each plot being affected. The affected plants are stunted and the leaves paler than the normal ones. The canes are usually thinner but the length

of the internode is not much reduced nor do the leaves carry any disease symptoms except for the paler colour. When the affected canes are split open water soaked appearance is prominently seen and very soon pearly yellow gummy liquid oozes out from the cut surface. Sometimes the canes develop cavities in the centre wherein the sticky liquid collects. Reddening of the vascular bundles was not observed in any of these affected plants.

(ii) *Multiple Shoot* : In the Nellikuppam Sugar Factory area the variety Co. 961 was found affected by the disease. Nearly 10 per cent of the plants in a plot were found affected. The diseased plant carries unusually numerous shoots arising from the top and from the lower nodes of the cane and the whole plant presents a bushy appearance and could be easily detected from a distance. The leaves are apparently healthy without any spots, stripes or chlorosis, except for the reduction in the size. When the affected shoots are split open the vascular bundles at the basal portions are usually discoloured deep red. In some cases the discolouration extends to the stem also. The internodes of the stem are very much reduced in length, especially towards the top of the cane.

(iii) *Vascular Reddening* : In Cuddalore and Nellikuppam areas the variety Co. 449 was found to be affected by this disease, nearly 25 per cent of the plants being affected at times. The plants appear chlorotic and on closer examination white bands are found on the leaves. Sometimes minute reddish spots, 0.5 to 1 mm in breadth and 1 to 2 mm in length, appear on these bands. The stem is usually thinner but no external symptoms of any disease incidence are observed. When the canes are split open characteristic reddening of the fibro-vascular bundles is observed. In severe cases almost every bundle is discoloured but in no case gummosis or any exudation could be seen. In the severely affected canes there was pith formation and drying up of the inner tissues.

(iv) *Red Stripe* : This disease was observed on the varieties Co. 449 and Co. 527 in Cuddalore and Nellikuppam areas and on Fiji B in Chidambaram and Annamalainagar. Nearly 50 per cent of the plants were affected in a field, but the intensity of infection on the leaves was relatively low, as only a few stripes were found in two or three leaves on a plant. The disease first appears as water soaked linear streaks which soon become chlorotic carrying the dark-red stripes. The stripes are 0.5 to 1 mm in breadth and 5 to 100 mm or even more in length. At times two or more stripes coalesce to form larger bands. Usually the lower half of the leaves are more affected than the tips. On the variety Fiji B younger

leaves were more commonly affected as against Co. 449 and Co. 527 wherein the older leaves were mostly affected. The canes from diseased plants, when cut open, did not exhibit any disease symptoms.

MATERIAL AND METHODS: The diseased plants were examined microscopically by taking transverse sections of the affected tissues and the presence of the bacteria observed in all the affected portions; in the cases of vascular reddening and redstripe the bacteria were mainly confined to the vascular bundles whereas in gummosis and multiple shoot most of the tissues were found affected. The bacterium from each of the diseased tissues was then brought into culture by the usual tissue culture method. The cultures were subsequently purified by single colony isolations. The types of the diseases and the bacterial isolations made are given in Table I.

Along with the above four isolates a culture of *X. rubrilineans* obtained from the Head of the Division of Mycology and Plant Pathology, Indian Agricultural Research Institute, New Delhi, was also included as isolate No. 5 and studied for the purpose of comparison.

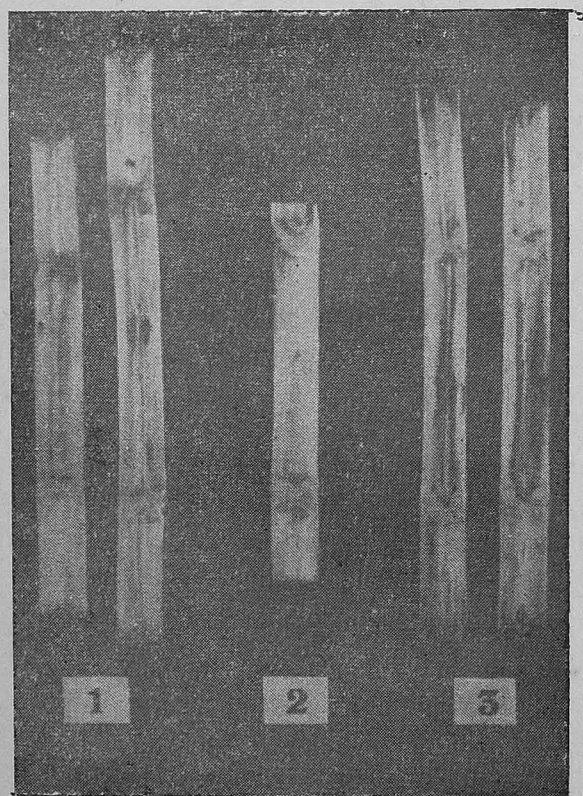
The pathogenicity of the cultures was tested on the stem as well as on the leaves. Sugarcane sets from healthy canes, about 10 months old, were collected from the field. They were cut into uniform setts with three nodes each. The cut ends were protected by immediately dipping in melted wax. The surface of the internode was then sterilized with alcohol and the central portion inoculated by first making a deep stab-wound with a sterilized hot scalpel and then placing the bacterial culture into the wound. On inoculation the cut mouth of the wound was sealed with wax and the sett wrapped in tissue papers and incubated at room temperature. They were examined periodically by splitting open and comparing with the control setts.

The pathogenicity tests on leaves were carried out by spreading 48 hour old bacterial culture from nutrient agar slants to the leaf surface, previously surface sterilized with alcohol and punctured by rubbing carborundum powder on the surface as recommended by Nour and Nour (1958). The inoculum was immediately covered with alkathene bags. The humidity level inside the bag was kept high by periodical sprayings. The leaves were examined periodically for the appearance of the disease symptoms.

The bacterial isolates were studied for their morphological, cultural and physiological properties following the detailed methods described by Dowson (1957). For the experiments to study the utilization of various carbon sources by

the bacteria, a basal medium containing ammonium hydrogen phosphate 1 g. potassium chloride 0.2 g, magnesium sulphate 0.2 g in a litre of distilled water (final pH 6.8) was prepared and then divided into small quantities to which one per cent W/V of various carbon sources added. The media were distributed in test tubes at 10 ml portions per tube and autoclaved at 10 lb pressure for 15 mts. They were then inoculated with the bacterial cultures grown on the synthetic media containing the above ingredients together with one per cent dextrose. On inoculation the tubes were incubated at room temperature and periodical observations made.

For testing the capacity of the bacteria to utilize various nitrogen sources a basal medium containing dextrose 10 g. potassium hydrogen phosphate 2 g. magnesium sulphate 0.2 g. and potassium chloride 0.2 g. in a litre of distilled water (final pH 6.8) was prepared and the various nitrogen sources added at the rate of 0.1 per cent by W/V and tubes prepared in the manner described above. The cultures grown on a synthetic medium with the above ingredients together with 0.1 per cent sodium nitrate were used as inocula.



Inoculation of bacterial cultures on sugarcane setts :

1. Isolate Nos. 1 and 2 on Co. 449 showing reddening of the vascular bundles.
2. Control setts.
3. Isolate No. 3 on Co. 449 showing symptoms similar to those produced by isolate Nos. 1 and 2.

FIG. 1

EXPERIMENTAL RESULTS : *Stem Inoculations :* All the four bacterial isolates together with isolate No. 5 (*X. rubrilineans* from I. A. R. I.) were inoculated on the setts of Co. 449 and Co. 527. The final observations recorded after 15 days are summarized in Table II.

When the setts were split open the vascular bundles were found to be severely discoloured, turning deep red as in the vascular reddening symptoms observed in the field (Fig. 1). In some cases the reddening extended from the place of inoculation upto the nodal region. The infected setts were examined microscopically and the bacteria isolated and found to be identical with the respective originals.

Leaf Inoculations : All the five isolates were inoculated on five sugarcane varieties during October 1958 and was repeated during November–December 1958. Observations recorded are summarised in Table III.

Isolates 1 and 2 caused minute reddish spots on Co. 467 and Co. 527 and not on the other three varieties. Isolate 3, though caused the same type of spots as in the above two cases, was found to be more virulent as it infected all the five sugarcane varieties tested. Isolates 4 and 5 caused typical red-stripe symptoms but the former was highly virulent infecting all the five sugarcane varieties and most severely on Fiji B, whereas the latter was infective only on Co. 449, Co. 467 and Co. 527, that too, in a less virulent form. The infected leaves were examined microscopically, the bacteria brought into culture and were found to be identical with the respective original isolates.

Morphological, Cultural and Physiological Characters : The comparative data on the morphological, cultural and physiological properties of all the five isolates are given in Table IV.

Isolates 1 and 2 are identical with each other in most respects. Isolate 3, though related to isolates 1 and 2 in many respects, appears to be distinct from them in hydrolysing starch, feeble liquefaction of gelatin and not producing NH_3 and H_2S . Isolates 4 and 5 are almost identical with each other and differ from the first three isolates in most respects.

Utilization of Carbon Sources : The results obtained on the utilization of various carbon sources by the five bacterial isolates are summarised in Table V.

None of the five isolates produced gas in any of the media containing the carbon sources. Isolates 1 and 2 utilized 11 out of the 14 carbon sources tested ;

they produced acid in glucose, mannose, arabinose, maltose, fructose and glycerol, but no acid in galactose, starch, salicin and sorbitol. Isolate 3 utilized 13 out of the 14 carbon sources producing acid in mannose, raffinose, galactose, salicin, glycerol, sorbitol, and lactose. In this respect it differs from the above two isolates. Isolates 4 and 5 utilized 13 out of the 14 carbon sources tested; they produced acid in glucose, maltose, raffinose, galactose, fructose and lactose and no acid in mannose, arabinose, sucrose, starch, salicin, glycerol and sorbitol.

Utilization of Nitrogen Sources: The results on the utilization of various nitrogen sources by the five bacterial isolates are summarised in Table VI.

Of the 16 nitrogen sources tested, isolates 1, 2 and 3 utilized 11 of them and isolates 4 and 5 utilized 13 of them. All the five isolates failed to utilize creatine. Isolates 1 and 2 did not utilize threonine, leucine, valine and cystine, whereas isolates 4 and 5 readily utilized all these four amino acids but not urea and uranium nitrate.

Host Range: The host range of the bacterial isolates was tested on potted plants of different Gramineous hosts by inoculating the leaves in the manner described earlier. The observations recorded are summarised in Table VII.

Isolates 1 and 2 could infect 7 out of the 14 hosts tested and they resemble each other in this respect. Isolate 3 had a narrower host range, infecting only four of the seven hosts infected by the first two isolates. Isolates 4 and 5 could infect six of the hosts tested and the former was relatively more virulent on all the six hosts than the latter.

Identity of the Organisms: On the basis of their morphological, cultural, physiological and nutritional properties as well as on their host range the isolates are classified as follows :

Isolates 1 and 2 resemble each other in most respects and fall under the broad descriptions of *X. vasculorum* (Cobb) Dowson except for some minor differences in their physiological properties. Isolate 3 comes close to the above two strains in many respects but differs from them in certain nutritional properties. Also it is more virulent on sugarcane varieties tested and more specific in its host range. Though these differences are significant the disease symptoms produced by this organism is typical to those caused by *X. vasculorum* on sugarcane and therefore the isolate is tentatively included as a strain of *X. vasculorum*.

Isolate 4 is identified as *X. rubrilineans* (Lee *et al*) Starr and Burkholder as it resembles the species in all descriptions (Breed *et al* 1957), except in not reducing nitrates. Isolate 5, obtained from I.A.R.I. with the label *X. rubrilineans*, is identical with isolate 4 in most respects except for its low virulence on the host plants tested.

Another related species, *X. rubrisubalbicans* (Christopher and Edgerton) Savulescu has been reported to cause mottle-stripe disease on sugarcane leaves in Louisiana (Christopher and Edgerton 1930). This bacterium is quite distinct from the isolates under study in the type of the disease caused and in many nutritional characters.

DISCUSSION: Not much of work has been done in India on bacterial diseases of sugarcane. Though it is believed that they are of minor importance no proper assessment of their prevalence and the damage caused has been made so far. In the present studies two important diseases have been investigated. One of them caused by *X. vasculorum* is widespread in other sugarcane growing countries, but is being recorded for the first time in India. The other disease, viz., red-stripe caused by *X. rubrilineans*, though known to be prevalent in the United Provinces and Bombay, has not been reported from Madras State so far.

X. vasculorum is known to cause gummosis, shoot rot and vascular reddening on sugarcane in other countries (Edgerton 1955). The symptoms of the disease caused in this country seem to vary with the sugarcane variety; on Co. 449 and Co. 527 typical gummosis has been observed, on Co. 961 multiple shoot and shoot-rot was observed and on Co. 449 vascular reddening, without any gummosis, was observed. The conditions leading to such variations in the disease symptoms on different varieties need to be investigated in detail. The three isolates obtained from the disease types, though fall within the broad descriptions of *X. vasculorum*, differ in certain physiological and nutritional properties. Such variations in the physiological and nutritional properties of phytopathogenic bacteria appear to be common as seen from the studies of Burkholder (1932) and Starr (1946). The possibilities of the existence of different varieties or strains of *X. vasculorum* is indicated by the prevalence of different disease types caused by the bacterium at the same time of the year. More detailed investigations are required to elucidate such possibilities.

X. rubrilineans obtained from I.A.R.I. and said to be a non-pathogenic isolate, proved to behave less virulent when compared to the *X. rubrilineans* isolate obtained locally. But the morphological, cultural, physiological and

nutritional properties of these two isolates were identical except that the I.A.R.I. isolate differed from the local isolate in forming smooth round colonies in nutrient agar as against large spreading colonies. The reasons for the variations in their pathogenicity need further investigation.

The results obtained on the host range studies of the two species indicate that *X. vasculorum* can pass on to *Zea mays* L., *Sorghum vulgare* Pers., *Panicum miliare* Lam., *P. miliaceum* L., *P. antidotale* Retz. and *Brachiaria mutica* Stapf. The bacterium has been reported to infect *Bambusa vulgaris* Schrad., *Cocos nucifera*, *Coix lachryma* L., *Dictyosperma alba* Wendle and Drude, *Panicum maximum* Jacq., *Thysanolaena maxima*, *B. mutica*, *Pennisetum purpureum* Schum., *Sorghum halapense* Wall, *S. sudanense* Stapf., *S. verticilliflorum*, *Sorghum* sp. and *Z. mays*, besides *Saccharum officinarum* L. (Orion 1941, Hughes 1939). In the present studies *S. vulgare*, *P. miliare*, *P. miliaceum*, and *P. antidotale* have been newly found to be infected by the bacterium on inoculation.

X. rubrilineans has been reported to infect *Sorghum vulgare*, *S. halapense*, *S. plumosum*, *S. verticilliflorum*, *S. sudanense* and *Z. mays* (Elliott 1951). In the present studies the bacterium has been found to infect, on artificial inoculation, *S. vulgare*, *Pennisetum typhoideum* Rich., *Panicum antidotale* and *B. mutica*, besides *Z. mays*.

According to Nour and Nour (1958) the new method of inoculating bacterial cultures with carborundum is more effective than the other reported ones. It is probable that in the present studies new hosts for the two bacterial species have been found out mainly because of the new inoculation technique followed.

SUMMARY

Four apparently distinct types of bacterial diseases on sugarcane varieties were collected during April–October 1958 from the fields in some places of South Arcot District, Madras State and were investigated in detail. It was found that gummosis, multiple shoot and vascular reddening diseases were caused by closely related bacterial strains coming under *Xanthomonas vasculorum* (Cobb) Dowson. The red-stripe disease was found to be caused by a virulent strain of *X. rubrilineans* (Lee et al) Starr and Burkholder.

Studies on the cultural, physiological and nutritional properties showed that the isolates from gummosis and multiple shoot resembled each other closely, but the isolate from vascular reddening was distinct from the former two in

certain nutritional properties. The isolate from red-stripe was found to be identical with an isolate of *X. rubrilineans* obtained from Indian Agricultural Research Institute, New Delhi.

The three isolates of *X. vasculorum* differed in their virulence and infectivity when tested on five sugarcane varieties and other Gramineous hosts. *X. rubrilineans* isolated locally was more virulent than the one obtained from I. A. R. I.

The host range studies revealed for the first time the infectivity of *X. vasculorum* on *Sorghum vulgare* Pers., *Panicum miliaceum* Lam., *P. miliare* Lam., and *P. antidotale* Retz. and of *X. rubrilineans* on *S. vulgare*, *Pennisetum typhoideum* Rich., *Panicum antidotale* and *Brachiaria mutica* Stapf.

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TABLE I
Details of the bacterial isolations made from different types of
sugarcane diseases

Disease type	Sugar-cane variety	Locality of occurrence	Date of collection	Bacterial isolate No.	Remarks
Gummosis	.. Co. 527	Nelli-kuppam	April, 58	1	From stem
Multiple shoot	... Co. 961	Nelli-kuppam	April, 58	2	From shoot
Vascular Reddening	... Co. 449	Nelli-kuppam	April, 58	3	From leaves and stem
Red stripe	... Fiji B	Chidambaram	Sept., 58	4	From leaves

TABLE II

Inoculation tests of bacterial isolates on sugarcane setts

Bacterial Isolate No.	Co. 449	Co. 527	Time taken for the infection symptoms to be visible
1	+++	+++	7 days
2	+++	+++	7 days
3	++	++	11 days
4	0	0	—
5	0	0	—

0 to +++ increasing intensities of infection symptoms.

TABLE III

Infectivity of the bacterial isolates on the leaves of sugarcane varieties

Isolate No.	Fiji B	Co. 449	Co. 467	Co. 527	Co. 961	Remarks
1	0	0	++	+	0	Spots $\frac{1}{2}$ to 1 mm x 1 to 2 mm in size ; no stripes formed.
2	0	0	++	+	0	-do-
3	+	+	+++	+++	+	-do-
4	++++	++	+++	++	++	Typical red-stripe symptoms observed.
5	0	+	++	++	0	-do-

0 to + + + + = increasing intensities of infection symptoms.

TABLE

Comparison of the morphological, cultural and physiological

Character tested	Isolate No. 1	Isolate No. 2
Shape and size of cell ...	Short rod, single or in pairs 0.4-0.6 x 1.0-1.6 μ	Short rod, single or in pairs 0.4-0.6 x 1.0-1.2 μ
Flagella ...	Single polar	Single polar
Spore stain ...	—	—
Capsule stain ...	—	—
Gram stain ...	—	—
Growth on nutrient agar ...	Pale yellow, gummy smooth colonies	Pale yellow gummy smooth colonies
Growth on nutrient broth	Turbid with slimy growth	Turbid with sedimenta- tion
Growth on potato plug ...	Dark brown, slimy	Dark brown, slimy
Growth in gelatin ...	Rapid liquefaction	Rapid liquefaction
Growth in litmus milk ...	Clearing, pink colour, no curdling	Clearing, pink colour, no curdling
Hydrolysis of starch ...	—	—
Nitrate reduction ...	+	+
Lipolytic activity ...	+	+
Indol test ...	—	—
NH ₃ production ...	+	+
H ₂ S production ...	+	+
M. R. Test ...	+	+
V-P Test ...	+	+

IV

properties of the bacterial isolates from sugarcane

Isolate No. 3	Isolate No. 4	Isolate No. 5
Short rod, single or in short chain 0.3-0.6 x 1.0-1.5 μ	Rods, usually in singles 0.8-1.0 x 1.2-1.6 μ	Rods, usually in singles 0.6-1.0 x 1.0-1.8 μ
Single polar	Single polar	Single polar
—	—	—
—	—	—
—	—	—
Pale yellow gummy large colonies	Yellow, smooth and glis- tening colonies	Yellow, smooth and glis- tening colonies
Turbid with sedimenta- tion	Turbid with pellicle for- mation	Turbid with pellicle forma- tion
Dark brown, slimy	Honey yellow, slimy and dripping	Honey yellow, slimy
Slight liquefaction	Slight liquefaction	Slight liquefaction
Clearing, mauve colour, no curdling	Rapid clearing, no curd- ling	Rapid clearing, no curdling
Slow hydrolysis	Rapid hydrolysis	Rapid hydrolysis
+	—	—
+	—	—
—	—	—
—	+	+
—	—	—
+	—	—
+	—	—

TABLE V

Utilization of carbon sources by the bacterial isolates from sugarcane.

C - source	Isolate No. 1	Isolate No. 2	Isolate No. 3	Isolate No. 4	Isolate No. 5
Glucose	+++ A	+++ A	+++ A	+++ A	+++ A
Mannose	+++ A	+++ A	+++ NA	+++ NA	+++ NA
Arabinose	+++ A	++ A	++ A	+++ A	++ A
Galactose	++ NA	+++ NA	+++ NA	+++ A	+++ A
Fructose	++ A	++ A	++ A	++ A	++ A
Sucrose	++ A	+++ A	+++ A	+++ NA	+++ NA
Maltose	+++ A	+++ A	+++ A	+++ A	++ A
Starch	+ NA	+ A	+ SA	++ NA	++ NA
Lactose	0	0	+ NA	++ A	++ A
Raffinose	0	0	+ NA	+++ A	++ A
Glycerol	+++ A	+++ SA	+++ NA	+++ NA	+++ NA
Salicin	++ NA	++ NA	++ NA	++ NA	++ NA
Mannitol	0	0	0	0	0
Sorbitol	+ NA	+ NA	++ NA	+++ NA	+++ NA

0 to +++ = increasing amount of growth. A = acid production;
NA = no acid production; SA = slight acid production.

TABLE VI

Utilization of nitrogen sources by the bacterial isolates from sugarcane

N-source	Isolate No. 1	Isolate No. 2	Isolate No. 3	Isolate No. 4	Isolate No. 5
L-Asparagine	+++ A	++ NA	+++ NA	+++ NA	+++ NA
L-Glutamic acid	+++ A	+++ A	+++ A	+++ A	+++ A
DL-Histidine HCl	++ SA	++ SA	++ SA	+++ SA	+++ SA
DL-Threonine	0	0	+ NA	+++ NA	+++ NA
L-Leucine	0	0	0	+++ SA	+++ SA
DL-Valine	0	0	0	+++ SA	+++ SA
L-Cystine	0	0	0	+++ A	+++ A
Creatine	0	0	0	0	0
Urea	++ SA	++ SA	+++ NA	0	0
Uranium nitrate	++ A	++ A	++ A	0	0
Sodium nitrate	++ NA	++ NA	++ NA	+++ NA	+++ SA
Potassium nitrate	++ NA	++ SA	++ NA	+++ A	+++ A
Ammonium chloride	+++ A	+++ A	++ A	+++ A	+++ A
Ammonium phosphate	+++ A	+++ SA	++ SA	++ NA	++ NA
Ammonium sulphate	+++ SA	+++ SA	++ NA	+++ A	+++ A
Ammonium oxalate	+++ SA	+++ A	++ NA	+++ A	+++ A

0 to + + + = increasing amount of growth.

A = acid production ; NA = no acid production ; SA = slight acid production.

TABLE VII

Host range of the bacterial isolates from sugarcane

Host		Isolate No. 1	Isolate No. 2	Isolate No. 3	Isolate No. 4	Isolate No. 5
<i>Saccharum officinarum</i> L. var. Co: 467	...	++	++	+++	++++	+
<i>Zea mays</i> L.	...	+++	++	+++	+++	+
<i>Sorghum vulgare</i> Pers.	...	+	++	0	+++	++
<i>Pennisetum typhoideum</i> Rich	...	0	0	0	++	+
<i>Eleusine coracana</i> Gaerth.	...	0	0	0	0	0
<i>Setaria italica</i> Beauv.	...	0	0	0	0	0
<i>Panicum miliare</i> Lam.	...	++	++	0	0	0
<i>P. miliaceum</i> L.	...	++	++	0	0	0
<i>P. antidotale</i> Retz.	...	+++	+++	+++	+++	+++
<i>Brachiaria mutica</i> Stapf.	...	++	+	+	+++	+
<i>Chloris gayana</i> Kunth.	...	0	0	0	0	0
<i>Paspalum scrobiculatum</i> L.	...	0	0	0	0	0
<i>Cenchrus setigerus</i> Vahl.	...	0	0	0	0	0
<i>Echinachloa frumentacea</i> L.	...	0	0	0	0	0

0 to + + + + increasing intensities of disease infection.

CERTAIN OBSERVATIONS ON THE EFFECT OF REFRIGERATION ON THE MITOTIC CHROMOSOMES OF URGINEA INDICA KUNTH. IN RELATION TO THEIR STAINABILITY

By K. RANGASWAMI AYYANGAR

Department of Botany, Annamalai University, Annamalainagar.

INTRODUCTION

It has been reported from this laboratory on a previous occasion that prolonged chilling of sprouted onions has had the effect of bringing about certain mitotic changes such as the inhibition of the achromatic figure, promiscuous scattering of chromosomes, irregular anaphasic movement etc. (Fig. 1—4). The present undertaking concerns certain preliminary observations on the staining capacity of the mitotic chromosomes of the Indian Squill, *Urginea indica* Kunth. after they are subjected to varying periods of refrigeration.

MATERIALS AND METHODS

For the purpose of this investigation, bulbs of *Urginea indica* Kunth. locally available in clayey soils were placed in jars containing tap-water. In three or four days, time, adventitious roots began to emerge from the disc. One set of such rooted bulbs were then kept in the refrigerator at a temperature of 5°C. — 7°C. while another set, the control was allowed to remain in the laboratory under normal conditions. The root tips from the bulbs kept in the refrigerator were squashed and stained in aceto-carmin according to the improved squash technique developed in this laboratory (2). Squashing and staining were done first after 24 hours of cold treatment, then after 48 hours and again after 72 hours. Some of these root tips were also squashed and stained employing Feulgen's basic fuchsin method (3). Every time the refrigerated root tips were squashed and stained, correspondingly the root tips of the control bulbs were also squashed and stained for the sake of comparison. The materials kept at low temperature for 72 hours showed the most conspicuous effect.

OBSERVATIONS

At the resting stage of the nucleus there was no great difference between the control and the experimental root tip cells, except that in the experimental

certain relatively darker stained granules were seen distributed within the nuclear reticulum. During the different phases of prophase, however, in the experimental nuclei, the chromosomal strands could be described only faintly whereas in the control nuclei, they were quite discernible owing to deeper staining. The nucleolus, however, could be seen more or less clearly both in the control and experimental nuclei. During the subsequent metaphase when the nuclear membrane had disappeared, the chromosomes in the experimental cells were seen merely as vague and hyaline threads although here and there on the chromosomes and especially in the attachment constriction region some portions appeared to be of relatively darker hue. In fact, in some of the chromosomes, the chromonema or the protein framework was brought into relief owing to the fact that the chromosome as a whole was not stained deeply. In the control cells, however, the chromosomes at this metaphase stage appeared to be uniformly and deeply stained. In the anaphase too, the same differential staining conditions were seen in the control and cold-treated cells, while in the telophase this difference in the stainability between the chromosomes of the control and experimental nuclei was at its minimum.

DISCUSSION

The foregoing observations clearly point out that during metaphase and anaphase when the chromosomes usually become fullfledged, the contrast in the staining propensity between the control chromosomes and the refrigerated chromosomes, happens to be most conspicuous. While the control chromosomes are normally stained and consequently appear as dark threads, the chilled chromosomes appear as merely vague and hyaline structures in which the chromonema framework twisted or otherwise can be made out. It is known now that the full fledged chromosome acquires chromaticity during the progress of mitosis chiefly because thymonucleic acid (DNA) accumulates in it and as a consequence, the chromosome develops an affinity to the basic dyes. Since the refrigerated chromosomes apparently do not possess any affinity for basic dye as has been shown in this investigation, the inescapable inference is that the non-stainability of the chilled chromosomes is to be attributed to the lack of formation of nucleic acid in the chromosomes. In other words, refrigeration has very largely inhibited the production of nucleic acid, the essential substance of which chromosomes are made and which lends them the capacity to take up basic stains. Previous report indicates that such a possibility exists in Trillium (i). Present work is, therefore, a pointer to the fact that nucleic-acid-starved chromosomes have only a low degree of stainability.

SUMMARY

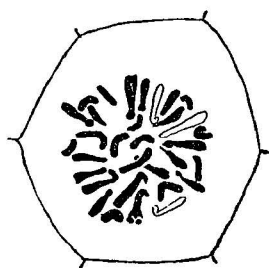
Previous work in this laboratory has shown that low temperatures bring about perceptible changes in the mitotic behaviour of chromosomes in the root tip cells of onion. The present undertaking concerns the effect of prolonged refrigeration on the mitotic chromosomes of *Urginea indica* Kunth. in relation to their stainability. Two sets of bulbs of *Urginea indica* Kunth. (the Indian Squill) were placed in bottles containing tap water for inducing formation of roots. Roots emerged in three or four days and thereafter one set was kept in the refrigerator for varying periods of time ranging from 24-72 hours. Acetocarmine and Feulgen's basic fuchsin squashes were prepared from the root tips of the chilled bulbs as well as from those of the control. The different stages of mitosis in both these squashes were critically examined. It was found that during the metaphase and anaphase stages of mitosis the chromosomes of the chilled nuclei were only faintly or not stained at all. In fact, they appeared as some vague and hyaline threads revealing their chromonema framework sometimes twisted and sometimes not twisted. In the control nuclei, the chromosomes being stained normally appeared as thick coloured strands. It is now known that the full fledged chromosome acquires chromaticity during the progress of mitosis chiefly due to the accumulation of thymonucleic acid (DNA) and as a consequence, the chromosome develops an affinity to the basic dyes. Since the refrigerated chromosomes apparently do not possess any affinity for basic dye, the inference is that the low-stainability of the chilled chromosomes is to be attributed to the lack of nucleic acid formation in the chromosomes. In other words, prolonged refrigeration has very largely inhibited the production of nucleic acid, the essential substance of which the chromosomes are made and which alone lends them the capacity to take up stains. The present work is, therefore, a pointer to the fact that nucleic-acid-starved chromosomes have only a low degree of stainability.

ACKNOWLEDGMENT

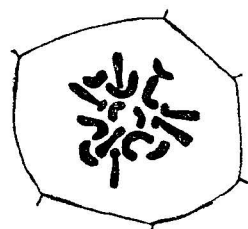
It gives me much pleasure to acknowledge my indebtedness to Professor T. C. N. Singh, M.Sc., D.Sc., D.Ph., F.B.S., Professor and Head, Department of Botany, for the interest he evinced in the work and for his valuable suggestions. I am also thankful to the members of the Botany Department Research Clup for their critical discussion of the matter during the weekly sessions.

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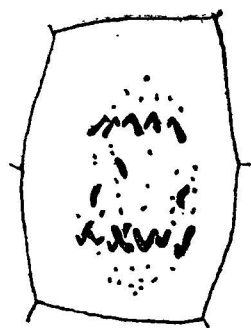
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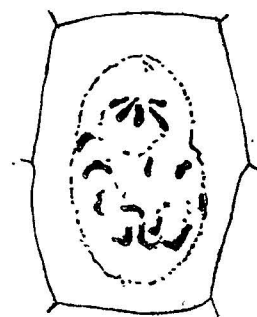
1



2



3



4

EXPLANATION OF TEXT FIGURES

Figure 1 : A normal cell showing 16 chromosomes.

Figure 2 : A tetraploid cell of the refrigerated root-tip showing twice (32) the normal number of chromosomes.

Figure 3 : Unequal distribution of chromosomes during anaphase.

Figure 4 : An aberrant cell in which an irregularly shaped nucleus is precociously organised.

STUDIES IN THE CYTOLOGY OF ABRUS PRECATORIUS LINN.

By C. SRINIVASAN, M.Sc.

Lecturer in Botany, Annamalai University, Annamalai nagar.

INTRODUCTION :

A study in the Morphology, Physiology and Cytology of *Abrus precatorius*, Linn. was kindly suggested by Dr. K. Rangaswami Ayyangar, M.Sc., Ph.D., F.B.S., Reader in Botany of this University for my research in 1948. The following is the thesis (in part) approved in fulfilment of the requirement of the Degree of Master of Science in Botany of the Annamalai University.

PREVIOUS WORK :

Abrus precatorius Linn. goldsmith's weighing bead, was first recorded by Linnaeus (1767). Roxburgh in 1832 distinguished three varieties of *Abrus precatorius* Linn. as follows :

1. Rose coloured flower, red seeds with black eye ;
2. Dark coloured flower, black seeds with white eye ;
3. White flower, white seeds with black eye;

but he has not named these varieties. Baker (Hooker 1879) has described the flowers as "reddish or white having seeds of bright scarlet and black, black or whitish or mixed black and white." Voigt (1845) has enumerated three varieties of *Abrus precatorius* Linn. such as (1) var. erythrospormus, (2) var. leucospermus and (3) var. melanospermus. Of these, var. erythrospormus and var. leucospermus correspond to the first and third varieties of Roxburgh (1832) but the third variety of Voigt (1845) namely var. melanospermus has seeds similar to those of the variety number (2) of Roxburgh (1832). Only the colour of the flower according to the description of Voigt (1845) differs from that of Roxburgh (1832).

The genus *Abrus* has been placed under the tribe *Vicieae* of the sub-family *Papilionaceae* by Baker (Hooker 1879) and Gamble (1919). It has also been suggested that its position in the *Vicieae* is not correct. Striecher (Senn 1937) on the basis of anatomical studies, concluded that *Abrus* should be separated from the *Vicieae*. Compton (1912) has indicated that *Abrus* is related to *Phaseoleae* rather than to *Vicieae*, since *Abrus* has tetrach root structure and epigeal germination which are the characteristics of *Phaseoleae* in general while the true *Vicieae*

has triarch root structure and hypogeal germination. Pepov (Senn 1938) has discussed the relationships of *Abrus* and has concluded that it should be removed from the *Vicieae* to a position in between the *Vicieae* and the *Phaseoleae* but closer to *Phaseoleae*. These conclusions of morphologists and taxonomists have strikingly been corroborated on the basis of the chromosome numbers. The diploid chromosome number of the red seeded *Abrus* was determined by Senn (1938) as $2n = 22$. The n number 11 is not found in the true *Vicieae* but is the predominant number of the *Phaseoleae*. The n number of the *Vicieae* is 7. The chromosome number of *Abrus* as $2n = 22$ has also been confirmed in the present investigation (Figs. 56 & 57). Darlington and Janaki Ammal (1945) have included this genus *Abrus* in the tribe *Phaseoleae* obviously because of the similarity in the chromosome numbers between *Abrus* and the other members of this tribe.

Earliest cytological workers in this family are Schleiden and Vogel (1839). They have described the floral development and endosperm formation of more than 50 species. The tribe *Vicieae* in which *Abrus* was first included was worked out by Namec (1904) Lundegardh (1912) and Sharp (1913). Senn (1938) found out the diploid chromosome number of *Abrus precatorius* Linn. to be 22. The tribe, *Phaseoleae*, in which *Abrus* has now been included, has been worked out by a few investigators. Brown (1917), Guignard (1881) and Weinstein (1926) have examined and described the microsporogenesis and megasporogenesis of *Phaseolus*. More recently chromosome numbers of species of *Phaseolus* have been determined by Krishnamurti (1948). The haploid number has been recorded by him as 11 and 12 in the genus. Ramamurti (1950) carried out cytogenetical investigations on *Phaseolus mungo* and *Phaseolus radiatus* with special reference to the behaviour of their hybrids. While thus other genera of the *Phaseoleae* have been the subject of cytological investigation in the hands of various authors comparatively very little attention seems to have been given to *Abrus*. Apart from the foregoing, no detailed work on various aspects of the plants such as external morphology, anatomy, seed-coat studies, physiology, ecology and cytology which has been dealt with in the present studies seems to have been done so far.

MATERIALS AND METHODS :

The two kinds of plants of *Abrus* white seeded and red seeded are available in the Botanic Garden of the University. Some seeds of both the kind were also got from the neighbouring villages of Quilon. Selected seeds of the two kinds of plants were sown in pots side by side in the Laboratory as well as in the Botanic Garden. Care was taken to grow the two plants as far as possible in identical environments using the same soil and mode of irrigation. Somatic chromosome

counts were made from root-tips fixed in Karpechenko's modification of Navaschin. Maximum mitotic activity was observed between 10 A. M. and 11 A. M. For meiotic studies the correct stage for fixation of anthers was determined by acetocarmine examination and fixed in Navaschin's fluid. The materials were dehydrated as usual in alcohol and embedded in paraffin wax using chloroform as the paraffin solvent. Sections were taken at thickness varying from 8 to 12 microns and stained in Newton's Iodine Gentian Violet and Haidenhain's Iron-Alum Haematoxylin. The drawings were made with the aid of Zeiss Abbe Camera lucida at the table level with ocular X 15 and 25, objective X 90 Apochromat Oil immersion.

OBSERVATIONS :

SOMATIC CHROMOSOMES

The somatic chromosome numbers of the two kinds of *Abrus* have been determined to be 22 ($2n$). For the sake of definiteness numerous metaphase plates in different sections of root-tips were examined and in all cases the chromosome count was found to be 22 only (Figs. 56 and 57). Further confirmation was obtained by counting the meiotic chromosome number. This number is 11 (n).

The karyotypes of red seeded *Abrus* and white seeded *Abrus* were analysed and measured (Figs. 56a and 57a). In the red seeded *Abrus* size of the chromosomes ranges between 2.1 microns and 0.8 micron. On the other hand in the white seeded *Abrus* the range is from 2.8 microns to 1 micron. Evidently the chromosomes of the red *Abrus* are generally smaller than those of the white. In both the *Abrus* plants most of the chromosomes showed median attachment constrictions, only a few having subterminal constrictions (Figs. 56 and 57). From the fact that two bivalents were seen to be attached to the nucleolus during diakinesis (Fig. 64) it may be inferred that there may be four somatic chromosomes with secondary attachment constrictions. The existence, however, of such satellited chromosomes could not be recognised. This may be due to a little overstain.

According to the size of the chromosomes, they fall into 10 types in both the *Abrus* plants. But here again there is a perceptible difference between the red and white seeded plants. While nine types are in pairs the tenth type is represented by 4 chromosomes which are the longest in the red (Fig. 56-a). On the other hand in the case of the white seeded *Abrus* it is not the longest chromosome that is represented 4 times but one of the chromosomes of the medium size (Fig. 57-a). Obviously in the red *Abrus* the longest chromosome pair

has become duplicated while the one of the medium pairs has undergone duplication in the white. The ten types of red seeded *Abrus* belong to two haploid groups which may be represented respectively as A, B, C, D and E; and A_1 , B_1 , C_1 , D_1 and E_1 . Evidently the latter set A_1 is duplicated (Figs. 56 and 56a). Similarly in the white seeded *Abrus* the haploid sets may be represented as A, B, C, D and E; and A_1 , B_1 , C_1 , D_1 and E_1 . Here the third chromosome of the second set is represented twice (Figs. 57 and 57-a).

MICROSPOROGENESIS

All the four anthers of each of the nine stamens are fertile. The primary archesporium of the anther is differentiated at a very early period. It consists of four bands of hypodermal cells, one in each lobe, each band consisting of four to six cells (Fig. 58). Such multicellular archesporia have been reported in *Phaseolus vulgaris* (Weinstein, 1926), *Cyamopsis tetragonoloba* (Ranganathan, 1947). The archesporial cells can be well distinguished from the remaining cells by their larger size, bigger nucleus and denser cytoplasm. The primary archesporial cells divide periclinally cutting off primary parietal cells to the outside and microsporogenous cells inside. The primary parietal cells form a tissue of about three layers the innermost of which functions as the tapetum. The tapetal cells remain uninucleate throughout (Fig. 59). Cooper (1933) classified the angiosperms into three groups on the basis of the behaviour of nucleus in the tapetum; (1) in which the tapetal cell continues to be uni-nucleate without division; (2) in which the nucleus divides once and remains binucleate; and (3) in which pluri-nucleate tapetal cells are present. Of these, plurinucleate condition is often met with. In the previously investigated species of *Leguminosae* uni-nucleate would appear to be the rule. The two kinds of *Abrus* conform to what appears to be the general rule in the *Leguminosae*. The primary sporogenous tissue does not undergo any further division. At the most 3 to 4 rows of 5 to 6 cells (Fig. 60) occur at each anther locule in the longitudinal section of the anther. In a cross-section of the anther of about the same age and size there are 4 to 5 cells (Fig. 61). These become rounded off and function as the pollen mother cells. There are no intercellular spaces among these pollen mother cells. The position of the nucleus is more or less central. There is a single, large deeply stained nucleolus. The pollen mother cells undergo a period of rest. (Fig. 62). Their nuclei become large and show traces of delicate network. The chromatin material takes up the form of a loose reticulum in the meshes of which deeply stained spherical bodies appear. As the nucleus grows the material of this reticulum resolves into convoluted threads. Gradually these threads contract which together with the nucleolus move towards one side of the nuclear membrane (Fig. 63). This is the typical synzetic stage.

At early diakinesis, the 22 chromosomes which form 11 bivalents are distributed along the periphery of the nucleus (Fig. 64) and are approximately equidistant from one another. The equidistant spacing of the bivalents according to Lawrence (1932) is due to repulsion phase which begins at early diakinesis and continues until mid-diakinesis and the equal spacing of the bivalents, suggests that the inter-bivalent repulsion is also equal. At late diakinesis the bi-valents come closer together towards the centre of the nucleus and this is probably due to a weakening of the force of repulsion. The migration of the bivalents from the periphery to the centre of the nucleus, the close approximation of the chromosomes of each bivalent and the duality of the chromosomes being lost—these mark the gradual change over from diakinesis to prometaphase. The converging movement of the bivalents which begins at mid-diakinesis proceeds until the bivalents are in close assemblage in the centre of the nucleus. They assemble in such manner that they come to lie in the same direction as the spindle fibres. The nuclear membrane now becomes indistinct because of gradual dissolution and soon in its place a number of fine delicate fibres appear. The nucleolus also disappears. Now this pro-metaphase stage merges almost imperceptibly into the metaphase.

Polar views of equatorial plates at metaphase show 11 distinct bivalents in each case (Fig. 65). The arrangement is also variable. The characteristic feature is the approximation of the bivalents. This pairing of different bivalents generally known as the secondary association has been recorded in a large number of plants (Lawrence 1931), Ragavan (1938), Venkatasubban (1944). In the plant under investigation a variable number of bivalents has been observed to be secondarily associated (Figs. 67 to 75). In the table number 13 are given the various kinds of secondary association. Twenty-one cases of secondary association have been observed and recorded. The value of secondary association ranges from one to six, the latter being the maximum value of the secondary association. From Figure 75, it will be seen that at this maximum stage there are five groups of bivalents, one group consisting of three secondarily paired bivalents, and four groups each consisting of two bivalents. The implication of the determination of the genetic constitution and phylogenetic derivation of *Abrus precatorius* Linn. (red seeded) has been discussed later.

In this stage (Fig. 76) of Anaphase I the homologous chromosomes of each bivalent move apart in the normal manner. This anaphasic movement has been attributed to two forces, the force of repulsion between the attachment constriction and the force of attraction exerted by the poles on the chromosomes (Alam, 1936). Due to the contraction of the spindle fibrils the chromosomes

gradually approach the poles. Ultimately two groups of chromosomes get organised in the poles of the cell (Fig. 77). These are the diad nuclei. No cell wall was formed between the diad nuclei at this stage of Telophase-I.

TABLE 13

Number of Secondary Association	No. of bivalents in association				Number of cases	Total number of cases
	1	2	3	4		
1	2	3	4	5	6	7
1	9	1	—	—	1	1
2	8	—	1	—	3	3
3	5	3	—	—	1	5
3	6	1	1	—	2	
3	7	—	—	1	2	
4	5	—	2	—	1	1
5	4	—	1	1	1	3
5	2	3	1	—	2	
6	1	3	—	1	2	8
6	1	2	2	—	1	
6	—	4	1	—	5	
Total						21

During Metaphase-II the chromatin reticula of the diad nuclei resolved themselves into two groups of distinct chromosomes in the pollen mother cell. Different views of this second meta-phase have been seen. In some pollen mother cells both the metaphase plates are in the polar view (Fig. 78). In some others both exhibit the side view (Fig. 79). Cases have not been wanting where one of the plates is in the side view and the other in the polar view (Fig. 80). The two groups of second metaphasic chromosomes now undergo the homotypic division and the resulting four groups of chromosomes move apart (Fig. 81) in this Anaphase-II.

The four groups of chromosomes at the poles reorganise themselves into the nuclei of the four microspores. Now furrowing begins (Fig. 82) in four directions at the completion of which the separating walls of the four microspores are secreted although in the beginning the four microspores or the pollen grains compactly fill the cavity of the pollen mother cell. Very soon they become

quite distinct by a process of rounding of. The four pollen grains so formed have been observed to be arranged generally in a tetrahedral fashion (Fig. 83). In a few cases all the four pollen grains have been seen in the same plane that is in the isobilateral position (Fig. 84). The mature pollen grain is ovoid in shape with three longitudinal grooves. In the polar view the pollen grain has a three lobed configuration (Fig. 85), the depressions being the longitudinal grooves where in also lie the germ pores. At the shaping stage the pollen grain is highly vacuolated and contains two nuclei, the large tube nucleus and the small generative nucleus (Fig. 86). As has been pointed out previously the pollen grains of white *Abrus* have been found to be larger in size than those of red. The general course of meiosis and the formation of the pollen grains in the white seeded *Abrus* was found to be in all essentials similar to those of the red seeded *Abrus* described above. Although secondary association of bivalents was also observed in the white seeded plant (Fig. 66) maximum association could not be determined for want of sufficient number of plates.

DISCUSSION :

MAXIMUM SECONDARY ASSOCIATION AND ITS SIGNIFICANCE

The occurrence of the secondary association of bivalents was first reported by Kuwada (1910). Since then this phenomenon has been recorded by various authors in a number of plants. Darlington and Moffett (1930) working on *Pomoideae* showed for the first time that this phenomenon is of significance in the elucidation of ancestral homology. On the basis of secondary pairing of bivalente they found that 7 was the basic number of this group. According to them the original ancestors of *Pomoideae* must have had 7 as their haploid chromosome number and these ancestors could have undergone natural hybridization resulting in a form with 14 chromosomes. The stimulus of crossing could have induced the duplication of only a few chromosomes of this 14-chromosomed form resulting in a trebly trisomic form of 17 chromosomes. The latter became balanced by further doubling or secondary polyploidy and thus according to these authors, existing polyploid forms of *Pomoideae* with 34 chromosomes ($2n$) have been derived with 17 as the secondary basic number. Lawrence (1931 A) is also of the opinion that secondary association is characteristic of all allopolyploids even as multivalent formation is commonly characteristic of autopolyploids.

Since the phenomenon of secondary association is a measure of ancestral relationship, this has come to be of great significance in the determination of the genetical constitution of allopolyploids. A large number of the present day plants are usually looked upon as allopolyploids evolved through a natural

hybridisation between two ancestral parents belonging to two distinct species accompanied by the doubling of the chromosome number. In typical allopolyploids resulting in this manner there is usually a very low percentage of multivalent formation. This is because the chromosomes derived from the two parents are not totally homologous, but somewhat different, and this fact is shown by the degree of attraction between the bivalents of the two parents. Usually therefore, pairing takes place between the chromosomes of the same parent and this implies that syndiploidy has already been brought about, either by somatic doubling or by fusion of unreduced gametes. In all polyploid plants of hybrid origin, autosyndesis that is association of the chromosomes of the same parent seem to be a means of getting over the difficulty of incompatibility between the rather distantly related chromosomes of the parental species and thus of tending to stabilise the hybrid plants. Such cases of autosyndesis will naturally result in the formation of bivalents only. But very often these bivalents themselves get approximated with one another and this secondary association indicates their ancestral relationship. For example Karpechenko (1927) in his allotetraploid obtained after a cross between *Raphanus sativus* and *Brassica oleracea*, found the bivalents exhibiting secondary association. This showed that in the hybrid there was the expression of affinity although not quite intimate, between the chromosomes of the original parental ancestors.

BASIC CHROMOSOME NUMBER AND ANCESTRY OF *ABRUS PRECATORIUS* LINN.

As the secondary pairing of the bivalents is thus associated with the ancestry of a species, it is helpful in the computation of the basic chromosome number. The basic chromosome number is indicated by the number of groups of bivalents in the meiotic metaphase when the secondary association is at its maximum. Thus in the *Pomoideae* (Darlington, 1928) 7 groups of bivalents were found at the stage of maximum association. So 7 was considered to be the basic chromosome number of this group. Under similar circumstances *Brassica oleraceae* (Catcheside, 1937) showed six groups of bivalents and therefore its basic chromosome number was regarded as 6*. In the red seeded *Abrus* under investigation a number of meiotic metaphase plates were examined for purposes of determining the maximum association. The observations have been recorded in the table 13. The value of association ranged from 1 to 6, the latter being the maximum value. Of the Twenty-one cases recorded, three showed the maximum

* In calculating the value of secondary association an association of two bivalents is counted as one, that of three as two and so on.

association of 6. These exhibited the following respective groupings of bivalents :— 1 (1), 3 (2), 1 (4); 1 (1), 2 (2), 2 (3); 4 (2), 1 (3). The frequency of the last mentioned grouping formed about 62% of the total cases showing the maximum association of 6. So it would appear that this particular grouping namely 4 groups of 2 bivalents each and one group of 3 bivalents, represents the genuine maximum association. This would mean that the diploid set of 22 chromosomes of red seeded *Abrus precatorius* Linn. Consists of 5 types. Then the haploid genome may be represented as follows :—

A A A
B B
C C
D D
E E

Thus the original ancestor of the red seeded *Abrus* would probably have had a basic chromosome number of five in which case this plant could be regarded as a secondarily balanced allopolyploid.

GENETICAL CONSTITUTION OF THE RED SEEDED *ABRUS* *PRECATORIUS* LINN. ON THE BASIS OF CHROMOSOME MORPHOLOGY

It may now be considered whether the foregoing conclusion in regard to the genetical constitution of the red seeded *Abrus* is borne out by a study of the morphology of the somatic chromosomes. Although this plant like many other genera in this family is considered a normal diploid, critical observations on the somatic cytology of the plant seems to suggest that it should have had an allopolyploid origin. On the basis of the size of the chromosomes and the position of their attachment constrictions it has been pointed out at an earlier stage that the somatic chromosomes fall into 10 types, two groups of 5 each. The haploid chromosomes of the two groups may be represented as A, B, C, D and A₁ A₁, B₁, C₁, D₁ and E₁. Thus in the light of the study of the secondary association the haploid constitution of the red seeded *Abrus* may be represented as :

A A₁ A₁
B B₁
C C₁
D D₁
E E₁

Obviously the chromosome A₁ has become duplicated. It would appear therefore that this plant is a secondarily formed allotetraploid derived from an ancestor

whose haploid number is 5. Many cases of secondary polyploidy seem to be quite common in nature (*Pyrus* : Darlington & Moffett, 1930 ; *Dahlia mercku* : Lawrence, 1931A ; *Brassica napus* : Catcheside, 1934 ; *Oryza sativa* : Nandi, 1936).

The following explanation will serve to illustrate the probable manner in which the present day red seeded *Abrus* could have been phylogenetically derived. The original ancestor of this plant must have had a haploid set of 5 chromosomes which may be marked as A, B, C, D and E. It is likely that another plant might have originated from this by gene mutations or changes in the chromosome morphology such as translocation, inversion etc. This new species would then have a different set of haploid chromosomes which may be designated A_1 B_1 C_1 D_1 and E_1 . A natural cross between these two species would have proved to be sterile owing to lack of pairing of chromosomes. Such instances of lack of pairing have been recorded in *Nicotiana* crosses (Good-speed & Clausen, 1927) and in the cross between *Raphanus sativus* and *Brassica oleracea* (Karpechenko, 1927). In these cases in spite of the identity in the numbers of chromosomes, pairing failed to take place in the hybrids so much so that occasionally only one bivalent was organized. Evidently the chromosomes of the two parents must have differed in their morphology. When therefore the ancestral hybrid of the red seeded *Abrus* proved to be as sterile due to lack of pairing of the chromosomes of its parental species, it is not improbable that some viable aneuploid gametes arose through meiotic irregularities. It may also be reasonably supposed that union between gametes with 6 and 5 as their haploid chromosome numbers could have given rise to all chromosomed trisomic plant which became secondarily balanced by further doubling of the chromosomes. The result was an allotetraploid with 22 as $2n$ number.

So in the light of the cytological data pertaining to meiotic behaviour and analysis of the somatic chromosome complement it may be suggested that the red seeded *Abrus* is a secondarily balanced allotetraploid. The genetical constitution of the white seeded *Abrus* seems to be similar in essentials to that of the red seeded *Abrus* described above. A close observation of the idiogram analysis of the white plant (Fig. 57a) supports this inference. There is however one difference in detail and that is as has been pointed out earlier, one of the medium sized chromosomes (C_1) has undergone duplication whereas in the case of the red seeded *Abrus* it is the longest chromosome (A_1) that has become doubled. Moreover the chromosome of the white seeded *Abrus* are larger in size than those of the red seeded *Abrus* (Figs. 56 & 57). It may be therefore presumed that the basic chromosome number of the white seeded *Abrus* is also 5 although for want of sufficient number of meiotic metaphase plates this could not be confirmed through a study of the secondary association.

SYSTEMATIC POSITION AND PROBABLE ORIGIN OF THE GENUS
ABRUS IN *PAPILIONACEAE* ON THE BASIS OF CHROMOSOME
 NUMBER AND MORPHOLOGY

According to the important systems of classification now commonly in vogue, the genus *Abrus* has been placed in the tribe *Vicieae* of the sub-family *Papilionaceae* in the *Leguminosae*. The following table (14) contains the various genera included under *Vicieae* and *Phaseoleae* tribes according to the Flora of British India (Hooker, 1879), Die Naturlichen Pflanzenfamilien (Engler, 1891), and Chromosome Atlas of cultivated Plants (Darlington and Janaki Ammal, 1945), (Table 14). The chromosome numbers of these genera have also been entered against their respective names. These numbers have been taken chiefly from the Chromosome Atlas and also the chromosome lists of Caizer (1926 and 1930) and Tischler (1938).

TABLE—14

Classifi- cation Tribe	Hooker		Engler		Darlington & Janaki Ammal	
	Name of Genus	Chromo- some number (n)	Name of Genus	Chromo- some number (n)	Name of Genus	Chromo- some number (n)
1	2	3	4	5	6	7
<i>VICIEAE</i>						
	<i>Abrus</i>	11	<i>Abrus</i>	11	<i>Vicia</i>	5, 6, 7
	<i>Cicer</i>	7, 8	<i>Cicer</i>	7, 8	<i>Cicer</i>	7, 8
	<i>Vicia</i>	5, 6, 7	<i>Vicia</i>	5, 6, 7	<i>Lens</i>	7
	<i>Lathyrus</i>	7	<i>Lathyrus</i>	7	<i>Lathyrus</i>	7
			<i>Pisum</i>	7	<i>Pisum</i>	7

PHASEOLEAE

Amphicarpa	10	Glycine	10	Amphicarpa	10
Glycine	10	Erythrina	11	Glycine	10
Erythrina	11	Erythrina	12	Erythrina	11
„	21	Canavalia	11	„	21
Canavalia	11	Phaseolus	11	Canavalia	11
Dioclea	12	„	12	Dioclea	12
Phaseolus	11	Vigna	11,12	Phaseolus	11,12
„	12	Pachyrrhisus	11	Pachyrrhisus	11
Vigna	11	Clitoria	8	Clitoria	8
Pachyrrhisus	11	Dolichos	11	Dolichos	11,12
Clitoria	8	Cajanus	11	Atylosia	11
Dolichos	11,12	Rhynchosia	11	Cajanus	11
Atylosia	11			Rhynchosia	11
Cajanus	11			Abrus	11
Rhynchosia	11				

A perusal of the table 14 would reveal the appreciable disparity in the chromosome numbers between the tribes *Vicieae* and *Phaseoleae*. While the haploid numbers of *Vicieae* are various, those of *Phaseoleae* are more or less uniform. For example in *Vicieae* the genus *Vicia* itself shows three different numbers namely 5, 6, 7. *Lathyrus* also shows 7 while *Cicer* contains 7 and 8 as its haploid numbers. *Abrus* which has also found a place in this tribe stands quite aloof from the point of view of its chromosome number which is $n = 11$. On the other hand in the *Phaseoleae* tribe the variation in chromosome numbers is neither so much nor so wide. Thus of the nearly fifteen genera for which chromosome numbers are available about twelve genera show 11 or 12 as the haploid number. Genera like *Clitoria*, *Amphicarpa*, *Glycine* show different numbers which are 8, 10 and 10 respectively. The difference of one chromosome found in the majority of the genera of *Phaseoleae* showing 11 or 12 as their haploid numbers might have arisen either by deletion of one chromosome from a genome of 12 or by the duplication of one chromosome from a genome of 11. Recent work in the cytology of several species of *Phaseolus* (Krishnamurthi, 1947), (Ramamurthi, 1948) has indicated the evolutionary possibility. On the whole therefore 11 or 12 are the predominant numbers. From this stand point the position of *Abrus*

with $n = 11$ in the *Vicieae* according to the earlier systematists, becomes anomalous. It will be more in consonance with the principles of cytotaxonomy if this genus is included in the *Phaseoleae*. Darlington & Janaki Ammal (1935), Senn (1938) are also of the same opinion.

It may be interesting to record in this connection that Pepov (Senn, 1938) in the course of his discussion on the inter relationship between *Vicieae* and *Phaseoleae* has suggested an intermediate position for *Abrus* nearer to *Phaseoleae*. The present investigations morphological, physiological and cytological lend little support to this view.

The existence of co-relation between chromosome number and taxonomy of plants has been recognised by a number of earlier workers. Such a relationship has been found in the *Ranunculaceae* (Langlet, 1932); (Babcock, 1942). Anderson (1937) has also stressed the importance of this aspect and has pointed out that morphology and karyology are but facets of the same problem namely phylogenetic taxonomy. The separation of *Yucca* from *Liliaceae* and *Agave* from *Amaryllidaceae* and their inclusion in one family *Agavaceae* on the basis of their identical chromosome morphology are an illustration of this point (McKelvy and Sax, 1933). This fact is corroborated by Hutchinson (1934) from a purely morphological point of view. The researches of Whitaker (1934) and Matsuura and Suto (Anderson 1937) have already pointed out the necessity of recasting family relationship of plants utilising the facts of Morphology and Cytology.

As pointed out earlier the redetermination and confirmation of the haploid and diploid chromosome numbers of *Abrus Precatorius* Linn. as 11 and 22, go to substantiate the view that the *Abrus* genus may well be removed from the *Vicieae* and placed in the *Phaseoleae*. The elaborate work on the karyology by Tschechow and Kartaschowa (1932) has shown that there is a very high degree of uniformity in the morphology of the chromosomes amongst the different genera of the *Phaseoleae*. According to these authors the chromosomes in this tribe for the most part show only median constrictions. It is on the basis of the idiogram studies with special reference to attachment constrictions, that they have concluded that the inclusion of *Clitoria* with $n = 8$ in the *Phaseoleae* showing distinctive chromosomes, is not warranted. Although they have not touched on the cytology of *Abrus*, yet a comparison of the *Phaseoleae* chromosomes pictured by them and the chromosomes of the *Abrus* determined in this investigation reveals a close similarity between them. From this it may be safely said that just as from the point of view of chromosome number and morphology *Clitoria* is to be removed from the *Phaseoleae* and preferably put in the closely related

Vicieae, even so the genus *Abrus* is better placed in the *Phaseoleae*. Such a systematic position is justified by the anatomical structure and the germination behaviour of *Abrus*, for *Abrus* shows a tetrach xylem and epigeal germination which are the general characteristics of *Phaseoleae* whereas *Vicieae* are characterised by triarch xylem and hypogeal germination.

With the removal of the 8 chromosomed *Clitoria* (n) from the *Phaseoleae*, there remain the following haploid numbers namely 10 (*Amphicarpa*), (*Glycine*), 11 (*Abrus*; *Rhynchosia*; *Erythrina*; *Cajanus*; *Canavalia*; *Atylosia*, *Pachyrrhizus*; *Phaseolus*; *Vigna*), and 12 *Dolichos*; *Phaseolus*; *Vigna*; *Dioclea*). So far as is known there seems to have been done little work in this tribe on the determination of the basic chromosome number from secondary association studies. For the present therefore the basic number of *Abrus* determined as 5 may be tentatively presumed to be the basic number of the entire tribe. As pointed out earlier the diploid number 22 possessed by different genera could have come about by secondary polyploidy. A further duplication of 2 of the 22 chromosomes would result in 24 chromosomes also.

Although the present cytological data would indicate the derivation of the 24- chromosomed genera from 22- chromosomed genera, it would be too presumptuous at this stage to point out the probable starting point or points for a phylogenetic scheme of the entire tribe. Further cytological and cytogenetical studies may throw some light on this problem.

SPECIATION AND NOMENCLATURE

The present studies on the Morphology, Anatomy, Physiology and Cytology of *Abrus precatorius* Linn. red seeded and *Abrus Precatorius* Linn. white seeded, reveal the existence of a very wide diversity between these two plants which are usually considered as varieties of the same species, *precatorius*. The differences between these plants have been observed and recorded in such characters as shape, size and weight of the seeds, size of the leaves and leaf-lets and stomatal indices, time of flowering, anatomical structures, germination behaviour irritability response and chromosome morphology.

An exhaustive catalogue of these differences has already been given in the previous chapters. But it will facilitate a better appreciation of the patent differences between the two plants if a general recapitulation of the previous observations is made. In the first place *Abrus Precatorius* Linn. red seeded is invariably characterised by tetrach xylem while *Abrus Precatorius* Linn. white seeded shows a tetrach or pentarch xylem quite commonly. The seed coat of these

plants also are so much different in structure that their permeability also varies. It has been seen that the strong impermeability of the red seed could be overcome with strong corrosives such as concentrated Sulphuric acid and Osmic acid, whereas the seed coat of the white *Abrus* did not offer any serious difficulty in this respect. Again the irritability response of the two plants to the influence of light of different wave lengths have been found to be at variance. The existence of a kind of nocturnal-diurnal relationship between the two plants has already been pointed out.

From the cytological point of view, distinct variations have been found between the red and white seeded *Abrus* plants. Although the number of chromosomes is the same in both the plants, yet there is difference in the morphology of the chromosomes. A reference to the idiograms of the red seeded *Abrus* (Fig 56-a) and white seeded *Abrus* (Fig. 57-a) would indicate the difference in their chromosome morphology. While in the red seeded *Abrus*, the longest (A_1) chromosome is represented four times, in the white seeded *Abrus* one of the medium sized chromosomes (third in the order of length B_1) is present four times. Another difference is that there is seen one pair of chromosomes with sub-terminal constriction in the red seeded *Abrus* while the chromosomes of the white seeded *Abrus* show median constrictions. Thirdly the size of the chromosomes of the red *Abrus* is smaller than those of the white seeded *Abrus*. The differences enumerated so far seem to be appreciable enough to be considered as of specific value.

The principle of failure to inter-breed and hybrid-sterility, as a basis of species distinction is also applicable in this case. Of course no natural crosses were observed between the red and white seeded *Abrus* plants although these were planted side by side and allowed to grow inter-twining one another. Further more almost all attempts made so far at bringing about artificial hybridisation have proved practically a failure. In one case only there was produced after crossing with white seeded *Abrus* as the female parent, small pod containing only one seed. The seed was inviable and did not germinate. The reciprocal cross with red seeded *Abrus* as the female did not succeed. The non-crossability between these two plants is presumably due to the lack of identity in the morphology of the chromosomes.

Of the two plants the red seeded *Abrus* seems to have drawn the attention of the authors of the Floras. No doubt the occurrence of what is being regarded as the white seeded variety of *Abrus* is also mentioned in all the Floras. Prominence has always been given to the scarlet seed wherever *Abrus Precatorius* is described. The popular designation of *Abrus Precatorius* as the goldsmith's

weighing bead, the crab's eye vine, weather plant (Bailey, 1914), Indian liquorice, rosary bead, love bean (Kirtikar and Basu, 1918), usually refers to the red seeded plant. According to the description by different authors, the red seeded plant is distributed widely throughout the tropical parts of the world. So this appears to be an ancient plant. Although no definite statistical data are available the white seeded *Abrus* seems to be less common than the red. Further, the white seeded plant is generally of a weaker constitution than the red seeded one. Field experiments wherein a large mixed population was raised, have shown that in the long run the red seeded plants flourish better and live longer without much care and attention than the white seeded ones. The whites have always been found less successful in competition with the reds. These facts namely weaker constitution and low pigmentation of the seed coat seem to suggest the possibility of the derivation of the white seeded plant from the red seeded one by some sort of gene mutation.

Such gene mutations not involving any change in the number of chromosomes have been recorded in some of the common pulses. Dixit (1932) has noted the appearance of a giant mutant of *Cicer arietinum*. He has suggested that, although the mutant possesses the same number of chromosomes $2n = 22$, this deserves the status of a new species as *Cicer gigas* since it shows many giant characters.

In the majority of mutational changes the mutants have been often found to be of a weak nature and are heterozygous for the character represented by the changed gene which is usually recessive. Lack of pigmentation resulting in albinism is often a common type of mutation in the animal kingdom. Even so the low degree of pigmentation of the Malpighian layer of the seed coat in the white seeded *Abrus* could have presumably come about by the mutation of a gene or a set of genes responsible originally for red colour.

Let us suppose R represents the gene determining the red pigmentation of the testa. Then the genetic constitution of the red seeded *Abrus* from the point of view of this gene would be R. R. The new plant with mutated gene will have the genetic constitution R r where r is the recessive gene controlling the low degree of pigmentation and will be apparently red seeded. It may be that in the course of evolution fertilisation between two such heterozygous forms has brought about a recombination of the recessive genes (r r). This would have resulted in the true breeding white seeded *Abrus* such as we have now.

A very important evidence which seems to lend support to the suggested derivation of the white seeded *Abrus* from the red seeded one, is the occasional

occurrence of simple leaves, in the red seeded *Abrus* immediately following the appearance of the cotyledons and preceding the formation of the usual pinnately compound leaves. It is common knowledge that ontogenetical studies of leaves have indicated that simple leaves have always preceded the compound leaves in the course of evolution and are therefore considered more primitive than the latter. This shows that the red seeded *Abrus* occasionally retains its relatively primitive character.

On the whole, two points stand out clearly from the foregoing discussion. 1. The white seeded plant is a probable derivative from the red seeded one. 2. It shows so many distinctive characters in contrast with those of the red that it may be raised to the level of a species. Recent researches in experimental taxonomy which includes breeding tests, cytological examination, physiological and ecological observations have tended to stress the necessity of assigning species rank even to those plants which, for all intents and purposes appear otherwise morphologically indistinguishable. Although, therefore, the red and white seeded *Abrus* plants have been hitherto considered varieties of the same species, *Precatorius* obviously on the basis of superficial observations, the present studies from various angles would have us believe that their distinctiveness is of specific magnitude.

NOMENCLATURE

From the descriptions given in the different systematic treatises a wide divergence of opinion seems to be extant in regard to the actual name of the *Abrus* plants. Senn (1938) has named the red seeded *Abrus* as *Abrus precatorius* var. *rubra* and the white seeded *Abrus* as *Abrus precatorius* var. *alba*. Dr. Biswas, Superintendent of the Indian Botanic Garden, Calcutta, has been kind enough to give the information that even as early as 1845, Voigt has recognised the red and white seeded individuals of *Abrus* which he has called *A. precatorius* var. *erythrospermus*, (red) and *A. Precatorius* var. *leucospermus* (white). Dr. E. Salisbury, Director of the Royal Botanic Garden, Kew, England, has also kindly informed that no earlier account of *Abrus* is available. According to the International Rules and Regulations of Botanical Nomenclature (Camp, Rickett and Weatherby, 1948) Article 52, "when a species is divided into two or more species, the specific epithet must be retained for one of them." In pursuance of this principle it is suggested that the red seeded *Abrus* may as usual be referred to as *Abrus precatorius* Linn. In the case of white seeded *Abrus* the feasibility of raising the varietal name, *leucospermus* already given by Voigt, to a higher taxonomical category may be considered. Then the white seeded *Abrus* may be called as *Abrus leucospermus* sp. nov.

SUMMARY

Detailed studies on the Morphology, Anatomy, Germination, Physiology of leaf movements and Ecology of *Abrus precatorius* Linn. red seeded and white seeded have been made in previous chapters.

Microsporogenesis of red seeded *Abrus* has been worked out. The meiotic and somatic chromosome numbers of both the plants have been found to be $n = 11$ and $2n = 22$.

Secondary association has been observed in the metaphase stage during meiosis and the maximum association has been found to be 6.

On the basis of maximum association the basic chromosome number and the genetical constitution of the red seeded *Abrus* have been determined for the first time. From studies of the somatic chromosome morphology and meiotic behavior, the possibility of the red seeded *Abrus* having been phylogenetically derived as a secondarily balanced allotetraploid has been suggested.

The evolutionary possibility of the white seeded *Abrus* having arisen as a mutant form from the red seeded *Abrus* has also been suggested on a cytotaxonomical basis.

Taking a synthetic view of the distinctive characters of these two plants pertaining to morphology, anatomy, physiology and cytology, the suggestion is made that they may belong to two species.

In the light of these investigations the assigning of a specific appellation, to the white seeded plant as *Abrus leucospermus* has been submitted for consideration.

ACKNOWLEDGEMENTS

It is a source of immense pleasure to record my grateful thanks to Dr. K. Rangaswami Ayyangar, M. Sc., Ph. D., F. B. S., Reader in Botany under whose valuable direction and technical guidance these investigations were carried out. I acknowledge my indebtedness to him also for having initiated me in this field of research on *Abrus* and his helpful criticisms and unfailing encouragement throughout the course of this work.

My thanks are also due to Dr. T. C. N. Singh, M. Sc., D. Sc., Head of the Department of Botany for his useful suggestions and providing me necessary facilities for doing this research.

EXPLANATION OF PLATES

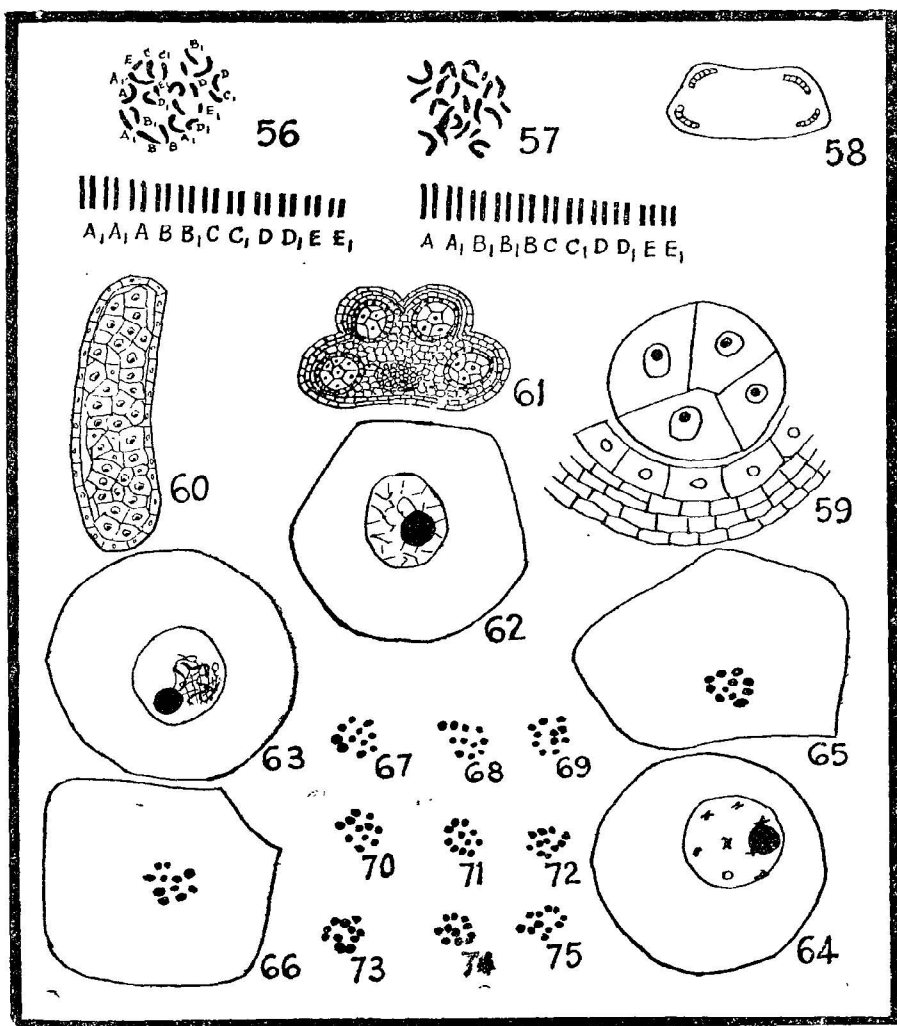
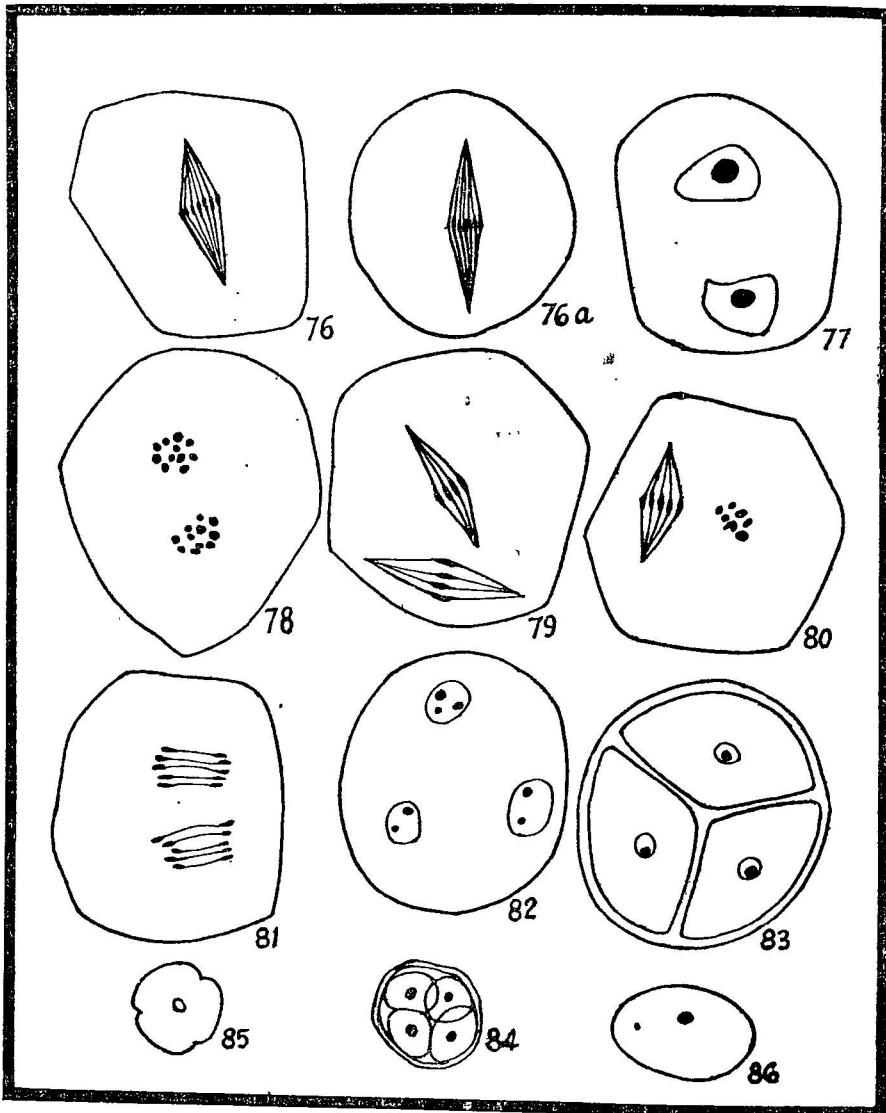


PLATE - I

- Fig. 56. Somatic chromosome of the red seeded *Abrus precatorius* Linn. Metaphase, polar view showing 22 chromosomes. X 4200.
- Fig. 56a. Idiogram analysis of somatic chromosomes of the red seeded *Abrus precatorius* Linn.
- Fig. 57. Somatic chromosomes of the white seeded *Abrus precatorius* Linn. Metaphase, polar view showing 22 chromosomes. X 4200.
- Fig. 57a. Idiogram analysis of the somatic chromosomes of the white seeded *Abrus precatorius* Linn.
- Fig. 58. Transverse section of the anther of the red seeded *Abrus* showing the primary archesporium. X 700.
- Fig. 59. Portion of the transverse section of the anther of the red seeded *Abrus* showing pollen mother cells and the uninucleate tapetum. X 1100.
- Fig. 60. Longitudinal section of the anther of the red *Abrus* showing the pollen mother cells. X 700.

- Fig. 61. Transverse section of the red seeded *Abrus* X 700.
 Fig. 62. A pollen mother cell in the resting condition. X 4200.
 Fig. 63. Synzetic stage of the pollen mother cell. X 4200.
 Fig. 64. Diakinesis. Note two bivalents are attached to the nucleolus. X 4200.
 Fig. 65. Meiosis. I Metaphase of the red seeded *Abrus precatorius* Linn. showing 11 bivalents in polar view. X 4200.
 Fig. 66. Meiosis. I Metaphase of the white seeded *Abrus precatorius* Linn. showing the 11 bivalents in the polar view. X 4200.
 Figs. 66-75. Meiosis. I Metaphase plates of the red seeded *Abrus* showing the various types of secondary association. X 4200.



- Fig. 76. Meiosis. I Metaphase of the red *Abrus*, side view. X 4200.
- Fig. 76a. Meiosis. I Metaphase of the white *Abrus*, side view. X 4200.
- Fig. 77. Diad nuclei of the red *Abrus*. X 4200.
- Fig. 78. Metaphase II of the red *Abrus*. Both the metaphase plates show polar view. X 4200.
- Fig. 79. Metaphase II of the red *Abrus*. Both the metaphase plates show the side view. X 4200.
- Fig. 80. Metaphase II of the red *Abrus*. One plate shows polar view while the other shows side view. X 4200.
- Fig. 81. Anaphase II of the red *Abrus*. X 4200.
- Fig. 82. Triad of the red *Abrus*. X 4200.
- Fig. 83. Tetrad of the red *Abrus* in the tetrahedral position. X 4200.
- Fig. 84. Tetrad of the red *Abrus* in the isobilateral position. X 700.
- Fig. 85. Polar view of the pollen grain of the red *Abrus*. X 1700.
- Fig. 86. Pollen grain of the red seeded *Abrus*. X 1700.

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ON THE EFFECT OF SOUND-WAVES ON THE RESPIRATION OF GERMINATING SEEDS OF GREEN GRAM (2)

By T. C. N. SINGH & K. H. NAGARATHNA,
Department of Botany, Annamalai University, Annamalainagar.

INTRODUCTION

Singh (1) through his experiments by exciting germinating seeds of Black-Gram (*Phaseolus mungo* L. var. *radiatus*) (3) with the aid of electric bell for half-an-hour, has already proved that the respiration values of these, as contrasted and compared with those of the control not excited by sound, are definitely higher. The data of these results on statistical analyses were found to be highly significant at both 5% and 1% levels by the 't'-test of Fisher. These experiments were conducted on WARBURG Respiration Apparatus (Georgii Kobold) Model V 8 purchased out of the munificent grant of the University Grants Commission of the Government of India, to whom our thanks are due in an eminent measure.

The results so far obtained have proved beyond doubt that the metabolic activity of plants is affected by the excitation of sound. It was, therefore, naturally felt expedient to examine these findings critically by conducting similar experiments on respiration with a very closely related cousin of Black-Gram, namely the Green-Gram (*Phaseolus mungo* L. = *P. max* L.) (3).

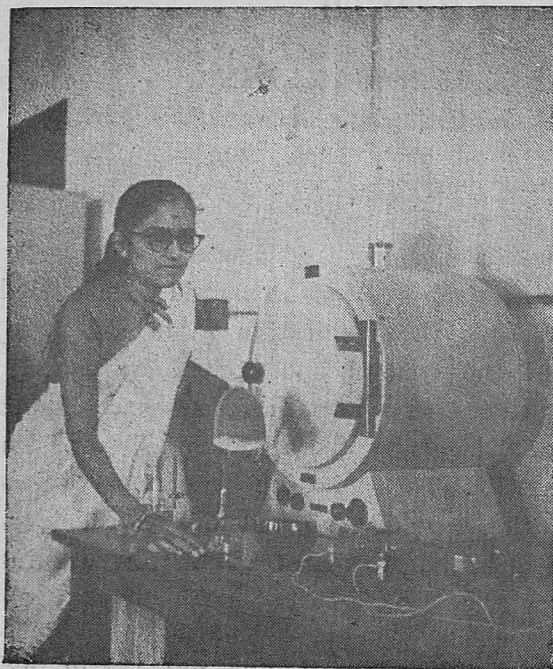
MATERIAL & METHOD

Green-Gram (*Phaseolus mungo* L. = *P. max* L.) is commonly grown in South India as a catch-crop in fields after the harvest of paddy. The seed coat is of light, dull, green colour.

To start with, seeds were critically selected by means of magnifying glasses and also with the aid of a binocular stereo-microscope; and care was taken to ensure that the seeds were of the same size and shape and that they were free from diseases and pests.

Seeds so selected were soaked in water at 11 A. M. in the forenoon in two separate petri-dishes and they were kept away in a cupboard for germination. On the following morning at 7 A. M. the germinated seeds in petri-dishes, were

examined and gently rinsed thrice with water. Out of these, one of them was exposed to the excitation of sound-waves emitted from an electrically run Cenco (U. S. A.) tuning-fork of 92 frequency for a continuous period of precisely half-an-hour. In



PHOTOGRAPH No. 1

PHOTOGRAPH No. 1, may be seen the exact method of the excitation of germinating seeds. Note the electrically run Cenco (U. S. A.) tuning-fork in operation on the right side on the table. The germinating seeds of Green-Gram (*Phaseolus mungo* L.) under excitation is contained in a petri-dish on the table being pointed by the touch of the hand on the left.

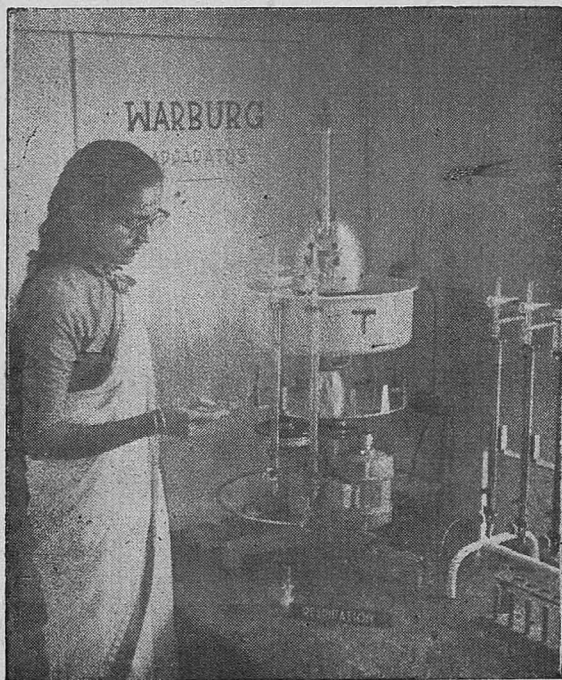
The other petri-dish with its germinating Green-Gram seeds was kept away in another room of the laboratory not disturbed by sound. Subsequently, both the petri-dishes were then brought in the laboratory, fitted with the WARBURG Respiration Apparatus.

Equal number of very well germinated seeds, was selected out from each of the petri-dishes and they were kept separately in another set of two petri-dishes respectively. Thereafter, the volume of each was separately determined by the displacement of water in a measuring cylinder. And in each case this volume was maintained at precisely 0.8 c.c. The seeds so measured were then placed in two separate reaction conical-flasks. They were then moistened by introducing 4 drops of water in each ; and later $N/2$ Caustic Potash solution was then filled three-quarters in the central well of the conical reaction-flask. Thereafter, these conical reaction-flasks were attached by means of metal springs to the manometers each provided with double column tubes of Brodie Solution. These manometers were then mounted on the brackets of the WARBURG Respiration Apparatus with the conical reaction-flasks dipping in the circular water-tank.

So done, the WARBURG Respiration Apparatus after adjusting the thermometer, was switched on and allowed to run for a few minutes. Thereafter, the double

columns of Brodie Solution in each manometer was equalised and set at the starting point marked with a red dot; and subsequently, the stop-cocks of the conical reaction-flasks and the manometers were finally closed to seal them off from the outside atmospheric communication and the WARBURG Respiration Apparatus was switched on again to rock to and fro, for a period of half-an-hour, after the expiry of which the manometric readings of the columns of Brodie Solution were recorded (PHOTOGRAPH No. 2). The temperature of the conical reaction-flasks was maintained at a constant temperature of 30°C .

PHOTOGRAPH No. 2 shows the WARBURG Respiration Apparatus mounted with a pair of manometers each fitted with a conical reaction-flask dipping in the water-tank (T) for maintenance of constant temperature at 30°C during the course of operation of the apparatus. The manometer on the left has the conical reaction-flask containing non-excited germinating seeds of Green-Gram; while that on the right the manometer has the conical reaction-flask containing musically sound excited germinating seeds of Green-Gram. In this pair of manometers, may be clearly seen the comparative rise of the Brodie Solution. The manometer on the right exhibits a greater rise of the Brodie Solution than the one on the left.



PHOTOGRAPH No. 2

OBSERVATIONS

As already pointed out, WARBURG apparatus operated for 30 minutes; and the oxygen absorbed during the process of respiration is recorded by noting the readings of the levels of Brodie Solution in both the columns of the manometers. A total of 25 experiments were done specially in the fore-noons with the aid of WARBURG Respiration Apparatus. The final values of the control and experimental sets of these experiments have been tabulated and statistically calculated for critically checking the significances of the differences which have been found between the two.

No.	Control	Experimental	d	d ²
1	2.4	4.8	2.4	5.76
2	2.7	4.1	1.4	1.96
3	9.3	16.8	7.5	56.25
4	11.2	13.8	2.6	6.76
5	3.6	4.4	0.8	0.64
6	11.0	16.0	5.0	25.00
7	4.6	9.0	4.4	19.36
8	4.1	8.1	4.0	16.00
9	3.8	7.0	3.2	10.24
10	4.4	8.3	3.9	15.21
11	5.3	10.1	4.8	23.04
12	5.1	7.2	2.1	4.41
13	4.9	7.7	2.8	7.84
14	7.6	10.1	2.5	6.25
15	4.3	7.4	3.1	9.61
16	4.9	8.2	3.3	10.89
17	4.5	6.3	1.8	3.24
18	4.4	6.2	1.8	3.24
19	3.1	4.3	1.2	1.44
20	2.6	5.0	2.4	5.76
21	5.7	7.8	2.1	4.41
22	6.7	8.3	1.6	2.56
23	6.0	7.8	1.8	3.24
24	4.2	5.9	1.7	2.89
25	0.9	1.3	0.4	0.16
TOTAL: 25	127.3	195.9	68.6	246.16

Mean : 5.092 7.836

Observed Mean Difference = 2.744.

$$\sigma^2 = 10.257 - 7.843 = 2.414$$

Therefore $\sigma = \sqrt{2.414}$
 = 1.553

$$\text{Standard Error (S. E.)} = \frac{\sigma}{\sqrt{n}} = \frac{1.553}{5} = 0.3106$$

$$\text{Critical Difference} = t \times \text{S. E.}$$

$$\text{Critical Difference at 5\% level} = 2.064 \times 0.3106 = 0.6410784$$

$$\text{Critical Difference at 1\% level} = 2.797 \times 0.3106 = 0.8687482$$

$$\text{Observed Mean Difference} = 2.744.$$

The values of critical differences at both the 5% and 1% levels are much lower than the observed mean difference of the Respiration values, therefore the result is significant in favour of the experimental observations.

DISCUSSION OF RESULTS

At this stage, it will be pertinent to make a critical comparative study of the results of the *respiration values* obtained for Black-Gram (*Phaseolus mungo* L. var. *radiatus*) (1), with results obtained in the present investigation for Green-Gram (*Phaseolus mungo* L.). The results in respect of each of them have therefore been tabulated in TABLE I.

TABLE I

a	b	c	d	e
Respiration values	Black-Gram	Green-Gram	Difference between b & c	Percentage difference in favour of b
Mean of control	10.68	5.092	+ 5.598	+ 109%
Mean of Experimental	15.25	7.836	+ 7.42	+ 95%
Observed Mean difference	4.56	2.744	+ 2.41	+ 66%

From a critical comparative study of the aforesaid TABLE I, it is abundantly clear that the respiration values of the Black-Gram (*Phaseolus mungo* L. var. *radiatus*) when compared with those of the Green-Gram (*Phaseolus mungo* L.) whether of the control set or of the experimental set, are definitely higher respectively to the extent of 109% in the control and 95% in the experimental; and the value of the Observed Mean Difference is also like-wise higher by 66%. Thus, therefore, it is obvious that there is specificity of respiration in each of the varieties of *Phaseolus*,

Considered from the view point of musically sound excitation of the germinating seeds, it must be stressed that all the conditions in respect of plant material and also those of the operation of the WARBURG RESPIRATION APPARATUS, were kept rigorously constant. The only variable factor was, namely that the experimental lot of germinating seeds was excited for half-an-hour by the musical humming sound of the Cenco Tuning-Fork, whereas the control set of germinating seeds was not excited with any sound whatsoever.

It is thus clear from a perusal of the results presented in the foregoing pages that in Green-Gram (*Phaseolus mungo* L.) the respiration values of the experimental sets were decidedly higher to a maximum of 100% with a minimum of 22% over those of the control; and these values when checked by the statistical analyses of 't' test of Fisher, have been found to be highly significant at both the 5% and 1% levels of significances. Thus the present observations fully confirm the previous findings of Singh (1) in respect of Black-Gram (*Phaseolus mungo* L. var. *radiatus*) where also similar results had been obtained (TABLE I) by the musical excitation of germinating seeds.

In conclusion it may, therefore, be opined beyond doubt that the respiration values of germinating seeds of Black-Gram and Green-Gram do get enhanced when excited by musical humming sound of the tuning-fork.

SUMMARY

Experiments were conducted on the respiration of germinating seeds of Green-Gram to investigate the effect of sound-waves through the use of WARBURG RESPIRATION APPARATUS (Georgii Kobold) Model V-8.

Selected healthy seeds of Green-Gram which had been soaked in water for 20 hours and had started germinating, were excited by directing the sound waves emitted from an electrically run Cenco (U. S. A.) tuning fork (of 92 frequency) continuously for a period of thirty minutes. Another similar set of germinating seeds was maintained as control not excited by sound.

The respiration values of the germinating seeds of both the sets were determined simultaneously by WARBURG RESPIRATION APPARATUS through a run period of half-an-hour at constant temperature of 30°C. As a result, it has been observed that the respiration values of excited germinating seeds were undoubtedly rendered much higher than those of the control not excited by sound, the maximum enhanced value attained being 100%.

The results of these investigations were even subjected to statistical analyses. The differences observed in favour of the experimental germinating seeds, were found in confirmation to be statistically significant at both 5% and 1% levels by the 't'—test of Fisher.

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SCIENTIFIC AND TAMIL NAMES OF THE ESTUARINE AND MARINE FISHES OF PORTO NOVO

By J. JACOB,

(*Marine Biological Station, Porto Novo*)

A comprehensive knowledge of the organisms available in the vicinity of a biological research laboratory is one of the essential requirements for successful planning and execution of long-range research programmes. With this in view, systematic collections have been and are in progress at the Marine Biological Station, Porto Novo (lat. $11^{\circ}29'$ N and long. $79^{\circ}47'$ E). This paper is a record of the fishes obtained from the Vellar estuary and the adjoining sea and is the first one in a series planned, on the fauna of this area.

The hydrological characteristics of this estuary, especially the salinity and temperature conditions, described before, (vide, Jacob and Rangarajan 1959a) make it possible for various marine organisms to enter the estuary and stay there for varying lengths of time. Further, some organisms are capable of tolerating a wide range of salinity (or are euryhaline) and consequently are at home in neritic waters of the coastal or littoral area, brackish waters in the lower reaches of the estuary and even the fresh waters in the upper reaches of the estuary. These can therefore pass from the sea to the other environments mentioned and vice versa and on account of these considerations it has not been thought desirable to draw a sharp line of distinction between the estuarine and marine fishes in the present account. Again, it would be beyond the scope of this paper to state the abundance or otherwise of the various species, their breeding seasons, economic importance etc., etc.

The classical works of Day (1878, 1889) are even to-day the standard references to students of Indian ichthyology. But numerous additions to the fish fauna of India, have been made during the last 70-80 years and such publications as the present one, may be expected to be helpful for a new compilation of the "Fishes of India". Further, many scientific names in Day's publications have been changed owing to subsequent researches by systematists and the International rules of nomenclature and this has resulted in a good lot of confusion. In the present list therefore, the latest scientific names are given and to help correlation the older names in Day (1878) are also cited. Besides these, the common names (English and local Tamil) are also provided as far as possible and these, it is hoped, will make this publication useful both to the scientist and the layman. The modern system of classification of fishes, i.e., that of Berg (1940) is adopted up to the family and the genera and species are arranged alphabetically.

THE SYSTEMATIC LIST.

class ELASMOBRANCHII

(cartilaginous fishes)

Subclass SELACHII

(sharks and rays)

Order LAMNIFORMES (SHARKS)

Family ORECTOLOBIDAE

Chiloscyllium indicum (Gmel)

குரங்கு சுரா

= Day : — do —

Ridge-back cat Shark

Stegostoma varium (Seba)

குரங்கு சுரா, கொமராசி சுரா

= Day : *Stegostoma tigrinum*

Zebra Shark

Suborder SCYLORHINOIDEI

Family CARCHARHINIDAE

Carcharhinus sorrah (Mull and Henl)

மடவை சுரா

= Day : *Carcharias sorrah*

Dog Shark

Galeocerda cuvieri (Le Sueur)

குரங்கு சுரா

= Day : *G. tigrinus* or *rayneri*

Tiger Shark

Hemigaleus balfouri Day

= Day : — do —

Balfour's shark

Scoliodon palasorrah (Cuvier)

பால் சுரா

= Day : *Carcharias acutus*

Grey dog Shark

Scoliodon walbeehmi Blkr= Day : *Carcharias walbeehmi*

Walbeehmi's sharp nosed shark

Family SPHYRNIDAE

Sphyrna zygaena (Linn)

கொம்பன் சுரா

= Day : *Zygaena malleus*

Hammer head Shark

Order RAJIFORMES

Family RHINOBATIDAE (SHOVEL
NOSE SHARKS)

Rhinobatos granulatus Cuv
= Day : *Rhinobatus granulatus*

படங்கான்
Granulated shovel nose ray

Rhinobatos obtuses (Mull and Henl)
= Day : *Rhinobatus halavi*

படங்கான் ; பரா

Rhynchobatus djiddensis (Forsk)
= Day : *R. djeddensis*

கச்சு உளுவை
White spotted shovel nose ray

Family TRYGONIDAE (STING
RAYS)

Amphotistius zugei (Mull and Henl)
= Day : *Trygon zugei*

மணத் திருக்கை
Pale edged Sting ray

Gymnura micrura (Schn)
= Day : *Ceratoptera ehrenbergii*

ஓட்டுத் திருக்கை
Short tailed butterfly ray

Gymnura poecilura (Shaw)
= Day : *Pteroplatea micrura*

Long tailed butterfly ray

Family MYLIOBATIDAE (EAGLE
RAYS)

Aetobatus narinari (Euph)
= Day : *Aetobatis narinari*

Spotted eagle ray

Aetomyaleus maculatus (Gray)
= Day : *Myliobatis maculata*

குருவி திருக்கை; பாஞ்சால் திருக்கை
Mottled eagle ray

Aetomyaleus nichofii (Schn)
= *Myliobatis nieuhofii*

குருவி திருக்கை; பாஞ்சால் திருக்கை
Nieuhof's eagle ray

Order TORPEDINIFORMES
(ELECTRIC RAYS)

Family TORPEDINIDAE

Narcine timlei (Schn)
= Day : — do. —

புள்ளித் திமிலை
Spotted electric ray

Narke dipterygia (Sehn)
= Day : *Astrape dipterygia*

திமிலை
Numbfish

Class TELEOSTOMI (BONY FISHES)
Subclass ACTINOPTERYGII

Order CLUPEIFORMES

Suborder CLUPEOIDEI

Superfamily ELOPOIDAE

Family ELOPIDAE

Elops saurus Linn
= Day : — do. —

ஆல்லாத்தி
Giant herring

Family MEGALOPIDAE

Megalops cyprinoides (Brouss)
= Day : — do. —

மெரக்கை ; மோராங் கெண்டை
Ox-eye herring

Superfamily CLUPEOIDAE

Family CLUPEIDAE (SPRATS,
SARDINES AND HERRINGS)

Subfamily DUSSUMIERIINI

Dussumieria acuta Val
= Day : — do. —

மொத கெண்டை
Rainbow sardine, common sprat

Superfamily CLUPEINI

Euplatygaster indica (Swain)
= Day : *Pellona indica*

தெரக்குத்துவா
Indian Shad

<i>Ilisha elongata</i> (Benn) = Day : <i>Pellona elongata</i>	கவைக்குத்துவா Slender shad, Indian herring
<i>Ilisha filigera</i> (Val) = Day : <i>Pellona filigera</i>	குத்துவா Indian herring, Jewelled shad
<i>Ilisha motius</i> (Ham) = Day : <i>Pellona motius</i>	தெரக்குத்துவா Indian herring
<i>Kowala coval</i> (Cuv) = Day : <i>Clupea lile</i>	சூடை White sardine
<i>Macrura kelee</i> (Cuv) = Day : <i>Clupea kanagurta</i>	சூடை Five spot herring
<i>Opisthopterus tardoore</i> (Cuv) = Day : <i>O. tartoor</i>	தளரி Long finned herring
<i>Sardinella albelli</i> (Val) = Day : <i>Clupea brachysoma</i>	சூடை Short bodied sardine
<i>Sardinella fimbriata</i> (Val) = Day : <i>Clupea fimbriata</i> (Part)	சூடை ; நொண்ணை The Indian Sprat, Fringe Scale Sardine
<i>Sardinella sindensis</i> (Day) = Day : <i>Clupea sindensis</i>	கவலை
<i>Tenuulosa sinensis</i> (Linn) = Day : <i>Clupea toli</i>	உள்ளம் Chinese herring

Subfamily DOROSOMATINI

<i>Anodontostoma chacunda</i> (Ham-Buch) = Day : <i>Chatoessus chacunda</i>	பொய்க் கெண்டை Gizzard shad
<i>Gonialosa modestus</i> (Day) = Day : <i>Chatoessus modestus</i>	
<i>Nematalosa nasus</i> (Bloch) = Day : <i>Chatoessus nasus</i>	பொய்க் கெண்டை Long ray bony breem

Family ENGRAULIDAE
(ANCHOVIES)

Anchoiella baganensis (Hard)
= Day : Not recorded

நெத்திவி ; தேராங்கண்ணி
White bait

Anchoiella bataviensis (Hard)
= Day : Not recorded

நெத்திவி ; தேராங்கண்ணி
White bait

Anchoiella commersonii (Lacep)
= Day : *Engraulis commersonianus*

நெத்திவி ; தேராங்கண்ணி
White bait, Commerson's anchovy

Anchoiella indica (V. Hass)
= Day : *Engraulis indicus*

நெத்திவி ; தேராங்கண்ணி
White bait, Indian Anchovy

Anchoiella tri (Blkr)
= Day : *Engraulis tri*

நெத்திவி ; தேராங்கண்ணி
White bait

(The large sized Anchovies are called usually தேராங்கண்ணி and the smaller ones நெத்திவி)

Coilia reynaldi Val
= Day : — do. —

Setipinna taty (Val)
= Day : *Engraulis taty*

பொருவா
Hair fin anchovy

Thrissocles malabarica (Bloch)
= Day : *Engraulis malabaricus*

அடுப்பு ஊதிபொருவா
Malabar anchovy

Thrissocles mystax (Schn)
= Day : *Engraulis mystax*

ஆத்துப் பொருவா
Mustached anchovy

Thrissocles setirostris (Brouss)
= Day : *Engraulis setirostris*

பொருவா
Long jaw anchovy

Suborder CHIROCENTROIDEI

Family CHIROCENTRIDAE

Chirocentrus dorab (Forsk)
= Day : — do, —

முள்ளு வாளை
Wolf herring

Suborder CHANOIDEI

Family CHANIDAE

Chanos chanos (Forsk)= Day : *Chanos salmoneus*

பால் கெண்டை

Milk fish, Salmon-herring

Order SCOPELIFORMES

Family SYNODIDAE

Harpodon nehereus (Ham)

= Day : — do. —

வங்க ராக

Bombay duck

Saurida tumbil (Bloch)

= Day : — do. —

தும்பிளி

Lizard fish

Order CYPRINIFORMES

Division SILURI

Suborder SILUROIDEI

Superfamily SILUROIDAE

Family ARIIDAE (ESTUARINE
CAT FISHES)*Arius nenga* (Ham-Buch)*

= Day : — do. —

கெளுத்தி

Arius parvipinnis (Day)*

= Day : — do. —

கெளுத்தி

Arius tenuispinis Day *

= Day : — do. —

கெளுத்தி

Osteogeneiosus militaris (Linn)

= Day : — do. —

பொரிக் கெளுத்தி

The bony whiskered or Soldier,
cat fish*Pseudarius jella* (Day)= Day : *Arius jella*

வெள்ளைக் கெளுத்தி

White cat fish

* Latest name uncertain.

Tachysurus maculatus (Thun)

= Day : *Arius falcarius*

Spotted cat fish

Family PLOTOSIDAE (CAT FISH EELS)

Plotosus anguillaris (Bloch)

= Day : *P. arab*

ஆக் கெளுத்தி
Striped cat fish eel

Plotosus canius Ham-Buch

= Day : — do. —

ஆக் கெளுத்தி
Canine cat fish eel

Family BAGRIDAE (RIVER CAT FISH)

Macrones gulio (Ham-Buch)

= Day : *Mystus gulio*

கெளுத்தி
Long whiskers cat fish

Order ANGUILLIFORMES

Suborder ANGUILLOIDEI

Family ANGUILLIDAE (FRESH WATER EELS)

Anguilla nebulosa nebulosa McClell

= Day : *A. bengalensis*

சேனா மீன்
Long finned eel

Family MURAENIDAE

Thrysoidea macrura (Blkr)

= Day : *Muraena micrura*

சேனா மீன்
Giant moray eel

Family MURAENESOCIDAE (FALSE CONGER EELS)

Muraenesox cinereus (Forsk)

= Day : — do. —

குளிரி
Silver conger eel

Muraenesox telabonoides (Blkr)

= Day : — do. —

கருங் குளிரி
Golden yellow conger eel

Family CONGRIDAE (TRUE CONGER EELS)

Uroconger lepturus (Rich)

= Day : — do. —

கடல் அனைக்குத்தி
Slender conger eel

Family ECHELIDAE (WORM EELS)

Muraenichthys vermiformis (Peters)

= Day: — do. —

Short finned worm eel

Family OPHICHTHYIDAE
(SNAKE EELS)*Ophichthys microcephalus* * Day

= Day: — do. —

Small headed snake eel

Pisoodonophis boro (Ham-Buch)= Day: *Ophichthys boro*அணைக்குத்திப் பாம்பு
Burrowing snake eel

Order BELONIFORMES

Suborder SCOMBERESOCOIDEI

Family BELONIDE (GAR FISHES)

Tylosurus strongylurus (V. Hass)

= Day: Not recorded

ஊசிக் கோலா ; கட்டைக் கோலா
Round tail alligator gar

Suborder EXOCOETOIDEI

Family HEMIRHAMPHIDAE
(HALF BEAKS)*Hyporhamphus gaimardi* (Val)= Day: *Hemirhamphus limbatus*மொட்டக் கோலா
Gaimard's half beak*Hyporhamphus xanthopterus* (Val)= Day: *Hemirhamphus*
*xanthopterus*மொட்டக் கோலா
Red tipped half beak

Family EXOCOETIDAE

Cypselurus poecilopterus (Val)= Day: *Exocoetus poecilopterus*பறவைக் கோலா
Flying fish

Order SYNGNATHIFORMES

Suborder AULOSTOMOIDEI

* Latest name uncertain,

Superfamily AULOSTOMOIDAE

Family FISTULARIIDAE
(TRUMPET FISHES)*Fistularia villosa* Klunz= Day : *F. serrata*

Flute mouth

Superfamily CENTRISCOIDAE

Family CENTRISCIDAE

Centriscus scutatus Linn= Day : *Amphisile scutata*

Razor fish

Suborder SYNGNATHOIDEI

Family SYNGNATHIDAE (PIPE
FISHES, SEA HORSES)*Hippocampus kuda* (Blkr)= Day : *H. guttulatus*

கடற் குதிரை

Sea horse

Syngnathoides biaculeatus (Bloch)= Day : *Gastrotokeus biaculeatus*

கல் பரம்பு ; கல் மீன்

Two barbel pipe fish

Trachyrhamphus intermedius (Kaup)= Day : *Syngnathus intermedius*

கல் பரம்பு ; கல் மீன்

Trachyrhamphus serratus (Schl)= Day : *Syngnathus serratus*

கல் பரம்பு ; கல் மீன்

Crested pipe fish

Order CYPRINODONTIFORMES

Suborder CYPRINODONTOIDEI

Superfamily CYPRINODONTOIDAE

Family CYPRINODONTIDAE

Panchax melastigma McClell= Day : *Haplochilus melastigma*

Estuarine top minnow

Panchax panchax blochii Arnold)= Day : *Haplochilus panchax*

Black spot top minnow

Order BERYCIFORMES

Family HOLOCENTRIDAE

Holocentrus rubrum= Day : *Holocentrum rubrum*

Red soldier fish

Order MUGILIFORMES

Suborder SPHYRAENOIDEI

Family SPHYRAENIDAE

(SEA PIKES, BARRACUDAS)

Sphyraena obtusata Cuv

= Day : — do. —

ஊளா

Blunt jawed sea pike

Sphyraena picuda Bloch

= Day : not recorded

ஊளா

Suborder MUGILOIDEI

Family MUGILIDAE (GREY
MULLETS)*Liza dussumieri* (Val)= Day : *Mugil dussumieri*

மடவை

Dussumier's mullet

Liza macrolepis (Smith)= Day : *Mugil troschellii* ?

உஸ்துளஞ்சாளா

Borneo mullet

Liza waigiensis (Quoy and Gaim)= Day : *Mugil waigiensis*

நரிக் கெண்டை

Diamond scale mullet

Mugil amarulus (Val)

= Day : — do. —

மடவை

Mugil cephalus Linn

= Day : Not recorded

மடவை ; மடவைக் கெண்டை

Grey mullet

Mugil speigleri (Blkr)

= Day : — do. —

மடவை

Order POLYNEMIFORMES

Family POLYNEMIDAE (THREAD
FINS, TASSEL FISHES)

Eleutheronema tetradactylum (Shaw)
= Day : *Polynemus tetradactylus*

எரைக் காலா
Four thread tassel fish

Polynemus indicus Shaw
= Day : — do. —

வாலங் காலா
Indian tassel fish

Polynemus plebius (Brouss)
= Day : — do. —

கட்டிக் காலா

Polynemus sextarius Bloch
= Day : — do. —

கட்டிக் காலா
Six thread tassel fish

Order PERCIFORMES

Suborder PERCOIDEI

Superfamily PERCOIDAE

Family CENTROPOMIDAE

Ambassis commersoni Cuv
= Day : — do. —

செலந்தான்
Glassy perchlet

Ambassis dayi Blkr
= Day : — do. —

கொடுவா செலந்தான்
Glassy perchlet

Ambassis gymnocephalus (Lacep)
= Day : — do. —

செலந்தான்
Naked head glassy perchlet

Lates calcarifer (Bloch)
= Day : — do. —

கொடுவா
Giant sea perch

Family SERRANIDAE (SEA
PERCHES, ROCK CODS)

Enneacentrus miniatus (Forsk)
= Day : *Serranus miniatus*

பன்னாக் கத்தளை
Vermilion coral cod

Enneacentrus sonnerati (Val)
= Day : *Serranus sonnerati*

பன்னாக் கத்தளை
Red coral cod

Epinephelus bleekeri (Vaill & Bocou)

= Day : *Serranus waandersi* or
Coromandelicus ?

பண்ணிச் சாத்தான்

Bleeker's reef cod

Epinephelus fario (Thun)

= Day : *Serranus maculatus* ?

பண்ணிச் சாத்தான்

Trout reef cod

Epinephelus tauvina (Forsk)

= Day : *Serranus salmoides* ?

பண்ணிச் சாத்தான்

Greasy reef cod

Family THERAPONIDAE (SQUEEING PERCHES)

Autisthes puta (Cuv)

= Day : *Therapon puta*

மஞ்சள் கீச்சான் ;

கோவைக் கீச்சான்

Therapon jarbua (Forsk)

= Day : — do. —

மட்டக் கீச்சான் or கட்டக் கீச்சான்

Crescent Squeeking perch

Family PRIACANTHIDE (BULLS EYES)

Priacanthus tayenus Rich

= Day : *P. holocentrum* ?

Spot finned bulls eye

Family APOGONIDAE (CARDINAL FISHES)

Apogon aureus (Lacep)

= Day : — do. —

முண்டக் கண்

Golden cardinal fish

Apogon septemstriatus Gunth

= Day : Not recorded

முண்டக் கண்

Seven banded cardinal fish

Family SILLAGINIDAE

Sillago sihama (Forsk)

= Day : — do. —

கிழங்கான்

Silver whiting

Family LACTARIIDAE

Lactarius lactarius (Schn)

= Day : *L. delicatulus*

சுதும்பு

Big jawed jumper, white fish

Family RACHYCENTRIDAE

Rachycentron canadus (Linn)= Day : *Elacate nigra*

கடவரா

Black king fish

Family CARANGIDAE (HORSE
MACKERELS, TREVALLY)*Alectis indica* (Rupp)= Day : *Caranx gallus*

தோக் காரை

Indian thread finned trevally

Atropus atropus (Bloch)= Day : *Caranx atropus*

வரிக் காரை

Carangoides armatus (Forsk)= Day : *Caranx armatus*

கொண்டிப் பாரை

Armed trevally

Carangoides malabaricus (Bloch)= Day : *Caranx malabaricus*

மட்டப் பாரை

Malabar trevally

Caranx sexfasciatus Quoy and Gaim= Day : *C. hippos*

உருட்டாம் பாரை

Six banded trevally

Chorinemus lysan (Forsk)

= Day : — do. —

தோப் பாரை

Leather skin, leather jacket

Chorinemus tol Cuv= Day : *C. moadetta*

தேளப் பாரை

Slender Queen fish

Decapterus russelli (Rupp)= Day : *Caranx kurra*

காணங் கழுதைப் பாரை

Gnathodon speciosus (Forsk)= Day : *Caranx speciosus*

வரிப் பாரை

Golden toothless trevally

Megalaspis cordyla (Linn)= Day : *Caranx rotleri*

Torpedo trevally

Selar kalla (Cuv)= Day : *Caranx kalla*

சூப்பனங் காரை

Golden scad

Selar mate (Cuv)= Day : *Caranx affinis*

மஞ்சள் பாரை

One finlet scad

Selaroides leptolepis (Cuv)= Day : *Caranx leptolepis*

ராமப் பாரை

Slender scaled scad

*Seriolichthys bipinnulatus**
(Quoy and Gaim)
= Day : — do. —

Family MENEIDAE (MOON FISH)

Mene maculata (Bloch) தம்பட்டங் காரை

Family CORYPHAENIDAE

Coryphaena hippurus (Linn) பரளா
= Day : — do. — Dolphin fish

Family LUTIANIDAE (SNAPPERS,
SEA PERCHES)

Lutianus johnei (Bloch) செப்பிலிச்சை
= Day : *L. johnii* Moses perch

Lutianus kasmira (Forsk) செப்பிலிச்சை
= Day : *L. bengalensis* ? Blue and yellow snapper

Lutianus sanguineus (Cuv) செப்பிலிச்சை
= Day : *L. erythropterus* Blood red snapper

Lutianus waigiensis (Quoy and Gaim) செப்பிலிச்சை
= Day : *L. marginatus* Waigeu snapper

Family NEMIPTERIDAE (THREAD
FIN BREEM, PINK PERCHES)

Nemipterus bleekeri (Day) துள்ளுக் கெண்டை
= Day : *Synagris bleekeri* Bleeker's threadfin bream

Nemipterus japonicus (Bloch) துள்ளுக் கெண்டை
= Day : *Synagris japonicus* Japanese threadfin bream

Synagris striatus * (Day)
Day : — do. — துள்ளுக் கெண்டை

Family CAESIODIDAE¹ (FUSILIERS)

Caesio caerulaureus (Lacep) Blue and gold fusilier
= Day : Not recorded.

* Latest name uncertain

1, Not found in Berg (1940)

Family LOBOTIDAE
(TRIPLE TAILS)

Lobotes surinamensis (Bloch)
= Day : — do. —

முச்சு
Brown triple tail

Family LIOGNATHIDAE (PONY
FISHES, SILVER BELLIES)

Gazza minuta (Bloch)
= Day : — do. —

Toothed pony fish

Gerres oyena (Forsk)
= Day : — do. —

Lined silver biddy

Gerreomorpha setifer (Ham-Buch)
= Day : *Gerres setifer*

ஊட்டாங்கண்ணி
Black tipped silver biddy

Leiognathus brevirostris (Val)
= Day : *Equula blochii*

முள்ளூக் காரை
Short nosed pony fish

Leiognathus bindus (Val)
= Day : *Equula bindus*

Orange finned pony fish

Leiognathus equulus (Forsk)
= Day : *Equula edentula*

முள்ளூக் காரை
Greater pony fish

Leiognathus fasciatus (Lacep)
= Day : *Equula fasciata*

முள்ளூக் காரை
Banded pony fish

Pentaprion longimanus (Cant)
= Day : — do. —

Long finned silver biddy

Pertica filamentosa (Cuv)
= Day : *Gerres filamentosa*

ஊட்டான்
Long rayed silver biddy

Secutor insidiator (Bloch)
= Day : *Equula insidiatrix*

காரை
Slender barred pony fish

Secutor ruconius (Ham-Buch)
= Day : *Equula ruconius*

காரை
Deep bodied pony fish

Family POMADASYIDE (GRUN-
TERS AND SWEETLIPS)

Gaterin cinctus (Schl)

= Day : *Diagramma cinctum*

Three banded sweet lip

Gaterin diagrammus (Linn)

= Day : *Diagramma lineatum* ?

Silver banded sweet lip

Pomadasys maculatus (Bloch)

= Day : *Pristipoma maculatum*

கொர்க்கான்

Spotted grunter

Pseudopristipoma nigra (Cuv)

= Day : *Diagramma crassispinum*

Black sweet lip

Family SCIAENIDAE (THE DRUMS,
JEW FISHES)

Johnius axillaris (Cuv)

= Day : *Sciaena axillaris*

கருங்கத்தளை

Black spot jew fish

Johnius belengeri (Cuv)

= Day : *Sciaena belengeri*

காசிக் கத்தளை

Johnius diacanthus (Lacep)

= Day : *Sciaena diacanthus*

கருங்கத்தளை

Two spined jew fish

Johnius dussumieri (Cuv)

= Day : *Sciaena glaucus*

கருங்கத்தளை

Dussumier's silver jew fish

Johnius maculatus Schn

= Day : *Sciaena maculata*

முண்டக்கண் கத்தளை

Black banded jew fish

Otolithus argenteus Cuv

= Day : — do. —

Silver banded jew fish

Sciaena dussumieri (Val)

= Day : *Umbrina dussumieri*

Dussumier's jew fish

Sciaena macropterus (Blkr)

= Day : *Umbrina macroptera*

சப்பைக் கத்தளை

Sciaena russellii (Cuv)

= Day : *Umbrina russellii*

கத்தளை

Russel's jew fish

Family LETHRINIDAE
(SEA BREAMS)

Lethrinella miniata (Schn)

= Day : *Lethrinus rostratus*

Long nosed pig face bream

Monotaxis grandoculis (Forsk)

= Day : *Sphaerodon heterodon*

Large eyed pig faced bream

Family SPARIDAE (SEA BREAMS,
SILVER BREAMS)

Argyrops spinifer (Forsk)

= Day : *Pagrus spinifer*

Long spined red bream

Acanthopagrus latus Houtt

= Day : *Chrysophrys datnia*

சங்கரா

Japanese silver bream

Family MULLIDAE (RED
MULLETS, GOAT FISHES)

Mulloidichthys auriflamma (Forsk)

= Day : *Mulloides flavolineatus*

சென்னுவரை

Golden banded goat fish

Upeneus sulphureus Cuv

= Day : *Upeneoides sulphureus*

சென்னுவரை

Yellow goat fish

Upeneus vittatus (Forsk)

= Day : *Upeneoides vittatus*

சென்னுவரை

Yellow striped goat fish

Family PSETTIDAE

Monodactylus argenteus (Linn)

= Day : *Psettus argenteus*

Silver bat fish

Family CYPHOSIDAE
(DRUMMERS)

Kyphosus cinerascens (Forsk)

= Day : *Pimelepterus cinerascens*

கொழக்கெண்டை

Ashen drummer

Family EPHIPPIDAE

Ephippus orbis (Bloch)

= Day : — do. —

பீநாறி

Spade fish

Platax orbicularis (Forsk)
= Day : *Platax vespertilio* ?

Round bat fish

Platax teira (Forsk)
= Day : — do. —

சடை வெளவால்
Long finned bat fish

Family DREPANIDAE

Drepane punctata (Linn)
= Day : — do. —

தெரட்டை
Spotted bat fish or Sickle fish

Family SCATOPHAGIDAE

Scatophagus argus (Linn)
= Day : — do. —

பிளிஞ்சான் ; பிளிச்சை
Spotted butter fish

Family CHAETODONTIDAE

Heniochus acuminatus (Linn)
= Day : *H. macrolepidotus*

நிழலாடி
Pennant coral fish

Family CICHLIDAE

Tilapia mossambica (Peters) *
= Day : Not recorded

Tilapia

Eetroplus maculatus (Bloch)
= Day : — do. —

செல்லாத காகு
Spotted etroplus

Eetroplus suratensis (Bloch)
= Day : — do. —

செத்தக் கெண்டை
Banded etroplus

Superfamily CEPOLOIDAE

Family CEPOLIDAE

Cepola abbreviata Val †
= Day : — do. —

தோகை
Band fish

Superfamily LABROIDAE

* Exotic fish, recently introduced into this estuary.

Family SCARIDAE (PARROT
FISHES)

Callyodon dussumieri (Val)

= Day : Not recorded ?

கோழி மீன்

Dussumier's parrot fish

Family OPISTHOGNATHIDAE

Opisthognathus rosenbergii Blkr †

= Day : — do. —

Superfamily URANOSCOPOIDAE

Family URANOSCOPIDAE (STAR
GAZERS)

Uranoscopus guttatus Cuv †

= Day : — do. —

தும்பி

Ichthyoscopus lebeck (Bloch)

= Day : *I. Inermis*

நெலக்கொர்க்கை

Suborder SIGANOIDEI

Family SIGANIDAE (SPINE FEET)

Siganus javus (Linn)

= Day : *Teuthis java*

ஓரா

Streaked spine foot

Siganus oramin (Bloch and Schn)

= Day : *Teuthis oramin*

ஓரா

White spotted spine foot

Siganus spinus (Linn)

= Day : *Teuthis marmorata*

ஓரா

Marbled spine foot

Siganus vermiculatus (Val)

= Day : *Teuthis vermiculata*

ஓரா

Vermiculated spine foot

Suborder ACANTHUROIDEI

Family ACANTHURIDAE
(SURGEON FISHES)

Acanthurus matoides Val

= Day : — do. —

கோழி மீன்

White tailed surgeon fish

† Latest name uncertain

Suborder TRICHIUROIDEI

Family TRICHIURIDAE
(RIBBON FISHES)

Trichiurus haumela (Forsk)
= Day : --- do. —

வாளை ; சாவாளை ; கார்த்திகை
Large headed ribbon fish [வாளை

Trichiurus muticus (Gray)
= Day : — do. —

வாளை ; சாவாளை ;
கார்த்திகை வாளை

Trichiurus savala Cuv
= Day : — do. —

வாளை ; சாவாளை ; கார்த்திகை
Small headed ribbon fish [வாளை
(Smaller ones are usually called
சாவாளை and larger ones கார்த்திகை
வாளை)

Suborder SCOMBROIDEI

Superfamily SCOMBROIDAE

Family SCOMBRIDAE
(MACKERELS)

Rastrelliger kanagurta (Cuv)
= Day : *Scomber microlepidotus*

காணங்கெழுத்தி ; காணங்கழுதை
Rake gilled mackerel

Family CYBIIDAE (SPANISH
MACKERELS)

Cybius commersoni (Lacep)
= Day : — do. —

வஞ்சனம் ; வஞ்சரம்
Barred spanish mackerel

Indocybim guttatum (Bloch and Schn)
= Day : *Cybius guttatum*

வஞ்சனம் ; வஞ்சரம்
Spotted spanish mackerel

Superfamily XIPHIODAE

Family HISTIOPHORIDAE (SAIL
FISH, MARLIN)

Histiophorus gladius (Brouss)
= Day : *Istiophorus gladius*

மயில் மீன்
Indian sail fish

Suborder STROMATEOIDEI

Family STROMATEIDAE
(POMFRETS)

Pampus argenteus (Euph)
= Day : *Stromateus cinereus*

வெள்ளை வெளவால்
Silver pomfret

Pampus chinensis (Euph)
= Day : *Stromateus sinensis*

வெள்ளை வெளவால்
Chinese pomfret

Parastromateus niger (Bloch)
= Day : *Stromateus niger*

கருப்பு வெளவால்
Brown pomfret

Suborder ANABANTOIDEI

Family ANABANTIDAE (CLIMB-
ING PERCH, BUBBLE NEST
BUILDER)

Anabas testudineus (Bloch)
= Day : *A. scandens*

பனையேரிக் கெண்டை
Climbing perch

Trichogaster fasciatus (Bloch and
Schn) †
= Day : — do. —

Bubble nest builder

Suborder KURTOIDEI

Family KURTIDAE (HUMP HEADS)

Kurtus indicus Bloch
= Day : — do. —

Indian hump head

Suborder GOBIOIDEI

Superfamily ELEOTRIOIDAE

Family ELEOTRIDAE (GUDGEONS)

Eleotris fusca (Schn)
= Day : — do. —

உளுவை
Brown gudgeon

Butis butis (Ham-Buch)
= Day : *Eleotris amboinensis* ?

உளுவை
Flat headed gudgeon

† Latest name uncertain.

Prionobutis koilomatodon (Blkr)

= Day : *Eleotris caperata*

உளுவை

Saw toothed gudgeon

Superfamily GOBIOIDAE

Family GOBIIDAE (GOBIES)

(உளுவை)

Acentrogobius masoni (Day)

= Day : *Gobius masoni*

உளுவை

Mason's goby

Acentrogobius neilli Day

= Day : *Gobius neilli*

Acentrogobius ornatus (Rupp)

= Day : *Gobius ornatus*

Ornate goby

Acentrogobius viridipunctatus

= Day : *Gobius viridipunctatus*

Green spotted goby

Apocryptes bleekeri (Day) †

= Day : — do. —

Apocryptes rictuosus (Val) †

= Day : — do. —

Pseudapocryptes lanceolatus (Bloch
and Schn)

= Day : *Apocryptes lanceolatus*

Pointed tailed goby

Callogobius seshaiyai Jacob and
Rangarajan *

Glossogobius biocellatus (Val)

= Day : *Gobius biocellatus*

Two spot goby

Glossogobius giuris (Ham-Buch)

= Day : *Gobius giuris*

Bar eyed goby

Gobioides anguillaris (Linn) †

= Day : — do. —

† Latest name uncertain.

* Discovered recently in Vellar estuary, (vide Jacob and Rangarajan 1960)

Gobioides buchanani (Day) †

= Day : — do. —

Gobioides caeculus (Bloch and Schn)†

= Day : — do. —

Gobioides cirratus (Blyth) †

= Day : — do. —

Gobius cyanomos (Blkr) †

= Day : — do. —

Gobius polynema (Blkr) †

= Day : — do. —

Oligolepis acutipennis (Val)

= Day : *Gobius acutipinnis*

Pointed finned goby

Oxyurichthys microlepis (Blkr)

= Day : *Gobius cristatus*

Small scaled goby

Trypauchen vagina (Bloch and Schn)

= Day : — do. —

Burrowing goby

Family PERIOPHTHALMIDAE

(MUD SKIPPERS)

Boleophthalmus boddarti (Pallas)

= Day : — do. —

வேட்டி ; கழுதைக்குறத்தி

Suborder COTTOIDEI

Superfamily SCORPAENOIDAE

Family SCORPAENIDAE

(SCORPION FISHES, FIRE
FISHES)

Dendrochirus zebra (Quoy and Gaim)

= Day : *Pterois zebra*

தும்பி

Zebra fire fish

Pterois russelli Benn

= Day : — do. —

தும்பி

Russell's fire fish

† Latest name uncertain.

Scorpaenodes guamensis (Quoy and Gaim)

= Day : *Scorpaenopsis guamensis*

கட்டைத் தும்பி

Scorpion fish, Guam stinging fish

Family SYNANCEIDAE

Minous monodactylus (Bloch and Schn)

= Day : — do. —

Grey goblin fish

Superfamily PLATYCEPHALOIDAE

Family PLATYCEPHALIDAE (FLAT HEADS)

Grammolites scaber (Linn)

= Day : *Platycephalus scaber*

வெட்டு உடுப்பாத்தி

Rough flat head

Suggrundus tuberculatus (Cuv)

= Day : *Platycephalus tuberculatus*

உடுப்பாத்தி

Knobby flat head

Order THUNNIFORMES

Family THUNNIDAE (MACKEREL TUNA)

Euthynnus affinis (Cant)

= Day : *Thynnus thunnina*

நெத்தச்சூரை

Tunny fish

Order PLEURONECTIFORMES

Suborder PSETTODIDEI

Family PSETTODIDAE

Psettodes erumei (Bloch)

= Day : — do. —

நாக்கு

Indian halibut

Suborder PLEURONECTOIDEI

Superfamily PLUERONECTOIDAE

Family BOTHIDAE (LEFT HAND FLOUNDERS)

Pseudorhombus arsius (Hum-Buch)

= Day : — do. —

நாக்கு

Large toothed flounder

Pseudorhombus triocellatus (Bloch)

= Day : — do. —

எருமை நாக்கு

Three spot flounder

Superfamily SOLEOIDAE

Family SOLEIDAE (நாக்கு)

Aesopia cornuta Kaup

= Day : *Synaptura cornuta*

Horned sole

Synaptura commersoni (Swain)

= Day : *S. commersoniana*

Commerson's sole

Zebrias quagga (Kaup)

= Day : *Synaptura zela*

Zebra sole

Family CYNOGLOSSIDAE (நாக்கு)

Cynoglossus semifasciatus Day *

= Day : — do. —

Malabar tongue sole

Paraplagusia bilineata (Bloch)

= Day : *Plagusia marmorata*

Two lined tongue sole

Order MASTACEMBELIFORMES

Family MASTACEMBELIDAE (SPINY EELS)

Macrognathus aculeatus (Bloch)

= Day : *Rhyncobdella aculeata*

ஆரால்

Order ECHENEIFORMES

Family ECHENEIDAE (SUCKER FISHES)

Echeneis naucrates Linn.

= Day : — do. —

உருட்டி

Slender sucker fish

Remora remora (Linn)

= Day : *Echeneis remora*

உருட்டி

Common remora

* Latest name uncertain.

Order TETRODONTIFORMES

Suborder BALISTOIDEI

Family TRIACANTHIDAE (THREE
SPINED FISHES, TRIPODS)*Triacanthus brevirostris* Schl

= Day : — do. —

Short nosed tripod fish

Family BALISTIDAE (FILE FISHES,
LEATHER JACKETS)*Alutera scripta* (Osborne)= Day : *Monacanthus scriptus*

நிழலாடி

Leather jacket

Balistes maculatus (Gmel) †

= Day : — do. —

நிழலாடி

Spotted file fish

Sufflamen capistratus (Shaw)= Day : *Balistes mitis*

முள்ளூரி

Masked file fish

Suborder OSTRACIOIDEI

Family OSTRACIIDAE (COW
FISHES, BOX FISHES)*Lactoria cornuta* (Linn)= Day : *Ostracion cornutus*

Long horned cow fish

Rhynchostracion nasus (Bloch)= Day : *Ostracion nasus*

Small nosed box fish

Tetrosomus gibbosus (Linn)= Day : *Ostracion turratus*

Thorn backed box fish

Suborder TETRODONTOIDEI

Family TETRODONTIDAE
(PUFFERS, BLOW FISHES,
GLOBE FISHES)*Arothron leopardus* (Day)= Day : *Tetrodon leopardus*

பெலாச்சி

Leopard puffer fish

† Latest name uncertain.

Arothron reticularis (Bloch)
= Day : *Tetrodon reticularis*

பெலாச்சி
Reticulated puffer fish

Gastrophysus lunaris (Bloch)
= Day : Not recorded

சித்திரப் பெலாச்சி
Rough backed blow fish

Family DIODONTIDAE
(PORCUPINE FISHES)

Diodon hystrix Linn
= Day : — do. —

முள்ளுப் பெலாச்சி
Spotted porcupine fish

Order LOPHIIFORMES

Suborder ANTENNARIOIDEI

Superfamily ANTENNARIOIDAE

Family ANTENNARIDAE (FROG
FISHES)

Antennarius hispidus (Bloch)
= Day : — do. —

Shaggy fishing frog

Antennarius leprosus Eyd and Soul
= Day : Not recorded

Ocellated fishing frog

DISCUSSION

In popular connotation the word “fish” most often means any animal living in water. This usage is very unscientific and inaccurate as it includes such diverse organisms as jelly fish (Phylum: Coelenterata), star fishes (Phylum: Echinodermata), Squids and cuttle fishes (Phylum: Mollusca) and even whales (Phylum: Vertebrata, Class: Mammalia), besides the true fishes (Phylum: Vertebrata, Class: Pisces). Again, vernacular or common names of fishes are based largely on appearance, colour, habit etc. and layman's (artificial) classification is non-indicative of such aspects as systematic position, genetic relationships or evolutionary trends.

Many of the common names refer to whole families or genera and in some cases even to widely differing taxonomic categories. A typical instance noted is the name “uluvai”, which denotes any of the three species of Eleotridae or the

nineteen species of Gobiids occurring locally. And curiously enough, the shark *Rhynchobatus djiddensis* is also an "uluvai" being named "kachu uluvai". Similarly the common English name "white bait" is used in Europe to include young herrings, sprats, and even young gobies, blennies, sand eels etc. In India, this name is used to refer to some species of Engraulidae. With reference to the present study, some more examples may be given to illustrate the vague and loose use of common names. The name "Valai" is applied to various widely differing fishes; *Chirocentrus dorab* is locally "mulluvalai", whereas, in other Tamil speaking areas, the names used are "valai" and "tuppuvalai"; some species of *polynemus* are also referred to as "thiravalai" and "bettihiravalai" in certain parts of Madras State. Species of *Trichiurus* are "chavalai", "valai" or "karthigaivalai" locally and also "mattachavalai" and "olavalai" elsewhere. A species of *Lutianus* is in certain localities (not Porto Novo) called "karuvalai" and *Euthynnus affinis* known here as "rathachurai" is "keluvalai" in some other places. Another vernacular name which needs mention is "kendai". The various species of mullets (Mugilidae) are locally called "madavakendai", "madavai" and "narikendai". Such names as "cheluvakendai", "chirayakendai", "gejameenkendai", "Velisa", "avulimeen" are also used elsewhere to refer to the mullets. Further, *Megalops cyprinoides* is "morankendai"; *Etroplus suratensis* is "sethakendai"; *Nematalosa nasus* and *Anodontostoma chacunda* are "poikendai" and *Kyphosus cinerascens* is "Kozhakendai". In certain other Tamil regions *Nemipterus* spp. are also referred to as "thullukendai".

Many examples of such all-embracing or collective names could be given and besides these, numerous instances could be cited where the same fish is known by very many different names. Such loose usage makes it almost impossible to place any reliance on vernacular names. This is true of English as well. In Great Britain, for example, the sea trout (*Salmo trutta*) is known as "salmon trout", "bull trout", "orange fin", "black tail", "round tail", "phinock", "truff", "scurf" and so on. The collective use of the term "white bait" was mentioned earlier. As an instance of the extreme confusion caused locally by the common names, may be mentioned the fact that in certain fishes, the young specimens are known by a name different from that used for the adult. A good example is provided by the species of *Anchoviella*, whose smaller specimens are called "nethil" or "nethali" and the larger ones are "therankanni". It has also been observed that the same species of fish is referred to differently during different seasons and the *Trichiuridae* provide a typical example. It has also been observed locally that no common names exist for quite a few fishes and this is only to be expected as these are invariably the economically unimportant fishes or rare ones or otherwise uninteresting from the layman's point of view. It is

therefore needless to emphasize that scientific names cannot be ignored and in fact are absolutely essential for maintaining precision. About 20,000 species of fishes are known to exist and the confusion that would follow from lack of universally accepted scientific names can better be imagined. The scientific name of a species, as stated by Dr. Regan, is a "clue to all that is known or that has been recorded in literature about its structure, habits, economic importance or anything else; without the correct name, we are in the dark and the conclusions we arrive at may be founded on erroneous grounds". In the scientific system of classification, every species is referred to by two names, the generic and trivial, which are generally in Greek, Latinised Greek, Latin or Latin form. In this system of binominal nomenclature, first introduced by the Swedish naturalist Linnaeus in 1758, the generic names describe the character of the group indicating its systematic position, genetic affinity etc., and the trivial names are more descriptive. This system has been universally accepted and the International Commission on Nomenclature guides the work of systematists throughout the world. It will now be obvious why without scientific names no scientific progress could be achieved. Further, lack of scientific names will also restrict the scope of any international co-operation on biological problems such as fisheries etc.

The common names however, may have some pragmatic value, but in the final analysis, the scientific worker must be equipped to sort out the different kinds of fishes.

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