Synthetic Studies towards New Pigments

Being a thesis by

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Submitted for the degree of
Master of Philosophy
in the Faculty of Science of the
University of St Andrews

19th December 1997

Declaration

I, Alasdair Nathan Garnett, hereby certify that this thesis, which is approximately 26,000 words in length, has been written by me, that it is a record of work carried out by me and that it has not been submitted in any previous application for a higher degree.

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Acknowledgement

There are a number of people and organisations that I wish to give thanks to at this stage-first of all, to Ciba-Geigy, for the funding to conduct this work, and to Prof. Abul Iqbal for his good-humoured advice and guidance. To my friends in lab 408a, for their help and humour, and to the other people around the department who have helped me throughout this year. Finally, to Dr. Frank Riddell, for his enthusiasm, supervision and for his faith in me that I could do it at all.

ABSTRACT

Phthalate ester synthesis

An investigation into various methods of synthesising phthalate esters suitable as precursors for phthalocyanine and other pigment synthesis was conducted. This was achieved via thermal Diels-Alder reactions between 2-substituted furans and dimethyl acetylene-dicarboxylate (DMAD), proceeding in high yield. Subsequent aromatisation of the resulting adducts by either sulphuric acid or low-valence titanium also proceeded in good yields. The phenols generated by the acid aromatisation were further reacted in high yields with a range of haloalkanes to form the expected aryl ethers.

Latent pigment investigation

Work was also carried out on the synthesis of reversibly soluble "latent" DPP (1,4-diketo-pyrrolo[3,4-*c*]pyrrole) pigments. The aim was to synthesise a moiety that could be incorporated into a DPP pigment, increasing its solubility in various media. The solublised DPP pigment should then be treatable *in situ* to precipitate a considerably less soluble aromatic DPP pigment.

$$\mathbf{2X} \xrightarrow{(1)} \mathbf{X\text{-}DPP\text{-}X} \xrightarrow{(2)} \mathbf{Ar\text{-}DPP\text{-}Ar}$$

It was necessary for the moiety X to be stable to the DPP forming conditions (1), but once it was incorporated into the soluble DPP it had to be easily converted without significant degradation to produce the less soluble aromatic DPP pigment under reasonably mild conditions (2). A variety of methods and moieties were investigated, the main efforts concentrating on two areas: heterobicycloheptadiene

"norbornadiene" analogue containing groups, which could aromatise to phenyl-type groups under thermal conditions while extruding various gases, and upon both *cis* and *trans*-stilbenyl containing groups which could cyclise to planar phenanthryl groups under suitably oxidative photochemical conditions.

CONTENTS

1) INTRODUCTION

1.01 Light

The phenomenon which we call "light" consists of a fluctuating electric field coupled to an orthogonal magnetic field with the same frequency. This combination of an electric field and a magnetic field, which progresses in a vacuum at a speed of around 3.0×10^8 ms^{-1}, "the speed of light", is known as electromagnetic radiation.

These wave like motions have a frequency, the number of fluctuations that pass a particular point per second. The frequency of this radiation may vary from extremely low to extremely high, and is related to a property known as the wavelength of light, the distance between successive peaks, by the following equation:

$$c = \upsilon \lambda$$

where: c = speed of light, 3×10^8 ms^{-1}

υ = frequency of light in Hertz (Hz)

λ = wavelength of light in metres

Since c, the speed of light, as a constant remains at $3x10^8$ ms^{-1}, it can be seen that if the frequency of the light is increased, then the wavelength of that light must decrease. If the frequency of the light is decreased, then the wavelength must increase. A further property of light of a particular frequency is the energy associated with it. Light of lower frequencies (longer wavelengths) possesses lower energy than light of higher frequencies (shorter wavelengths). This energy is related to the frequency by the following equation:

$$\mathbf{E = h\upsilon}$$

where E = Energy of incident photon, in J
h = Planck constant, 6.626×10^{-34} Js
υ = Frequency of radiation in s^{-1}

The range of frequencies and corresponding wavelengths and energies is known as the electromagnetic spectrum. As stated previously, the frequency of light can vary over a large range, and the corresponding range in wavelengths varies from over one metre in the low energy long-wave radio region of the electromagnetic spectrum, to under 10^{-14}m in the high energy, short wavelength cosmic ray region.

The region of the spectrum this report is concerned with lies somewhere in the intermediate regions, in the range of wavelengths from 700 nm to 420 nm. These are the wavelengths of light that the human eye can respond to, in the region known as the visible spectrum the components of which are perceived to humans as colour.

1.02 Colour of light

The colours which we are able to perceive range in wavelength from around 400 nm for violet, the higher end of the visible spectrum, progressing gradually through blue, green, yellow and orange to around 700 nm for red, the lower energy region of the spectrum. The human eye, if confronted with a mixture of wavelengths, will register the most intense as being the dominant colour, with the wavelengths of lesser intensity providing hues to the main colour, and so giving an individual shade.

If an incandescent object emits light of a particular wavelength, then it will appear to be of a particular colour. If the temperature of the object increases, and thus the energy available to emit as light increases, the object will start to emit light of a higher energy (shorter wavelength), and the colour will change to one of shorter wavelength. The object will still, however, continue to emit considerable amounts of light of the longer wavelengths (lower energy) as well.

The light from the sun contains a mixture of all of the wavelengths that the human eye can detect, and this mixture, not having a dominant wavelength is perceived as being "white" light. The colours of which white light is composed may be viewed by the use of a prism, which splits a beam of white light into its constituent colours, from the longer wavelength red and orange to the shorter wavelength blue and violet.

1.03 Colour of objects

If an object reflects all light, i.e. it absorbs no incident light, it appears to be white. If it absorbs all incident light, then it appears to be black. If it absorbs some wavelengths, and reflects others, then it will appear to be of the particular colour that corresponds to the wavelength that is reflected most. For example, if the main wavelength reflected is of a value of 650 nm, the colour will be perceived to the human eye as red, with hues and undertones dependent on the other minor wavelengths reflected.

From a molecular point of view, the fundamental reason why a particular material is able to absorb or reflect light of different frequencies depends upon whether the incident light is of a frequency that corresponds to the energy required to promote an electron from a lone pair or bonding orbital to a non-bonding or anti-bonding orbital in the molecules of that material. If this occurs, then the light of that frequency is absorbed, and the electron is promoted to the higher level, to fall back later to the lower level. Normally the difference in energies between these levels is too high (in the UV region of the spectrum) for the absorbance to correspond to visible light. However, the presence of certain functional groups can lower the energy difference into the visible region. These groups are known as chromophores and auxochromes.

1.04 Chromophores and auxochromes

Chromophores are functional groups within a molecule that cause it to absorb electromagnetic radiation of a particular frequency. For the purposes of this report, these frequencies lie in the range of *ca:* 700nm to 400nm, the visible spectrum. The feature of chromophores that allows them to function in this way is usually the presence of unsaturation, of a multiple or π-bond between two atoms or more in the group. Examples of common chromophores are given below:

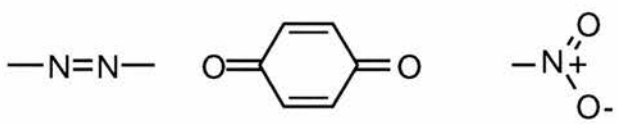

Fig 1.1 Azo, quinone and nitro groups.

An important way of modifying colour is to introduce extended π–bond conjugation into a molecule. Since, in a π-conjugated system, the energy difference between bonding and antibonding energy levels is reduced, it requires less energy, i.e. longer wavelengths, to promote the electrons into the higher state, and this can often bring the absorption into visible wavelengths. With further conjugation beyond two double bonds the separation of the energy levels is reduced still further, and so the wavelength of absorption is shifted even more to the longer wavelengths. Most compounds used as colouring agents have extensive conjugation.

The wavelength of maximum absorption and therefore the colour of the compound can be further modified by the presence of other functional groups called auxochromes. These groups cause further changes in the electronic transitions already available in the

chromophores and allow a much wider range of colours than would otherwise be available. They tend to have lone pairs of donatable electrons. Some common auxochromes are given below:

$R\text{-}NH_2$	Amines	Ar-OH	Phenols
-Cl or -Br	Halogens	R-O-R	Ethers

Fig. 1.2 Common auxochromes

A final method of altering the colour properties of a material is to alter the crystal structure of the solid. Many materials exist in a variety of crystalline forms, in which the molecules and atoms are aligned in a particular lattice structure. Since the wavelength of light that is absorbed depends to an extent on the particular crystal structure of the material on which it is incident, it is apparent that the wavelengths absorbed by the material in the solid state may be far removed from the wavelengths absorbed the material in solution. Hydrogen bonds, either intramolecular or intermolecular, are very important in this area, as they can promote particular crystal structures that allow particular colours to be reflected.

A major factor in colour chemistry is the understanding of how to modify the absorbance and reflective properties of materials by modifying the chromophores, the auxochromes and the crystalline structure of the compounds used as colouring agents. Much research has been conducted on two major fields of colour chemistry: those of dyes and pigments.

1.05 Dyes and pigments

The Shorter Oxford English dictionary defines a dye as: "A substance used for dyeing: *esp.* a colouring matter used in solution." A pigment is defined as: "Any substance used for colouring or painting: *spec.* a dry substance usually in the form of a powder, which when mixed with oil, water, etc., constitutes a paint." Although both dyes and pigments are coloured, there is a clear difference between them. This is that, in their application, their solubilities are different.

In the case of dyes the coloured material must be soluble during its application, for example, onto textiles. Pigments, however, are not soluble to any great extent during their application, for example in paints, rubber, inks and plastics.

A better chemical explanation is that "Whereas dyes react with material at a molecular level, pigments are generally macromolecular"[1]. Dyes tend to be much more intimately bound to the substrate molecules than pigments, which retain their own discrete particle structure, dispersed within the medium.

Dyes and pigments may originate from either natural or synthetic sources, and may contain both organic and inorganic components. They have been widely used since prehistoric times by people all over the world to decorate themselves, their homes and their belongings.

1.06 Historical sources of colour

For thousands of years humans have used what materials they could find around them in the environment to create and manipulate colour. Inorganic minerals containing metal oxides were used to decorate caves in prehistoric Europe, the dyes used to colour clothing throughout the world were produced from vegetable sources, in renaissance Europe the blues used by the great painters were produced from lapis lazuli, a rare mineral imported at great expense from what is now Afghanistan. More recently, the development in the nineteenth century of chemical methods of duplicating many old pigments, and producing new ones led to a great expansion in the range of colours available for people to exploit in their homes and in their art.

1.07 Nineteenth century colour developments

During the nineteenth century, as chemistry developed, science began to look at ways of developing better ways of producing colours using the new technology. Until then, pigments were derived from natural mineral sources and were subject to large variations in quality. An example is Iron(III) oxide, Fe_2O_3 "Red ochre", which varied from yellow to red due to physical and compositional differences. With the introduction of many new or improved pigments, such as Cobalt blue in 1800, French ultramarine (blue) in 1824, Veridian (green), and Chrome yellow in 1840, the consistency problems were solved. The main problem was that most of these pigments used inorganic metal salts for colour, and many of these were rather toxic, as well as being expensive. The search then turned to the rapidly expanding field of organic chemistry to supply readily available and inexpensive synthetic organic pigments that did not involve toxic or expensive metal ions.

1.08 Phthalocyanines

In the nineteen thirties a new class of pigments were developed at ICI (Imperial Chemical Industries) that contained much smaller quantities of metal ions. These were a class of N_4 macrocycles similar to the porphyrins called phthalocyanines[2]. They have a variety of desirable properties such as intense blue/green colours, usually very low solubilities, high colour fastness, high thermal stability and relative economy of manufacture from a variety of phthalate derivatives and metal salts.

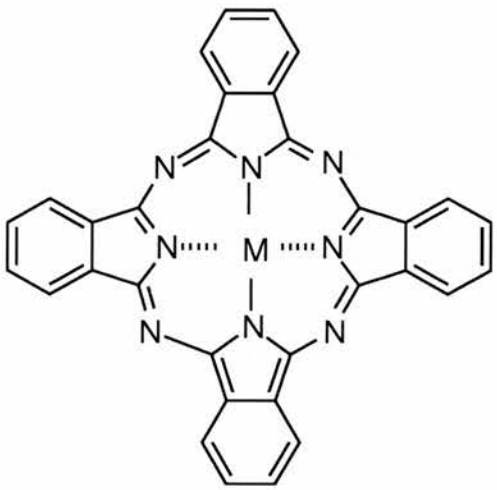

Fig. 1.3 Structure of a phthalocyanine.

A typical synthesis of phthalocyanine would involve a mixture of a suitable phthalic anhydride, copper(II) chloride and urea heated at 150-200°C in the presence of a suitable catalyst. Other metal ions may be used instead of copper, various auxochromes may be present, and with the addition of sulphonate groups around the aromatic rings the solubility of the phthalocyanine in polar solvents may be increased if desired.

1.09 Azo pigments

A class of entirely organic pigments developed in the last century are the azo pigments. These are typically red, orange or yellow pigments containing one chromophore (-N=N-) azo linkage which are produced by the diazotization of aromatic amines, followed by the coupling with an appropriate compound. In the case of monoazo pigments, coupling of the diazonium salt with β-naphthol gives a red pigment, the same diazonium salt with an acetoacetarylamide gives a class of pigments called "Hansa Yellows".

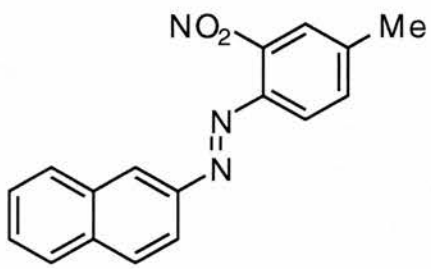

Fig. 1.4 Structure of a monoazo pigment.

A more recent development of these monoazo pigments are the diazo pigments. These are produced in a similar fashion to the monoazo pigments, however they contain two chromophore (-N=N-) azo linkages within the molecule. The colour range is similar to the monoazo pigments and can be altered by a variety of auxochromes. They have a higher molecular weight, and thus their colour fastness is better than the simpler and smaller monoazo pigments. Their thermal stability, and colour intensity are also good, though their light fastness can vary somewhat. It is also possible to produce triazo, tetrazo and polyazo pigments by a similar methodology.

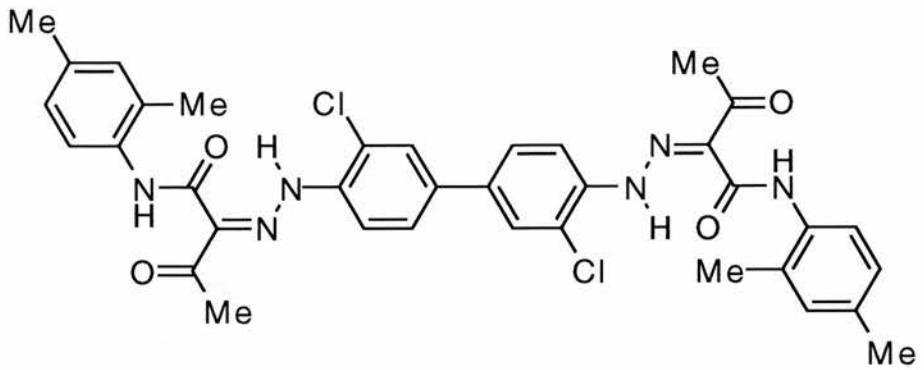

Fig. 1.5 Structure of a diazo pigment.

1.10 DPP pigments

A third class of modern pigments, again entirely organic, are the 3,6-diaryl-1,4-diketo-pyrrolo[3,4-*c*]pyrroles, otherwise known as DPPs[3]. These molecules were initially synthesised by accident in the mid 1970's, during research into the synthesis of 2-azetinones,[4] but their potential to be used as pigments was quickly realised and developed by Ciba-Geigy during the late seventies and early eighties and culminated with the release of diphenyl DPP, an intense scarlet high performance pigment, in the 1980s. Many other DPPs have been developed by Ciba-Geigy, by incorporating various other components onto the central DPP skeleton.

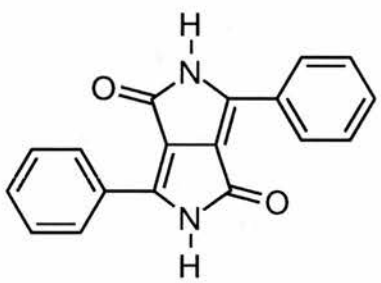

Fig 1.6 Structure of diphenyl DPP.

A typical synthesis of a symmetrical DPP involves reacting a suitable aromatic nitrile with a dialkyl succinate in the presence of a strong non-nucleophilic base such as sodium t-amyloxide in refluxing t-amyl alcohol[5].

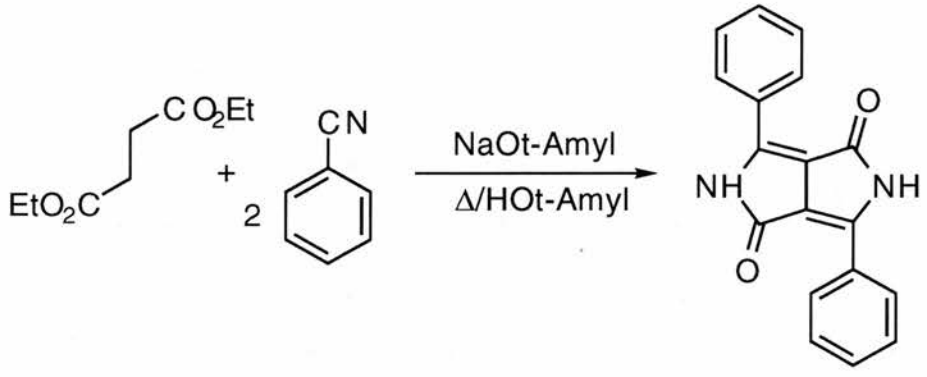

Fig. 1.7 Synthesis of diphenyl DPP.

The mechanism of this reaction is *via* a nucleophilic enolate attack on the nitrile, followed by ring closure, elimination of alkoxide, rearrangement of the pyrrole ring followed by repetition to give the final symmetrical DPP.

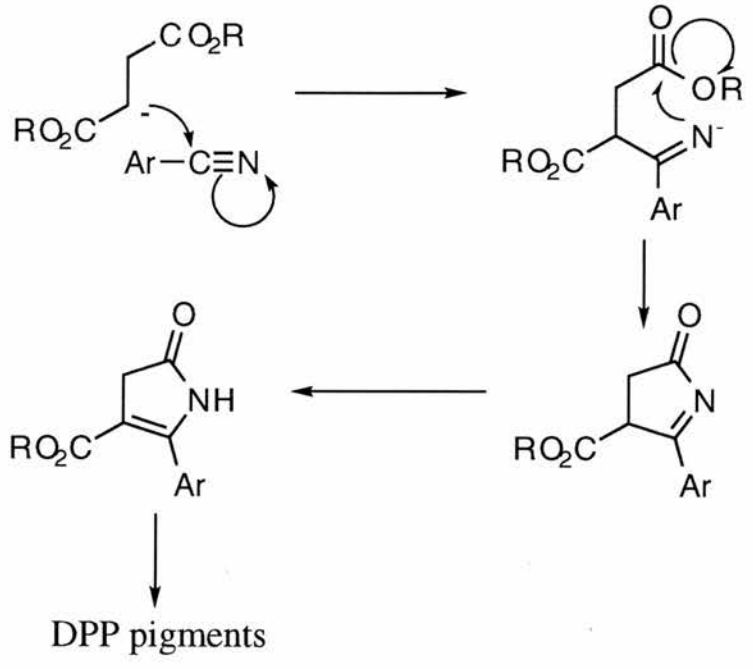

Fig. 1.8 Mechanism of DPP formation.

DPPs typically have intense red through to purple colours. They have very good thermal stabilities and colour fastness. They are very slightly soluble in polar organic solvents where their photostability is not good, though their photostability in the solid phase is very good indeed. They are used in the high performance end of the pigment market, particularly in the area of automotive paints where very good light and weather resistance is essential.

1.11 Pigment requirements and definitions

Although the basic definition of a pigment as opposed to a dye has been given previously in this report, there are some specific properties and requirements of pigments that it is necessary to define and explain in order to understand the problems and requirements associated with their development and usage.

1.11a Particle size

In order to colour a particular medium, a pigment must be dispersed in that medium. The initial state of a pigment immediately after synthesis is of crystallites, which may be cubes, needles, bars, etc. fused together into aggregates. These aggregates are further joined together in a weaker fashion into agglomerates. The exposed surface area is reduced by the formation of aggregates and agglomerates, and since the colour is imparted by the surface of the pigment particles, the intensity of the colour is reduced. To increase colour intensity, the particle size must be decreased. However, if the particle size is decreased too far, other factors will suffer such as the opacity, or hiding capacity, of the pigment. The typical range of organic pigment sizes is around 0.1-0.5 μm, though ranges outside this are possible.

1.11b Light stability

Implicit to the requirement of a pigment, that of imparting colour to a medium, is the necessity that the pigment be exposed to light, usually of a variety of wavelengths, often including the potentially more damaging UV radiation from the sun. A pigment exposed to these conditions must exhibit suitable resistance to light for the application to which it is put. A pigment used, for example in the automotive industry, would be of little use if it were not stable to visible or UV light for any length of time.

1.11c Thermal stability

Many processes in which pigmented media are involved require heat. Examples include the high speed dispersal mills used in pigment production, the injection moulding of many thermosetting polymers, and in the final application in items that are intrinsically hot during use. A pigment must be stable to the thermal conditions to which it might reasonably be exposed. This does not simply mean one acute exposure to a particular temperature, but either repeated or continuous exposure.

1.11d Chemical stability

Many of the applications of pigments may involve exposure to chemical attack, usually from acids, bases, or bleaching agents. It is necessary for a particular pigment to be resistant to those chemical agents to which it is likely to be exposed.

1.11e Opacity

This is a property related to particle size. Light passing through a transparent medium will either go straight through or be reflected from the substrate below. If the incident medium is opaque, however, the light will not penetrate, and will be either absorbed or reflected. A better way of describing pigments than transparency or opacity is by the term hiding power-the reduction of transfer of light through a medium. This is achieved by the absorption of light by the particles of the pigment as described earlier, and by the scattering of the incident light. Scattering is dependent on the particle size and wavelength of the incident light. The greater correspondence between particle size and light wavelength, the greater the scattering. The addition of inorganic pigments to increase scattering is a good way of increasing hiding power, as long as the pigment colour strength is adequate.

1.11f Colour strength

This is a property that relates to the amount of a particular pigment that is required to produce any given colour intensity. It has been determined that pigments in a medium absorb scatter and reflect light incident upon them. The degree to which this occurs determines the colour strength of the pigment.

1.11g Dispersal

The dispersal of the pigment into its medium is by a milling process, which both breaks down the agglomerates into aggregates and primary particles and also "wets" the particles-breaking down the air-solid boundary, replacing it with an air-liquid boundary. The ease of dispersability is dependent on the number of surface contacts between pigment particles, and so pigments with smaller particle size are

harder to disperse than those with larger particle size. For economic reasons pigments are very rarely dispersed to the ultimate degree, due to the energy and time required to do so. Any way of increasing the dispersal properties of a pigment would be a valuable technique for improving the colour, opacity and performance of pigments.

2) DISCUSSION ON PHTHALATE ESTER SYNTHESIS

The phthalate skeleton is of value to colour chemists in view of its ready incorporation into a variety of pigments, *cf:* phthalocyanines, as outlined previously. Therefore any new approach to phthalates with unusual substitution patterns and substituents is of interest.

2.01 Longer chain alkyl substituted phthalate skeletons

Phthalic skeletons with longer chain alkyl substituents are of interest in this case because of the steric hindrance of the alkyl group interfering with the intra and intermolecular bonds between pigment molecules, and so causing the intermolecular interactions between the pigment and the molecules of the medium to be altered. This has a direct bearing of the dispersability of the pigment in the medium. Crystal structure and colour may also be altered by the addition of alkyl groups to the pigment molecules.

A useful general method of gaining access to phthalates involves reacting (usually) electron rich conjugated dienes with electron deficient olefins in a Diels-Alder reaction, followed by the aromatisation of the resulting unsaturated adduct by various means. Since the Diels-Alder reaction was to be utilised and attempted in several schemes during the course of this research project it is appropriate to include here a short discussion of the reaction.

2.02 The Diels-Alder reaction

Although several isolated examples of what were to become known as Diels-Alder reactions had been reported during the earlier part of the century[6] it was not until the nineteen twenties and thirties that Otto Diels and Kurt Alder began a systematic study of the general cycloaddition reaction between conjugated dienes and olefins[7].

Fig. 2.1 General scheme of the Diels Alder reaction.

It was discovered that the general reaction above was possible for a wide variety of conjugated dienes, and olefins, with both being able to be linear or cyclic. Acetylenes were also found to react with conjugated dienes similarly[8].

Fig. 2.2 Diene/acetylene Diels-Alder reaction.

The presence of certain groups on either the diene or the olefin/acetylene (the dienophile) have been found to enhance the reaction. For normal Diels-Alder reactions, the presence of electron withdrawing groups on the dienophile tend to increase the rate of reaction, the presence of electron donating groups tend to decrease it.

Typical substituents on the dienophile may include CHO, COOR, COR, COOH and CN, though other groups may be present. It is entirely possible for the dienophile to have two of these activating groups present.

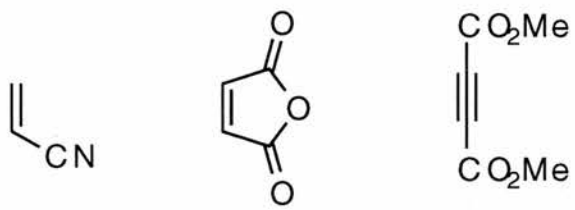

Fig. 2.3 Acrylonitrile, maleic anhydride and DMAD.

The presence of electron donating groups on the diene tend to increase the rate of reaction, electron withdrawing groups tend to reduce it. Typical electron donating groups include alkyl and alkoxy, though others may be present. No specific substituents on the diene are required for the reaction, although if either of the double bonds are part of an aromatic system the reactivity is reduced, and it must be possible for the conjugated double bonds to achieve a cisoid conformation, otherwise no reaction occurs.

Fig. 2.4 Cisoid diene and non-cisoid diene.

In cases where there is an unsymmetrical diene or dienophile it can be seen that two products are possible, though one is usually favoured.

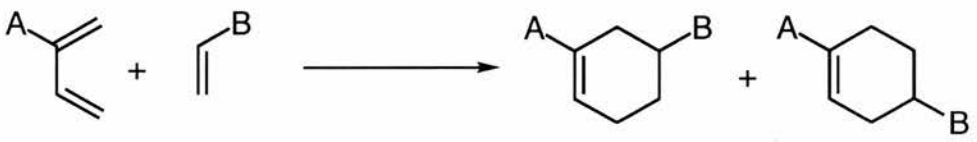

Fig. 2.5 Reaction between unsymmetrical reagents.

Diels-Alder reactions are extremely useful in organic synthesis, giving access to a very wide variety of compounds that would be otherwise difficult to synthesise. Yields of the reaction tend to be high, and the reaction is generally quite clean, though polymerisation of the reagents can sometimes be a problem. The use of Lewis acid catalysts can enhance the reaction, by both speeding up and increasing the yield of the reaction. Where the (electron deficient) dienophile contains atoms with lone pairs of electrons present the Lewis acid complexes with these lone pairs, so decreasing further the electron density in the olefin or acetylene, and increasing the attraction to the (electron rich) diene[9].

2.03 Previous work on phthalates

During previous work involving phthalocyanine synthesis, maleic anhydride and alkyl substituted 1,3-butadienes were reacted to give the Diels-Alder adduct, and these tetrahydrophthalic anhydrides were aromatised by addition of bromine followed by dehydrobromination at high temperature[10].

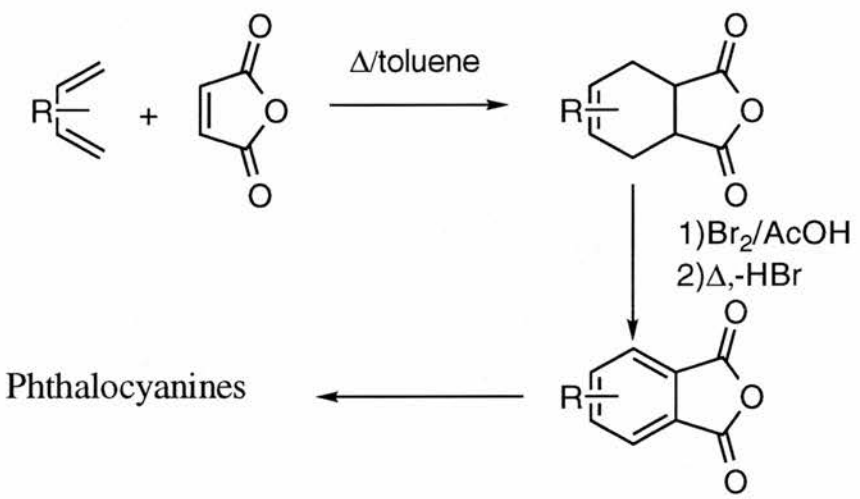

Fig. 2.6 Scheme of previous diene/maleic anhydride work.

Although this scheme obtains good overall yields of anhydrides, it suffers from the disadvantage that the initial 1,3-butadienes are expensive, with only one, 3-methylbuta-1,3-diene or isoprene, being cheap. 4-methylbuta-1,3-diene or piperylene, 2,3-dimethylbuta-1,3-diene and 2,4-dimethylbuta-1,3-diene are rather expensive and any other more complex dienes are either commercially unavailable or prohibitively expensive for any kind of scale up of reaction above *ca:* 10 gram scale.

Work carried out at the same time used various 2-alkyl substituted furans as dienes, with the advantages of greater economy and/or easy commercial or synthetic availability, followed by attempted aromatisation of the furan/maleic anhydride adduct using a variety of Lewis and Brønsted acids[11].

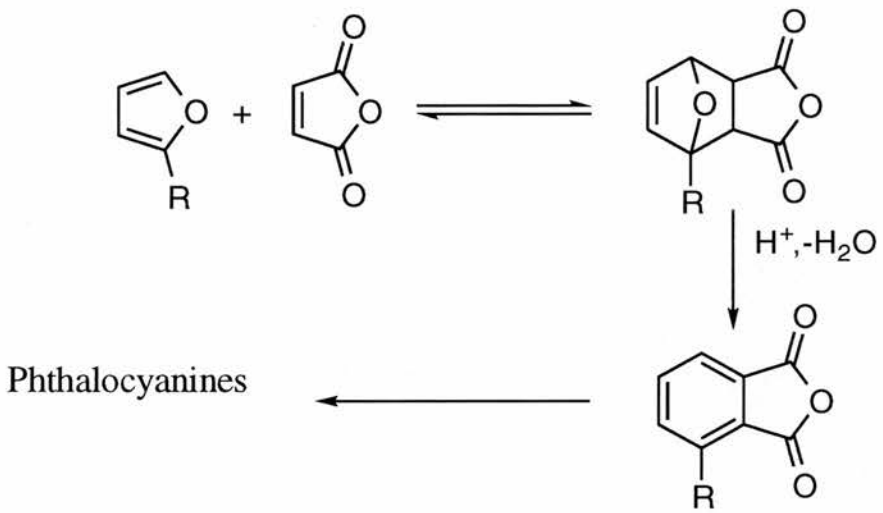

Fig. 2.7 Scheme of previous furan/maleic anhydride work.

However, although furans react readily with maleic anhydride under thermal conditions, the adducts of furans and alkene dienophiles are quite unstable in solution, forming an equilibrium between the adduct and the starting materials[12]. Strong acids are known to promote the polymerisation of furans, and since the removal of a reagent from one side of an equilibrium reaction encourages the thermal equilibrium to shift to that side, supplying more of the compound to be removed, it was found that in almost all cases, either no reaction at all took place, or the presence of strong acids resulted in the polymerisation of all of the furan present, rather than the aromatisation of the Diels-Alder adduct to the desired 3-alkyl phthalic acid derivatives.

Only in the presence of concentrated sulphuric acid did any aromatisation of the 2-methylfuran adduct occur, and that in low yield. The results are listed below.

ACID REAGENT	RESULT
$HBr/AcOH/Ac_2O$ @ 25°C	Starting material
H_3PO_4, 83% @ 0°C	Starting material
H_2SO_4/Ac_2O @ 0°C	Aromatisation, 8% yield
H_2SO_4/Ac_2O @ 20°C	No aromatisation
CF_3COOH/Ac_2O @ 0°C	Starting material
$BF_3.Et_2O/Ac_2O$ @ 0°C	Polymerisation

Fig. 2.8 Attempted acid aromatisation and yields.

It was understood that the main problem with the above scheme was the ease of reversibility of the initial Diels-Alder reaction. If an adduct of a furan/dienophile that did not undergo such ready retro Diels-Alder reaction could be found, then it was theorised that the aromatisation step would be much more successful. Although the Diels-Alder adducts between furan and double bonded dienophiles are known to be unstable in solution, furan adducts with triple bonded dienophiles are much more stable, and it was this fact that led to the suggestion that if a furan/acetylene adduct, an "oxabicycloheptadiene" were synthesised than it would be more readily aromatised than the furan/maleic anhydride adduct.

2.04 Synthesis of furan/DMAD adducts

A search of the literature found several precedents for using acetylenic dienophiles, one that seemed promising involved reacting furans with diethyl acetylenedicarboxylate (DEAD), followed by aromatisation of the adduct in methylene chloride with concentrated sulphuric acid.The yields of the resulting diethyl 3-alkyl-6-hydroxy phthalates were quoted as being good, and the conditions seemed to be mild. Moreover, the reaction appeared to be general. It was therefore decided to investigate this approach further.

A literature procedure was followed to synthesise the 2-alkyl substituted furans. This involved lithiation of the furan with n-butyl lithium, followed by reaction of this "furyl lithium" with the relevant primary alkyl halide to generate the 2-alkylfurans in good yields[13]. This procedure was conducted to produce furans with alkyl groups at the "2" position of up to 10 carbon length (n-decyl).

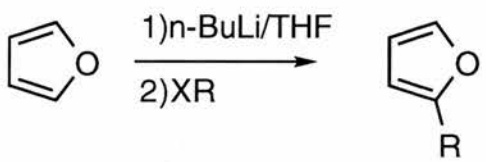

Fig. 2.9 2-Alkylfuran generation.

The furans were reacted with an equimolar amount of DMAD, without solvents, in good yields following literature precedents[14].

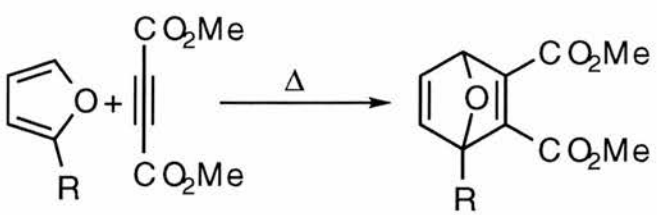

Fig. 2.10 Furan/DMAD reaction.

2.05 Aromatisation of furan/DMAD adducts with H^+

The resulting adducts, the dimethyl 7-oxabicyclo[2.2.1]hepta-2,5-diene-2,3-dicarboxylates (DMOHDs) were then aromatised in generally good yields to the dimethyl 3-alkyl-6-hydroxyphthalates by addition of concentrated sulphuric acid to a solution of the DMOHD in cold methylene chloride[15], followed by stirring at room temperature for several hours.

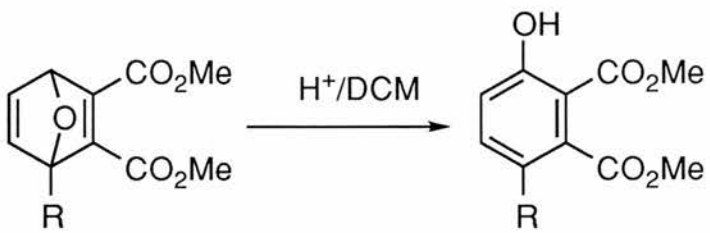

Fig. 2.11 The aromatisation of DMOHDs.

Of interest at this stage is the mechanism of the aromatisation. The initial reaction seems to be protonation of the bridgehead oxygen, followed by bridge cleavage to leave the positive charge on the ring, If an electron donating group is present on the ring the positive charge will end up adjacent to it. Evidence for this alkyl group charge stabilisation effect is given by the slower reaction time and lower yields for the non-alkyl substituted 6-hydroxyphthalate esters generated by the aromatisation of furan/DMAD adducts.

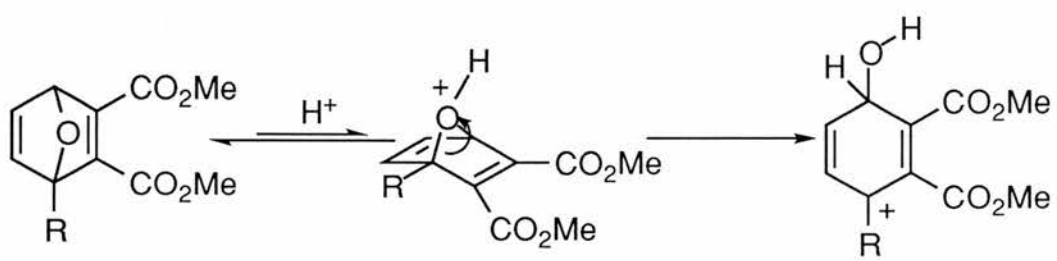

Fig. 2.12 Protonation and bridge cleavage.

This carbocation then rearranges, with the expulsion of a proton and migration of the group geminal to the oxygen, with simultaneous migration of the unsubstituted double bond, followed by tautomerisation to the phenol.

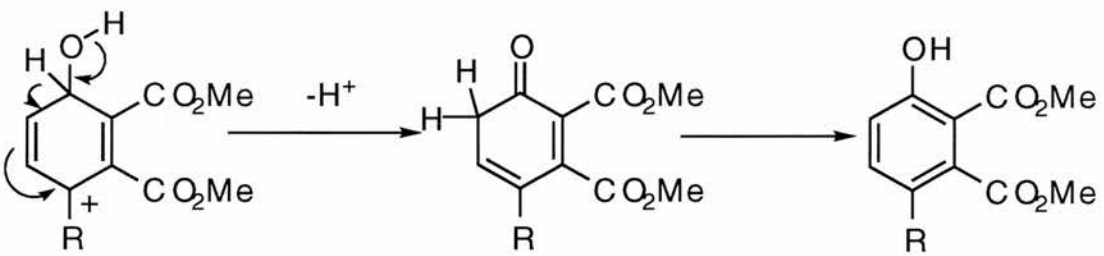

Fig. 2.13 Rearrangement and tautomerisation to phenol.

Evidence for the geminal group migration was obtained by the use of a 2,5-di-n-dodecylfuran/DMAD adduct, which, as expected, rearranged to give the 3,5 di-n-dodecyl-6-hydroxyphthalate skeleton, albeit with the loss of the ester alkyls to form the phthalic anhydride, with only one aromatic proton present in the ^{1}H NMR spectrum. High resolution mass spectra proved the formula of the material produced. The most interesting feature of this particular reaction is the size of the alkyl group involved in the migration, an n-dodecyl group of relative molecular mass of 169.33.

2.06 Alkylation of dimethyl 3-alkyl-6-hydroxyphthalates

The resulting dimethyl 3-alkyl-6-hydroxyphthalates are of interest to colour chemists in themselves. However, it was then possible to alkylate the phenolic group with a variety of substituents by using potassium carbonate as a base to deprotonate the phenol in the presence of the relevant alkyl halide in moist acetone. In the case of the alkylations using alkyl bromides, a trace amount of sodium iodide was used to speed up the overall substitution reaction with a catalytic Finkelstein reaction generating small quantities of the more readily substituted alkyl iodides, the iodide species being recycled for further bromide displacement after the nucleophilic attack by the phenolate ion.

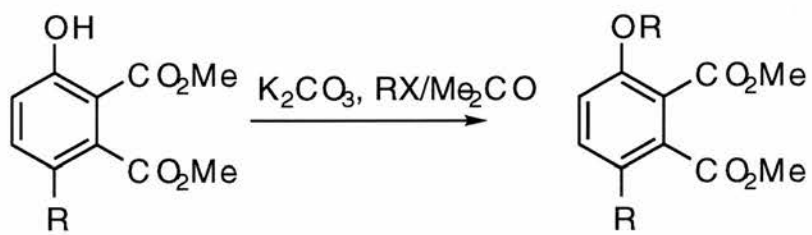

Fig. 2.14 Alkylation of phenols.

Primary, secondary and benzyl substituents were added to a variety of dimethyl 3-alkyl-6-hydroxyphthalates in good to excellent yields. Although the synthetic procedure stopped at this stage, it should be a simple procedure to saponify the phthalate ester groups, acidify to the phthalic acids, then react to form the relevant pigments.

2.07 Low Valence Ti aromatisation of furan/DMAD adducts

Another investigated method for generating phthalate esters from furan/acetylene adducts involved reacting the DMOHD adduct with low valence titanium, generated from titanium tetrachloride and lithium aluminium hydride in THF, to aromatise with the loss of the bridging oxygen producing the desired dimethyl 3-alkylphthalates[16].

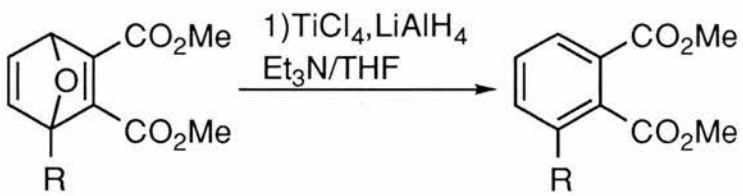

Fig. 2.15 Low valence titanium aromatisation.

This process was conducted on several DMOHDs, with varying alkyl chain length. Yields were good, with very good reproducibility. A possible mechanism for the low valence titanium aromatisation involves a free radical splitting of the oxygen bridge by oxidative coupling with a titanium(II) species, forming a Ti(III) radical species. Double bond migration and reduction of Ti(III) back to Ti(II) followed by loss of Ti(III) oxide yields the aromatic system[17].

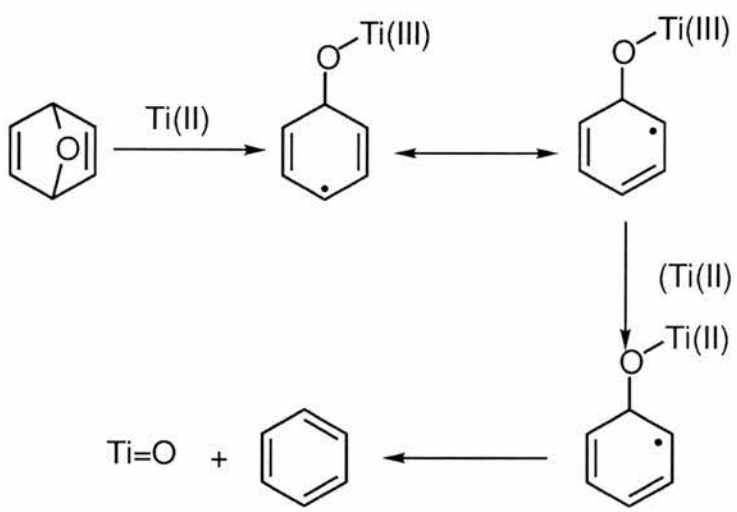

Fig. 2.16 Mechanism of LVT aromatisation.

2.08 Coumalin derivatives as a route to phthalate skeletons

A final method of generating phthalate esters briefly investigated involves reacting coumalic acid derivatives with DMAD in a Diels-Alder reaction.

Coumalic acid was produced by reacting malic acid with fuming sulphuric acid, following a literature procedure[18].

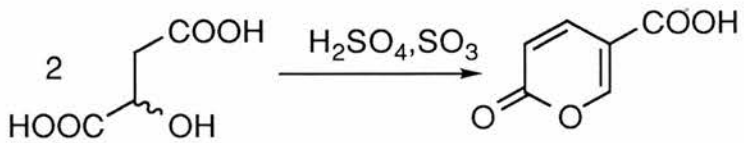

Fig. 2.17 Coumalic acid production.

Coumalic acid will react as a Diels-Alder diene with electron-deficient dienophiles such as DMAD, the adduct of which immediately aromatises to give carbon dioxide and the aromatic 1,2-dimethyl mellitate ester. This reaction proceeded cleanly at 170-180°C[19].

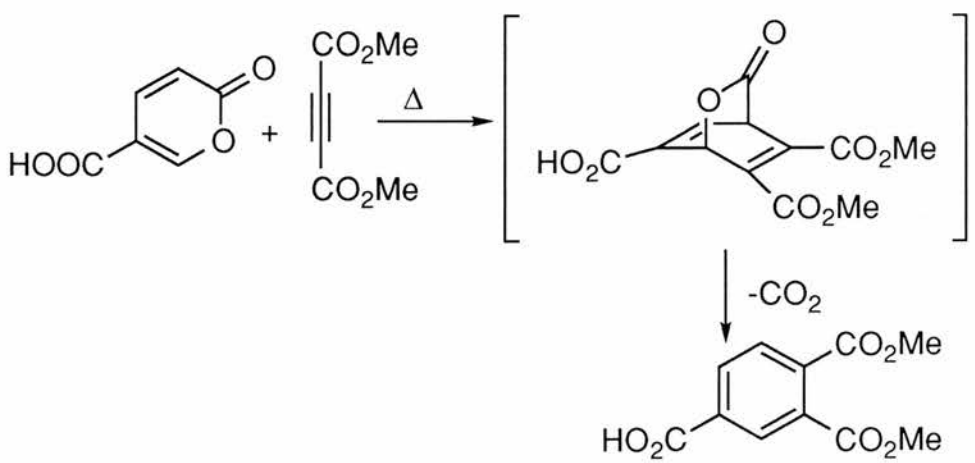

Fig. 2.18 1,2-Dimethyl mellitate production.

The reaction is also very successful for the nitrile derivative of coumalic acid, produced from coumalic acid by a method involving the reaction of coumaloyl chloride with sulphamide at 120°C[20].

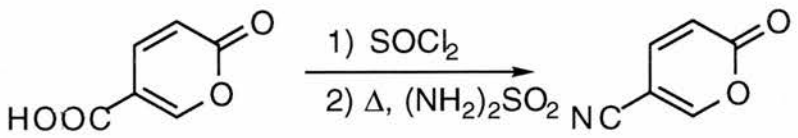

Fig. 2.19 Coumalonitrile production.

The coumalonitrile reacted cleanly with DMAD at 170-180°C, giving dimethyl 4-cyanophthalate in high yield. This reaction product is of interest not only to phthalocyanine and phthalate pigment chemistry, but to the production of DPPs, since the dimethyl 4-cyanophthalate could react to form a DPP pigment under the standard DPP forming conditions.

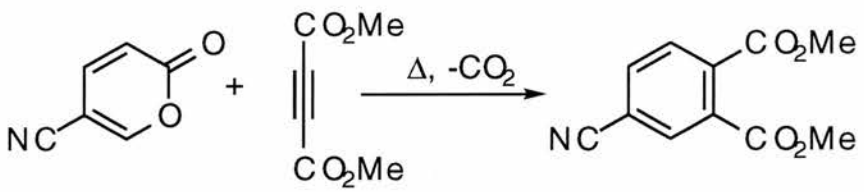

Fig. 2.20 Dimethyl 4-cyanophthalate production.

3) DISCUSSION ON LATENT DPP SYNTHESES

When DPPs were first introduced in the mid 1980's they were the first entirely new chromophore in over thirty years. Development of the applications of DPPs continues, and an area of great interest in DPP chemistry at the moment is the concept of "Latent DPP Pigments". These are DPP pigments that are synthesised as a precursor then incorporated into the application medium. They are then treated in a particular fashion that induces an irreversible reaction to occur, generating the final DPP pigment in its desired form and colour within the medium itself. The properties most of interest are the solubility and therefore dispersal properties of the pigment. Since it has already been established that the dispersion of an insoluble pigment is both time and energy consuming, if the DPP pigment can be rendered reversibly soluble in various media this would be of interest.

3.01 tert-BOC-protection of DPP pigments

The concept of latent pigments arose from the practice developed within Ciba-Geigy of reversibly increasing the solubility of DPP pigments by tert-BOC (tert-butoxycarbonyl) protecting the N-H bond of the amide groups in the DPP pigments by reacting the DPP pigment with di-tert-BOC anhydride at room temperature in the presence of DMAP, with THF or DMF as solvent. This reduces the hydrogen bonding between molecules, and introduces a steric effect, reducing the ease with which the material can crystallise. The overall effect is to increase the solubility of the DPP pigment[21].

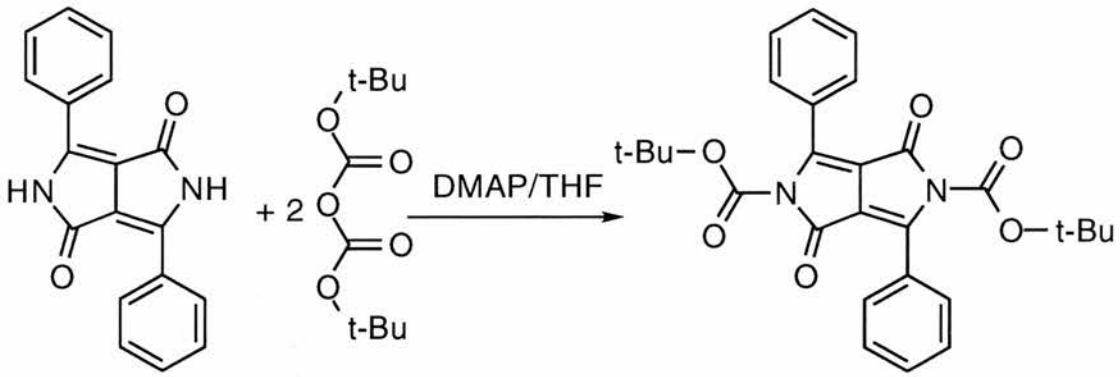

Fig. 3.1 Tert-BOC protection of a DPP.

The process can be reversed by heating the tert-BOC protected DPP to around 180°C. This causes the tert-BOC group to be eliminated as isobutene and carbon dioxide, leaving the DPP N-H group regenerated, and the DPP pigment particles evenly dispersed throughout the medium.

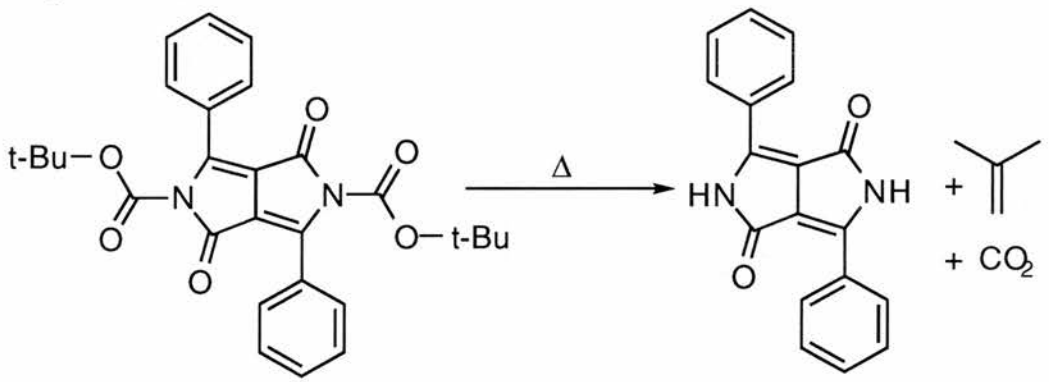

Fig. 3.2 Thermal decomposition of a tert-BOC DPP.

The major drawback to this technique is the cost and waste of half of the tert-BOC anhydride during the protection procedure. It was suggested that a DPP pigment containing other groups that increased the solubility in various media, yet treatable *in situ* to generate a "standard" high insolubility DPP pigment would be of great interest.

3.02 Necessary properties of latent DPP pigment

There are several properties of the groups that must be present in a latent DPP pigment to allow both greater solubility and decomposition to the standard DPP that must be taken into account.

3.02a Solubility

The most important feature of the latent DPP pigment is that it must have a greater affinity for the medium, that it be more soluble in the medium than the final DPP pigment, and therefore be present in the medium as separate and discrete molecules, rather than as solid crystalline particles.

3.02b Stability to DPP forming conditions

The solubilising groups on the latent DPP pigment must of course be stable to the DPP forming conditions themselves, namely, strong base, and temperatures of around 100-110°C. If the latent DPP pigment decomposes under those conditions, either to the final DPP pigment, or degrades completely, then it is of little or no use.

3.02c Mildness of conversion reaction conditions

The treatment of the latent DPP pigment to give the standard DPP must be of a nature that does not interfere with or damage the medium that it is incorporated into. The difficulty of reaching the DPP pigments with most reagents once they are incorporated into the medium is considerable. The medium that DPPs are most likely to be used in are polymers, so, for example, aqueous reagents such as acids or bases are likely to be of little use.

3.02d Inadvisability of use of metal species

Any treatment involving metal ions, either as bases, or involving free radical reactions is almost certain to leave metallic residues in the medium, which is likely to have deleterious effects on the performance or colour of the medium. The use of acids is also not advisable for similar reasons.

A better method could involve a unimolecular rearrangement of the latent DPP under the influence of light or heat. However, because of the incorporation of the pigment into a polymer containing medium the temperature of the conversion reaction is important, any temperatures above *ca:* 200-250°C are likely to degrade the polymers present. DPPs are also known to have limited stability to light in solution.

3.03 Summary of ideal properties of latent DPP pigment

The ideal properties of the latent DPP pigment may be summarised below:

1) Good solubility in organic media.

2) Thermal and chemical stability to DPP forming conditions.

3) Conversion reaction must be done using reasonably mild reaction conditions, probably involving light or heat, and preferably unimolecular.

The above criteria suggest a variety of solutions, some more likely than others. The criteria of good organic solubility requires that the precursor molecules have reduced intermolecular interactions. A good method of achieving this is to increase the steric hindrance of the molecules, decreasing the ability of the pigment molecules to stack in the crystal structure.

If the structure of diphenyl DPP is considered, it can be seen that the planar phenyl rings may easily stack within the crystal structure. If the phenyl rings could be replaced with another, bulkier group that is not planar, yet can rearrange to give a phenyl or similar planar aromatic group, then this may be of use. If this can also be done unimolecularly, under the influence of light or heat, then this will solve the problem of reagent inaccessibility to the latent DPP. Possible groups that were considered as being of interest were bicycloheptadienes, "norbornadienes" and stilbenes.

3.04 Discussion on bicycloheptadienes "norbornadienes"

It was thought that a possible solution to the latent pigment problem might be a DPP molecule containing a bicycloheptadiene "norbornadiene"-like group of the general type:

Fig. 3.3 Bicycloheptadiene like structures.

The moiety X may be either hetero atoms or carbon/hetero atoms. This group is similar to those produced by the reaction of furans with DMAD, with the exception that the moiety X should aromatise more easily, the bridge component being eliminated ideally as a gas, as in the following scheme:

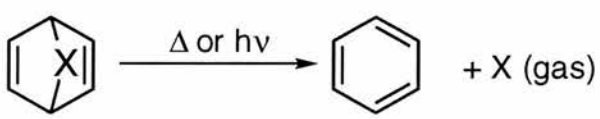

Fig. 3.4 Aromatisation of bicycloheptadiene like structures.

There are a quite limited number of bridging groups which can eliminate to give gases. Those that can are: an azo group (-N=N-), giving nitrogen upon aromatisation, a lactone group (-COO-), giving carbon dioxide, a sulphone ($-SO_2-$), giving sulphur dioxide, a ketone (-CO-), giving carbon monoxide and an ethylene group ($-CH_2CH_2-$), giving ethene.

This sort of group is generated by the Diels-Alder reaction of coumalin derivatives with acetylenes, as detailed previously in the chapter concerning phthalate esters, the (-COO-) bridge of the intermediate lactone being expelled immediately as carbon dioxide during the aromatisation. This immediate expulsion gives an indication of a problem concerning these compounds, which is their high instability towards heat, the twin driving forces of gas expulsion and aromatisation making the reaction very likely to proceed. It was thought that if a variant of these compounds that could aromatise above temperatures of around 120°C (DPP forming temperature) then a DPP containing that group might be synthesised. This DPP would not be as planar as the standard diphenyl DPP, so would hopefully be more soluble in various media. The DPP could then revert to a more planar aryl DPP under stronger thermal conditions, as is shown on the following schematic:

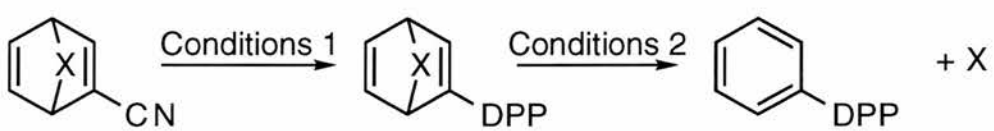

Fig. 3.5 Scheme of latent DPP synthesis and application.

The order of ease of expulsion from the ring of the various gas molecules proceeds: $N_2>CO_2>SO_2>CO$[22]. Since stable compounds of the type containing a lactone (-COO-) group are not known[23] it is reasonable to presume that the same is true for the more easily extruded azo (-N=N-) containing group. Compounds containing the sulphone (-SO_2-) group are known but they tend not to be stable at temperatures above *ca:* 0°C. It would seem that only the ketone or ethene bridge containing groups would be stable at the DPP forming conditions.

3.04a 7-Oxobicyclo[2.2.1]hepta-2,5-diene DPPs

The obvious method of synthesising this class of compounds is *via* a Diels-Alder reaction between an acetylene such as propiolic acid and the diene, cyclopenta-2,4-dienone, trapping the intermediate ketone at a temperature below the aromatisation temperature.

There is precedent for this reaction[24], and the adduct should be stable at DPP forming temperatures. However, cyclopenta-2,4-dienone itself is not a stable compound, being unavailable commercially or by any remotely feasible synthetic route. The only stable commercial sources of the cyclopenta-2,4-dienone nucleus is with at least two phenyl and 2 alkyl groups attached to the ring, such as 2,5-diethyl-3,4-diphenylcyclopenta-2,4-dienone.

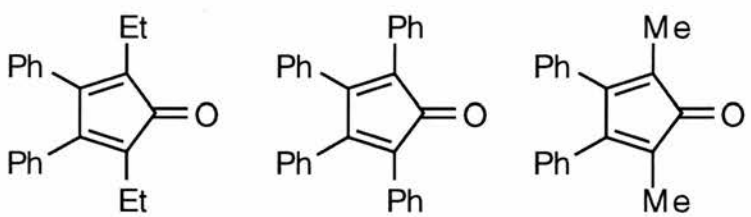

Fig. 3.6 Commercially available cyclopentadienones.

The Diels-Alder reaction between these dienes and propiolic acid would probably take place, the resulting adducts converted to the nitriles and then to the DPPs by standard methods. The resulting DPP would, however, have at least two planar phenyl groups present. The effect of these large groups upon the solubility properties of the latent DPP was not thought to be promising, given the well-known relationship between increasing pigment molecular weight and decreasing solubility in the medium. It was therefore decided not to proceed with the cyclopenta-2,4-dienone nucleus approach.

3.04b 7,8-Diazabicyclo[2,2,2]octa-2,5-diene DPPs

Work was then concentrated on a much more indirect approach based on a protected synthesis of the (-N=N-) containing 7,8-diazabicyclo[2,2,2]octa-2,5-diene group. This was done *via* the Diels-Alder reactions of azo esters with 1,3-butadienes to form dialkyl tetrahydropyridazinedicarboxylates, followed by oxidation to the dialkyl dihydropyridazinedicarboxylates. This was then to be followed by further Diels-Alder reactions with nitrile containing acetylenes. The resulting adducts could be converted to DPPs, and the ester groups removed by hydrolysis. At this stage the DPPs could then be incorporated into the medium. Oxidation of the (-NHNH-) group could be done by passing an oxidising agent through the medium.

3.04c Bicyclo[2.2.2]octa-2,5-diene DPPs

Another area that work was conducted on was the attempt to synthesise DPP pigments containing the bicyclo[2.2.2]octa-2,5-diene group, produced by a Diels-Alder reaction between 1,3-cyclohexadienes and acetylenes, followed by the conversion of the carboxylic acid group to a nitrile. This was then to be converted to a DPP pigment. If a DPP could be synthesised containing this group, then it could have interesting solubility properties in polymeric material, due to the lack of hetero atoms in the group, while permitting the thermal extrusion of ethene to generate the less soluble aromatic group on the DPP. Although less thermally stable than the 7-oxobicyclo[2.2.1]hepta-2,5-dienes (CO extruding) groups, the resulting compounds might be stable enough to be of interest. It was thought that since there were precedents for synthesising unsubstituted versions of these groups from available materials it might be worthwhile pursuing research in this area.

3.05 Protected 7,8-diazabicyclo[2,2,2]octa-2,5-diene group synthesis

It was first decided to attempt a synthesis of a protected 7,8-diazabicyclo[2,2,2]octa-2,5-diene containing a nitrile group that could be incorporated into a DPP. The method devised was to build up an initial diisopropyl 1,2-dihydropyridazine-1,2-dicarboxylate, to which was then added an acetylenic nitrile.

3.05a Synthesis of non-methyl substituted tetra- and dihydropyridazine derivatives

Initially, a literature procedure was investigated that involved a Diels-Alder reaction between coumalin and a diazo ester, followed by loss of CO_2 from the adduct to form the required diisopropyl 1,2-dihydropyridazine-1,2-dicarboxylate. The coumalin was prepared by the pyrolysis of coumalic acid, using a literature procedure[25].

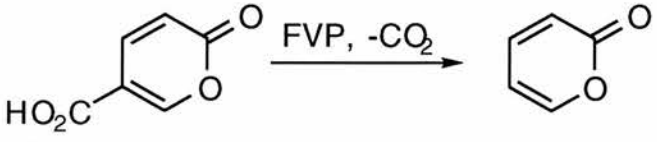

Fig. 3.7 Coumalin production by flash vacuum pyrolysis.

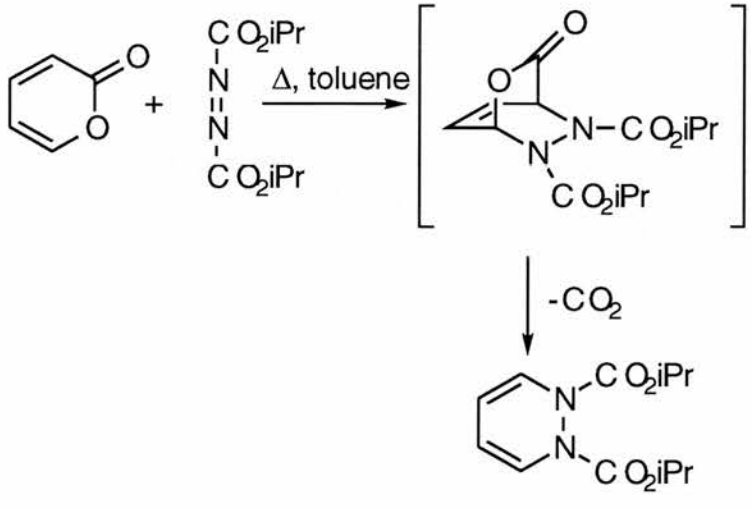

Fig. 3.8 Coumalin reaction with an azo ester.

This reference[26] quoted low yields, probably due to further reaction of the product, diisopropyl 1,2-dihydropyridazine-1,2-dicarboxylate with the diazo ester, generating a bicyclo adduct.

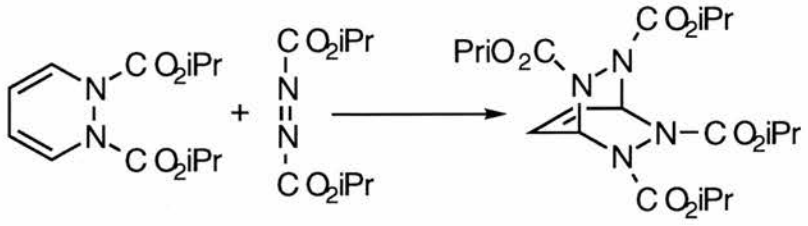

Fig. 3.9 Formation of bicyclo adduct.

This adduct could then react further with both coumalin and the desired product. Indeed, after refluxing coumalin and diisopropyl azodicarboxylate for 48 hours in toluene, although CO_2 had been evolved, none of the desired product could be isolated from the complex mixture and it was decided to abandon this approach and to attempt a two step approach *via* diisopropyl 1,2,3,6-tetrahydropyridazine-1,2-dicarboxylate.

A literature procedure was used to synthesise diisopropyl 1,2,3,6-tetrahydropyridazine-1,2-dicarboxylate *via* a Diels-Alder reaction between buta-1,3-diene and diisopropyl azodicarboxylate in toluene. The yield was very good, and the purity was also high[27].

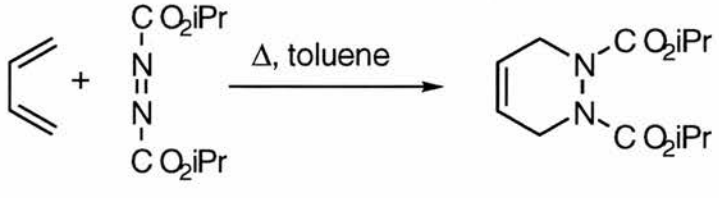

Fig. 3.10 Diels-Alder synthesis of diisopropyl 1,2,3,6-tetrahydropyridazine-1,2-dicarboxylate.

The oxidation to the diisopropyl 1,2-dihydropyridazine-1,2-dicarboxylate was attempted by the monobromination of the diisopropyl 1,2,3,6-tetrahydropyridazine-1,2-dicarboxylate with N-bromosuccinimide in carbon tetrachloride, a Wohl-Ziegler bromination, followed by evaporation of solvent and dehydrobromination using 2,6-lutidine in boiling toluene[28]. This gave a modest yield of the desired product.

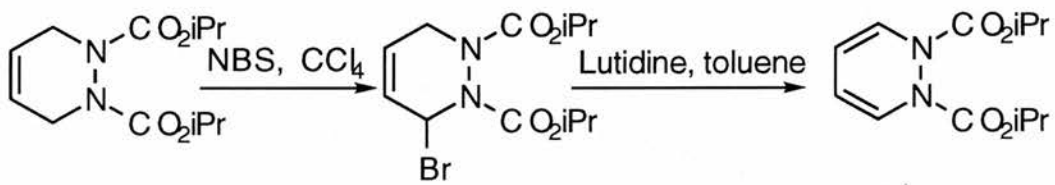

Fig. 3.11 Synthesis of diisopropyl 1,2-dihydropyridazine-1,2-dicarboxylate

The mechanism of this reaction probably proceeds *via* a free-radical mechanism, with the main propagation steps as:

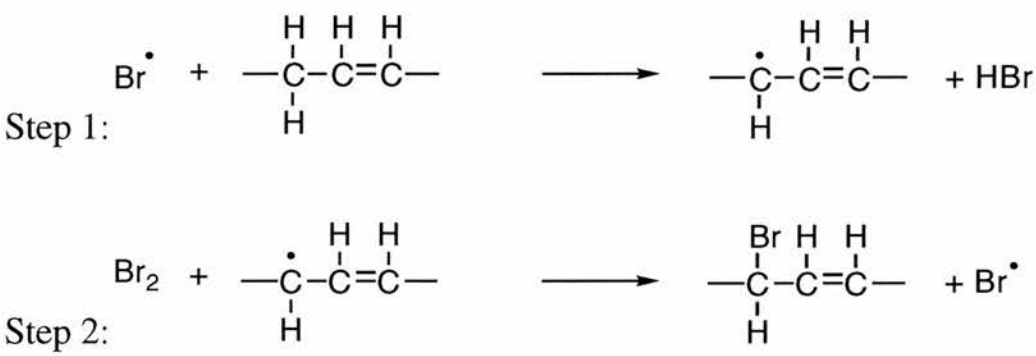

Fig. 3.12 Mechanism of Wohl-Ziegler bromination.

The source of the Br_2 in step 2 is a rapid ionic reaction between the HBr produced in step 1 and the N-bromosuccinimide.

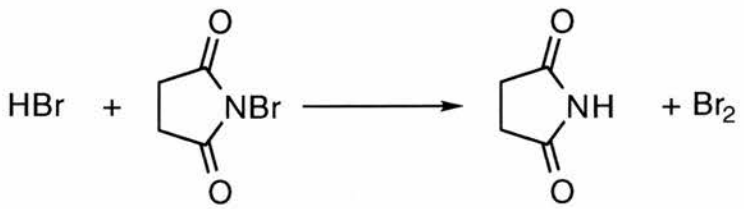

Fig. 3.13 Debromination of NBS by HBr.

The purpose of the NBS is probably to act as both a steady-state, low concentration source of Br_2, and to use up the HBr from step 1. Br_2 is present in too low a concentration during the reaction to add across the double bond in the expected fashion, since during conventional brominations, after the initial attack, either free radical or electrophilic, the second bromine atom adding accross the double bond originates from another bromine containing species. If the concentration of the brominating species is low enough, there is little probability that the reaction will occur. The initial reaction is reversed to give starting material, and therefore, under low concentration conditions, the free radical reaction competes successfully. A free radical source should be required for the reaction to occur, such as peroxides or UV light, but this was not mentioned in the reference utilised in the synthesis of diisopropyl 1,2,3,6-tetrahydropyridazine-1,2-dicarboxylate. A possible source of the necessary free radicals is from light incident upon the reaction mixture, or traces of an initiator contaminating the reaction mixture.

3.05b Synthesis of 3-phenylpropynonitrile

The material required to react with the diisopropyl 1,2-dihydropyridazine-1,2-dicarboxylate, 3-phenylpropynonitrile was produced in modest yield by the one pot reaction of ammonia gas with 3-phenylpropynoic acid (3-phenylpropiolic acid) in the presence of polyethyl phosphate (PEP)[29], itself synthesised by the reaction of diethyl ether with phosphorus pentoxide in chloroform[30].

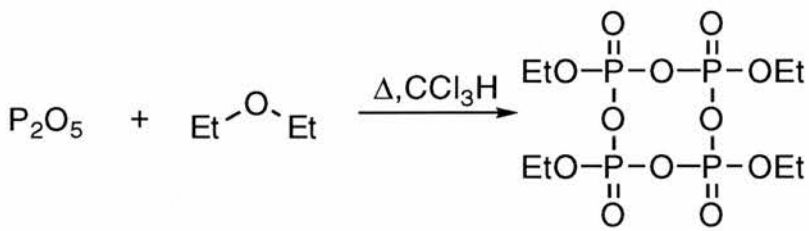

Fig. 3.14 PEP synthesis.

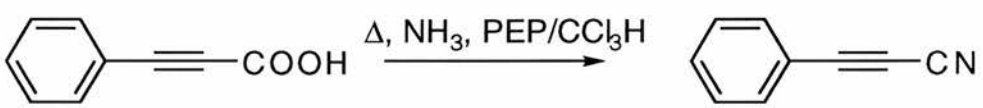

Fig. 3.15 3-Phenylpropynonitrile synthesis.

The initial reaction of the ammonia with the acid is to generate the ammonium salt, which is then dehydrated to the amide (isolable), and further dehydrated to the nitrile.

3-Phenylpropynonitrile was selected as a dienophile due to the stabilising effect of the phenyl group. If the phenyl group were not present the propynonitrile would not be stable to air and traces of moisture, as well as being highly toxic and volatile.

3.05c Diels-Alder reaction of an unsubstituted dihydropyridazine derivative

The diisopropyl 1,2-dihydropyridazine-1,2-dicarboxylate and the 3-phenylpropynonitrile were then heated together in toluene to attempt the following reaction:

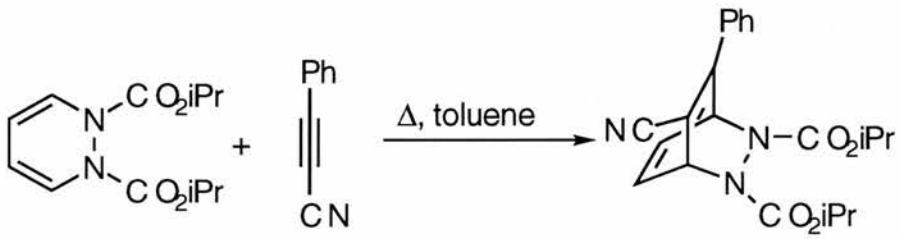

Fig. 3.16 Attempted Diels-Alder reaction.

However, even prolonged heating at reflux failed to generate any of the desired product. A Lewis acid catalyst was added, ZnI_2, which also failed to produce any desired product. It appeared that the unsubstituted diisopropyl 1,2-dihydropyridazine-1,2-dicarboxylate was simply too electron-deficient to react under thermal conditions with 3-phenylpropynonitrile.

It was decided to attempt to synthesise ring methyl substituted variants of the diisopropyl 1,2-dihydropyridazine-1,2-dicarboxylate in order to increase the electron density of the ring and so increase the chance of a Diels-Alder reaction occurring.

3.05d Synthesis of methyl substituted tetra and dihydropyridazine derivatives

Diisopropyl 4,5-dimethyl-1,2,3,6-tetrahydropyridazine-1,2-carboxylate was synthesised by reacting 2,3-dimethylbuta-1,3-diene with diisopropyl azodicarboxylate, in good yield, using a similar method to that with buta-1,3-diene.

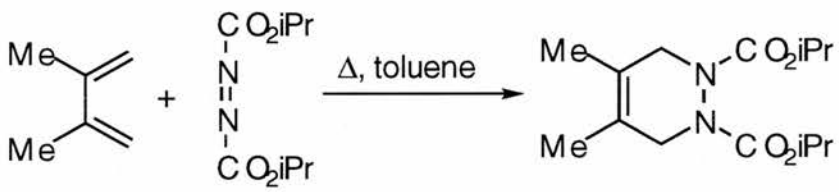

Fig. 3.17 Synthesis of diisopropyl 4,5-dimethyl-1,2,3,6-tetrahydropyridazine-1,2-carboxylate.

The yield of the diisopropyl 4,5-dimethyl-1,2,3,6-tetrahydropyridazine-1,2-carboxylate was very good and the purity of high standard.

The reaction to generate the diisopropyl 4,5-dimethyl-1,2-dihydropyridazine-1,2-dicarboxylate, the Wohl-Ziegler monobromination with N-bromosuccinimide and subsequent dehydrobromination with 2,6-lutidine was not successful, possibly due to either steric hindrance of the methyl groups or high thermodynamic stability of the double bond of the diisopropyl 4,5-dimethyl-1,2,3,6-tetrahydropyridazine-1,2-dicarboxylate resisting allylic shifting.

An alternative scheme was suggested, involving the dibromination of the initial diisopropyl 4,5-dimethyl-1,2,3,6-tetrahydropyridazine-1,2-dicarboxylate using standard procedures, followed by dehydrobromination with sodium isopropoxide in isopropanol:

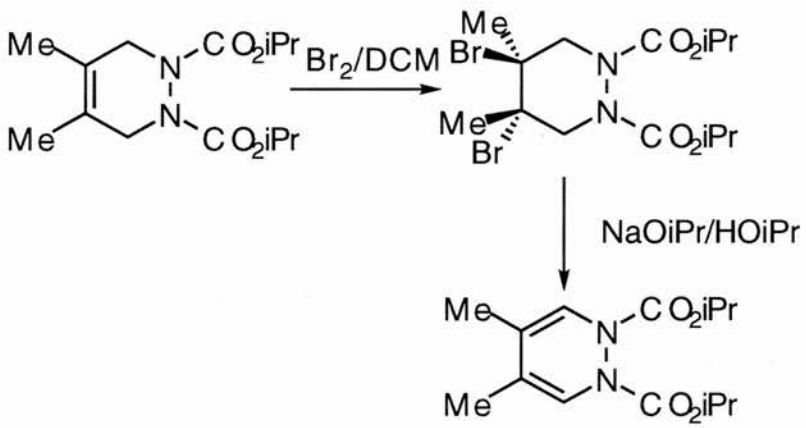

Fig. 3.18 Scheme of bromination/dehydrobromination.

The dibromination of the diisopropyl 4,5-dimethyl-1,2,3,6-tetrahydropyridazine-1,2-dicarboxylate with bromine in dichloromethane gave the expected diisopropyl 4,5-dibromo-4,5-dimethyl-1,2,3,6-tetrahydropyridazine-1,2-dicarboxylate in high yield *via* the normal reaction mechanism.

The dibromo adduct was then reacted with sodium isopropoxide in isopropanol, produced by the reaction of a slight molar excess (with respect to the dibromide) of sodium with isopropanol.

The crystalline product of this reaction, obtained in good yield, was not as expected, being a product of 1,3 nucleophilic addition-elimination product of isopropoxide to the initial monobromide.

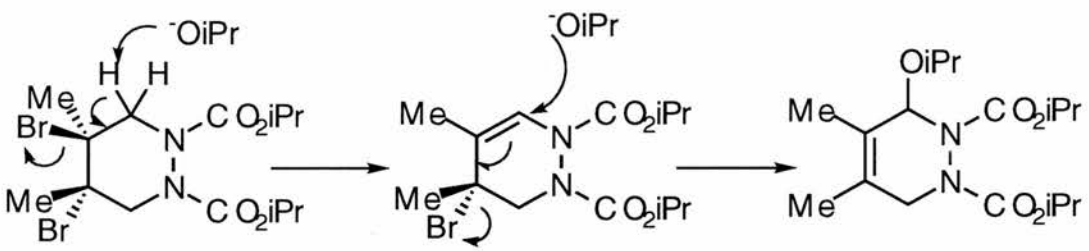

Fig. 3.19 Mechanism of 1,3 nucleophilic addition-elimination.

It appears that the formation of the single tetrasubstituted double bond is thermodynamically much preferred.

Since it was now apparent that it would be difficult to synthesise diisopropyl 4,5-dimethyl-1,2-dihydropyridazine-1,2-carboxylate, an attempt was made to synthesis a monomethyl substituted dihydropyridazine. This was done using isoprene (2-methylbuta-1,3-diene) and piperylene (penta-1,3-diene) reacted with diisopropyl azodicarboxylate, using the same method as for buta-1,3-diene.

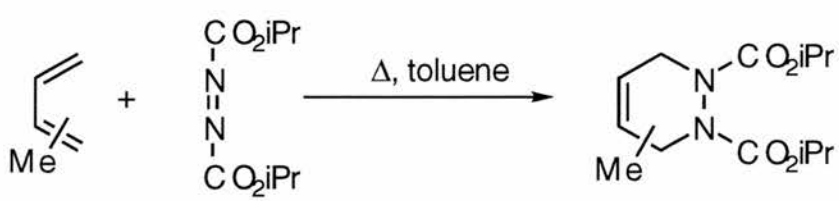

Fig. 3.20 Synthesis of monomethyl tetrahydropyridazines.

These reactions proceeded cleanly, and in high yield, giving both of the expected diisopropyl 3/4-methyl-1,2,3,6-tetrahydropyridazine-1,2-dicarboxylates. These were then reacted with bromine, as before.

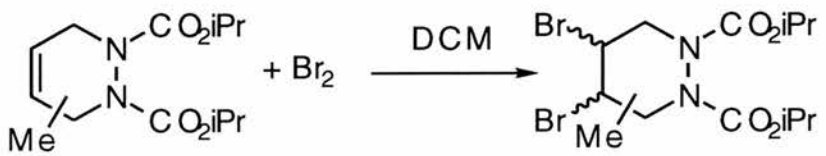

Fig. 3.21 Bromination of monomethyl tetrahydropyridazines.

These were then treated as before, with a solution of sodium isopropoxide in isopropanol. The hope at this stage was that with only one alkyl group present, the 1,3-nucleophilic addition-elimination of isopropoxide to the 3-bromo-alk-1-ene fragment would become less likely, the resulting 4,5-alkene being less thermodynamically stable.

However, as before, the 1,3-nucleophilic addition-elimination occurred, and the resulting products were found not to be as desired, being a mixture in both cases of the 3 and 6 addition products.

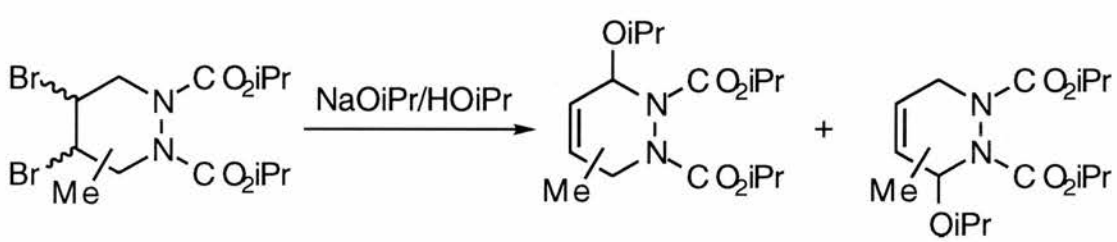

Fig. 3.22 1,3-Addition-elimination of isopropoxide.

A final attempt at base elimination was made using potassium t-butoxide as base upon the diisopropyl 4,5-dibromo-4,5-dimethyl-1,2,3,6-tetrahydropyridazine-1,2-dicarboxylate in the hope that the low nucleophilicity of the base should minimise the chance of the 1,3-nucleophilic attack. However, even with heating, no reaction took place under these conditions, possibly due to excess steric hindrance.

The two diisopropyl 3/4-methyl-1,2,3,6-tetrahydropyridazine-1,2-dicarboxylates were also treated with NBS in a Wohl-Ziegler reaction, then with 2,6-lutidine, as detailed previously. This resulted, in the case of the isoprene adduct, in no conversion to the desired diisopropyl 4-methyl-1,2-dihydropyridazine-1,2-dicarboxylate, again possibly due to steric effects of the methyl group. With the piperylene adduct, however, a moderate yield of the desired diisopropyl 3-methyl-1,2-dihydropyridazine-1,2-dicarboxylate was achieved. It was therefore possible to proceed to the next stage of the proposed synthetic pathway.

3.05e Diels-Alder reaction of a methyl substituted dihydropyridazine derivative

Diisopropyl 3-methyl-1,2-dihydropyridazine-1,2-dicarboxylate was heated with 3-phenylpropynonitrile in toluene in attempt to generate the Diels-Alder adduct. However, no Diels-Alder adduct was isolated or identified, presumably due to the dihydropyridazine ring still not being electron rich enough to react with the 3-phenylpropynonitrile. It was therefore not possible to continue with this area of research, and it was decided to try a totally different approach to the problem.

3.06 Synthesis of bicyclo[2.2.2]octa-2,5-dienes

The final attempt to synthesise a DPP containing a group that could aromatise under thermal conditions, while being stable to DPP pigment forming conditions concentrated upon bicyclo[2.2.2]octa-2,5-dienes. These groups can be synthesised by the Diels-Alder reaction of 1,3-cyclohexadienes with acetylenic dienophiles such as DMAD or propiolic acid derivatives.

It was decided to attempt a thermal Diels-Alder reaction between propiolic acid and 1,3-cyclohexadiene. This was to be followed by a mild condition conversion of the resulting bicyclo[2.2.2]octa-2,5-diene-2-carboxylic acid to the corresponding nitrile, using established procedures.

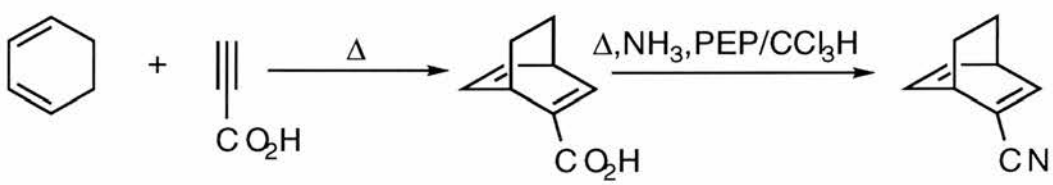

Fig. 3.23 Bicyclo[2.2.2]octa-2,5-diene-2-carbonitrile synthesis.

The final DPP pigment synthesis from the bicyclo[2.2.2]octa-2,5-diene-2-carbonitrile was to be done under standard DPP pigment forming conditions, with a solution of the nitrile, sodium tert-amyloxide and diethyl succinate stirred together under nitrogen in refluxing tert-amyl alcohol.

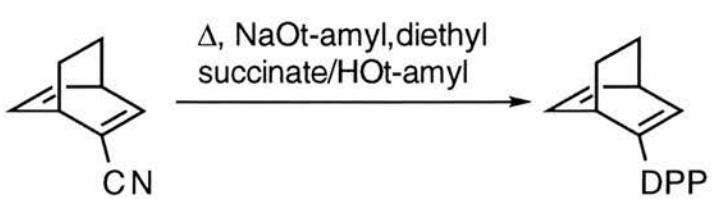

Fig. 3.24 Bicyclo[2.2.2]octa-2,5-diene DPP synthesis.

This particular sequence of reactions was chosen because of a number of practical considerations. Propiolic acid is commercially available, and relatively non-toxic and stable, whereas the nitrile is unavailable commercially, more volatile, highly toxic, and is unstable to both moisture and air. It was also felt that the acid group would confer greater dienophilicity to the acetylene in the Diels-Alder reaction than the nitrile.

A literature procedure[31], albeit low-yielding, was attempted in the synthesis of the bicyclo[2.2.2]octa-2,5-diene-2-carboxylic acid, reacting propiolic acid with 1,3-cyclohexadiene in solution with dioxane at 100°C for 12 hrs. However, although the reaction sequence was repeatedly followed, only benzoic acid was isolated, indicating that the Diels-Alder reaction had indeed occurred, but the intermediate was not stable under the reaction conditions, and immediately aromatised, eliminating ethene.

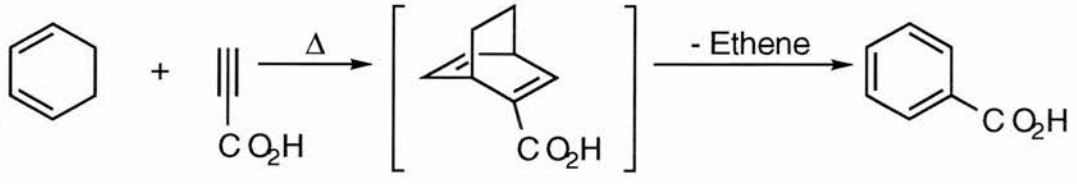

Fig. 3.25 Elimination of ethene from Diels-Alder adduct.

Attempts to repeat the experiment using milder conditions over a longer time period again produced none of the desired bicyclo product. It was therefore not possible to pursue the reaction scheme any further.

3.07 Synthesis of bicyclo[2.2.1]hepta-2,5-dienes

Although it had not been possible to synthesise a latent DPP pigment utilising aromatising norbornadiene analogues it was decided to attempt to synthesise a DPP pigment containing non-aromatising, but similarly structured groups. This was done to examine the effect, if any, of having non-planar groups incorporated into the DPP pigment. The chosen non-aromatising group was norbornadiene, since it has a very similar structure to the groups upon which synthetic work had been attempted or considered.

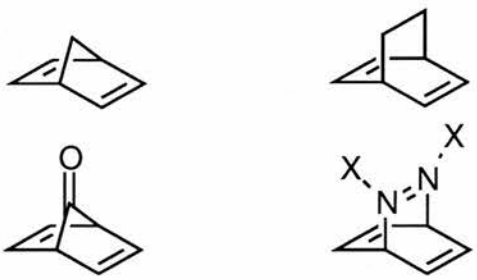

Fig. 3.26 Norbornadienyl and other aromatising groups.

This group is readily available from thermal Diels-Alder reactions between cyclopentadienes and acetylenes, and is thermally stable to over 180°C, well above the DPP forming temperatures. It was hoped that if a DPP pigment containing one or more of this group could be synthesised, although not suitable as a latent pigment, the solubility of this DPP would give an indication as to whether further work should be done on the area of thermal extrusions of gases from bicycloheptadiene analogues to generate aromatic DPP pigments.

It was decided to react freshly distilled cyclopentadiene with propiolic acid without a solvent *via* a literature method[32] to generate the norbornadiene-2-carboxylic acid.

Fig. 3.27 Synthesis of norbornadiene-2-carboxylic acid.

This reaction proceeded rapidly, giving a high yield of adduct. This unstable norbornadiene-2-carboxylic acid was then converted into the nitrile by previously established methods.

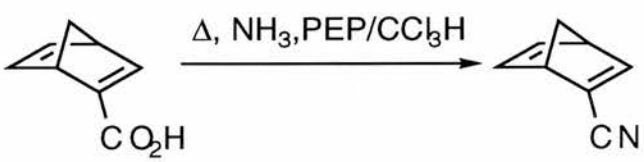

Fig. 3.28 Synthesis of norbornadiene-2-carbonitrile.

The resulting unstable norbornadiene-2-carbonitrile, obtained in low yield was then subjected to standard asymmetrical DPP forming conditions, i.e. a phenyl lactam ester such as ethyl 2-phenyl-5-ketopyrrole-3-carboxylate and sodium t-amyloxide in refluxing t-amyl alcohol. This, however, did not yield the desired DPP pigment.

A possible reason for this is that the non-aromatic double bond in conjugation with the nitrile is vulnerable to Michael attack by a nucleophile (either oxygen or carbon in this system), so preventing the DPP formation.

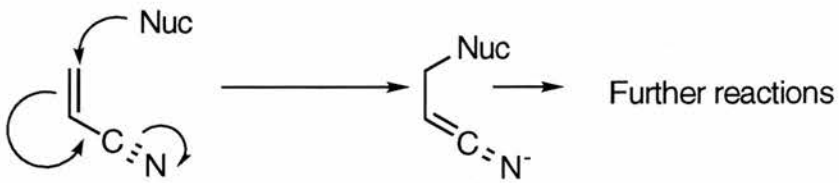

Fig. 3.29 Michael addition of nucleophiles to (non-aromatic) conjugated double bonds.

It seems, therefore that although DPPs containing the norbornadiene-type structure may possibly be soluble in various media, they are impossible to make *via* normal techniques, due to both thermal instability and chemical inaccessibility of the norbornadiene-type moiety, as well as chemical instability to the DPP forming conditions. Work was therefore discontinued on this area.

3.08 Discussion on stilbene containing DPPs

Another possible solution of the latent pigment problem looked into was the photochemical or thermal rearrangement of a non-planar, possibly non-aromatic group to a planar aromatic group. Given the large thermodynamic advantage of aromatisations, any non-aromatic groups should be very unstable, aromatising very easily, and therefore hard to manipulate without decomposition or aromatisation. An alternative reaction scheme, using more stable and readily available groups was then investigated.

It is well known that under conditions of irradiation with UV light and the presence of an oxidising agent such as oxygen or trace amounts of iodine, stilbenes oxidatively photocyclise to phenanthrenes. The reaction is quite clean, and the yields are good[33].

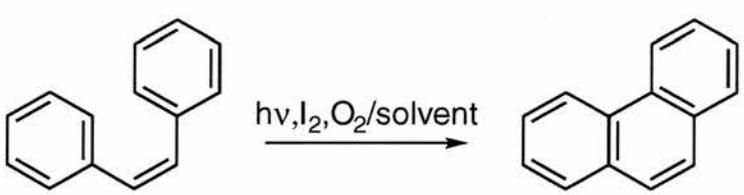

Fig. 3.30 Photochemical cyclisation of stilbenes.

Although the *cis*-isomer is the isomer that reacts to form the intermediate dihydrophenanthrene, the *trans*-isomer may be used, as under the reaction conditions it is in equilibrium with the *cis*-isomer. It was suggested that if a DPP pigment containing stilbenyl groups were to be synthesised, the mobile, rotatable nature of the terminal aromatic ring might interfere with the packing of the pigment molecules in the solid, and therefore influence the solubility of the DPP in various media.

The *trans*-stilbenyl DPP could then be irradiated with UV light in the presence of an oxidising agent such as oxygen or a trace of iodine to generate a more planar, and hopefully less soluble phenanthryl substituted DPP pigment. It was therefore decided first to attempt to synthesise mono*trans*-stilbenyl containing DPP, followed by di*trans*-stilbenyl DPP, This was to be done using *trans*-stilbene-4-carbonitrile as a stilbenyl containing moiety that could be incorporated into a DPP pigment molecule in place of benzonitrile, using standard conditions.

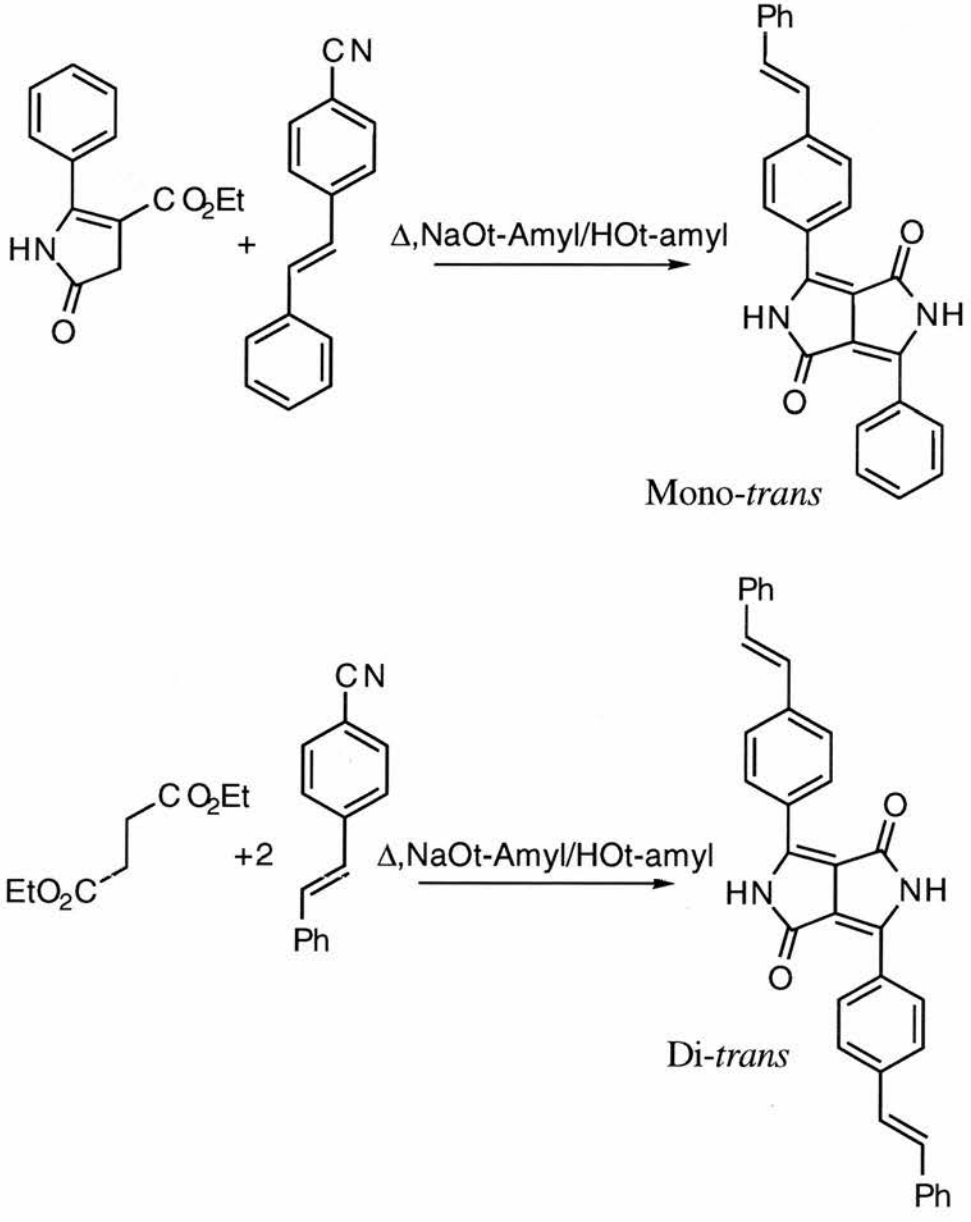

Fig. 3.31 Synthesis of *trans*-stilbenyl DPPs.

3.09 Synthesis of stilbenes

Stilbenes are thermally stable molecules, which may be synthesised by a number of reactions, an example being the reaction between an aromatic aldehyde and a benzyl Grignard reagent, followed by the dehydration of the resulting alcohol. However, they are most readily synthesised by a variety of Wittig-type[34] reactions between aromatic aldehydes and phosphorus ylides, or phosphoranes, produced by the treatment by base of benzyltriphenylphosphonium salts, themselves produced by the reaction between triphenyl phosphine and benzyl halides. A wide variety of experimental methods have also been developed to favour either the *cis* or *trans* isomer, depending upon requirements[35].

Stilbenes may also be synthesised by a modification of the Wittig reaction, the Horner-Emmons or Wadsworth-Emmons reaction[36], using ylides prepared from dialkyl benzylphosphonates, themselves prepared by the Arbuzov reaction between trialkyl phosphites and benzyl halides. Again, it is possible to arrange the experimental conditions to favour the higher yield of the isomer preferred, either *cis* or *trans*.

Since the initial discovery of the Wittig reaction and its modifications a great deal of research has been devoted to the development of methods of varying the ratio of the *cis/trans* olefin isomers thus produced. Some of these methods are discussed below, with an outline of the scope and mechanisms of the Wittig reaction and its various modifications.

3.09a Discussion of the Wittig reaction

The reaction between phosphorus ylides and carbonyl groups was first reported in 1953 by Wittig and Geissler[37]. This involved the reaction between methyltriphenylphosphonium bromide and phenyl lithium, forming an ylide. This ylide could then react with benzophenone to generate 1,1-diphenylethene and triphenylphosphine oxide in very high yields.

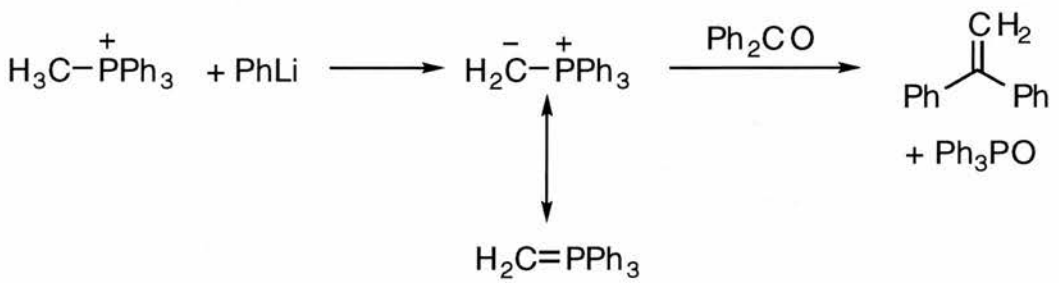

Fig. 3.32 Synthesis of 1,1-diphenylethene.

This method of generating alkenes has since found very wide application in organic synthesis, and is perhaps one of the most important techniques in the field of synthetic organic chemistry to be discovered. The conditions of the reaction are generally quite mild and the yields are good.

Of considerable advantage is the lack of ambiguity concerning the specific location of the double bond produced. This is exemplified in the synthesis of methylenecyclohexane from cyclohexanone[38].

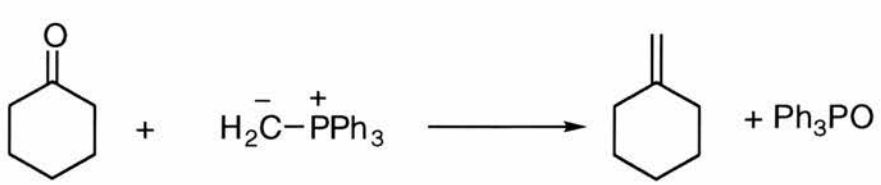

Fig. 3.33 Synthesis of methylenecyclohexane.

This produces a fair yield of only the thermally less stable isomer without any of the more stable 1-methylcyclohexene which would be produced in the alternative method involving a Grignard reagent followed by dehydration with acid.

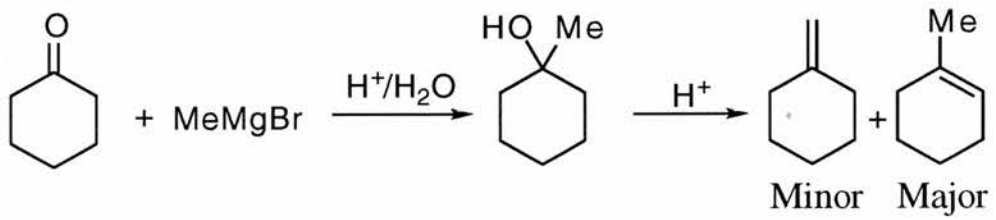

Fig. 3.34 Scheme of Grignard reaction and dehydration to two alkenes.

A general scheme of the Wittig reaction is as follows. The ylide itself may be generated by the deprotonation of a triphenylphosphonium salt by a strong base such as n-BuLi.

Fig. 3.35 General Wittig scheme.

R^1 and R^2 on the carbonyl may be alkyl, aryl, H, or contain OH, OR, halogen or even ester groups. The nature of R^3 and R^4 on the ylide, however, are critical with regard to the stability and reactivity of the ylide to the carbonyl containing group. If the ylide contains a group α to the carbanion which can delocalise the charge, such as a carbonyl or nitrile, then the ylide is much more stable than one which lacks this functionality. The ylide is less reactive towards carbonyl compounds, and in extreme cases where the carbanion charge is stabilised into an aromatic system it is found that the ylide is unreactive towards all carbonyls.

If there is no stabilising group, the ylide is very reactive to all carbonyls, and is also unstable to air and moisture to the extent that it may not be isolated. Ylides that contain groups such as vinyl, benzyl and alkynyl are intermediate in their reactivity and stability.

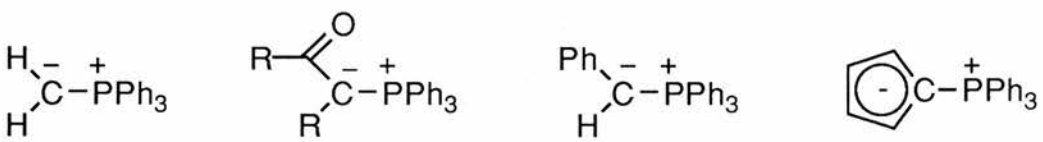

Fig. 3.36 Unstabilised, stabilised, benzylic & aromatic stabilised ylides.

The mechanism of the Wittig reaction proceeds *via* a nucleophilic attack of the ylide upon the carbonyl group, followed by the rearrangement of the oxaphosphetane ring to give the olefin and the triphenylphosphine oxide.

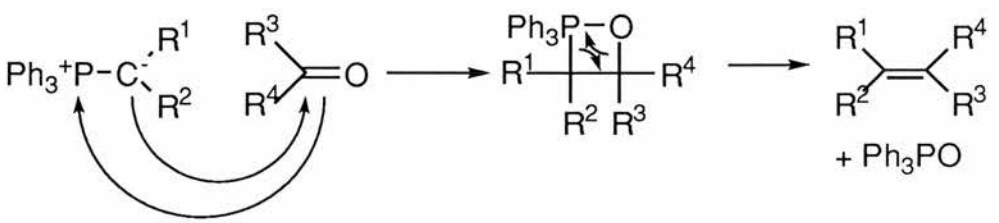

Fig. 3.37 Mechanism of Wittig reaction.

Of importance here is the observation that the rate determining step depends upon the nature of the initial ylide. For reactive ylides the initial step to the oxaphosphetane is rapid, the rearrangement to phosphine oxide and the olefin is the slower, rate determining step. For unreactive ylides it is the initial nucleophilic attack which is the rate determining step, the collapse to the phosphine oxide and the olefin being rapid due to the electron withdrawing groups conjugating with the newly forming double bond.

In the specific case given above, that of the synthesis of methylenecyclohexane there is, of course, only one stereoisomer produced. However, in Wittig reactions where the double bond does not end up in a terminal position it is possible to generate mixtures of the *cis* and *trans*-isomers. Furthermore, these are often not simply 50:50 mixtures-one isomer or the other usually predominates.

The reasons for this lie in the initial reaction of the ylide with the carbonyl containing compound to form an oxaphosphetane. As can be seen below, this intermediate can exist in one of two forms, the *threo* and *erythro*. Since the elimination of the P=O containing group is *syn* to the existing C-C bond it follows that the thermodynamically more stable *threo* form leads to the *trans* (E) olefin isomer. The thermodynamically less stable *erythro* form leads to the *cis* (Z) olefin.

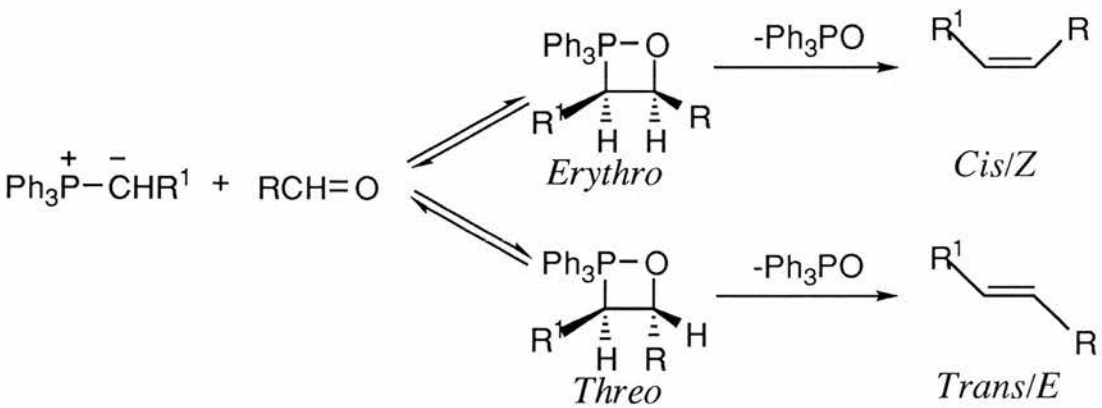

Fig. 3.38 Scheme of *cis/trans* olefin production.

The natural preference of the ylide and carbonyl is to react in such a way as to form the *erythro* (ultimately *cis*) isomer, probably due to the steric effects of the three bulky phenyl groups on the phosphorus. However, an equilibrium exists between the two isomers, therefore any method of shifting this equilibrium, or of altering the stability towards decomposition of a particular oxaphosphetane to the relevant olefin will alter the ratio of the *cis* and *trans*-isomers in the final olefin.

Generally, slowing the collapse to the olefin by stabilisation of the oxaphosphetane intermediate leads to the *threo* and thus, ultimately, *trans* olefin being preferred, with oxaphosphetane destabilisation and rapid collapse to the olefin leading to the *cis* isomer.

The methods of achieving this depend upon the reactivity and reasons for the reactivity of the initial ylide. The choice of conditions to favour a particular desired isomer is rather complex, with many possible options to consider to alter the *cis/trans*-selectivity of the reaction.

3.09b Discussion on the Wadsworth-Emmons reaction

The Wadsworth-Emmons variation of the Wittig reaction proceeds *via* a broadly similar pathway to that of the Wittig, starting with an alkyl phosphonate instead of a triphenylphosphonium salt.

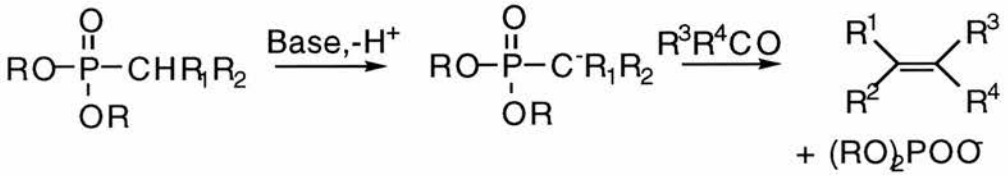

Fig. 3.39 Scheme of Wadsworth-Emmons reaction.

This method has a number of important advantages over the Wittig reaction. These include the greater nucleophilicity (and therefore reactivity) of the carbanion, caused by a lower effective positive charge on the phosphorus, leading to a greater concentration of negative charge on the carbanion. The final P=O by-product, rather than the water insoluble triphenylphosphine oxide is a dialkyl phosphate salt, which is water soluble, and hence much easier to separate from the reaction mixture. The starting material for the phosphonate esters, trialkyl phosphites are also cheaper than the equivalent triphenyl phosphines.

The stereochemistry of these reactions generally favours the formation of the *trans*-isomer, due to resonance stabilisation of the intermediate, analogous to the oxaphosphetane intermediate of the Wittig reaction. This allows thermodynamic equilibrium to be achieved, and hence the *threo* (*trans*-forming) isomer is favoured[39]. Extensive conjugation of groups with the newly forming double bond also greatly encourages the formation of the *trans*-olefin isomer[40].

3.09c Syntheses of *trans*-stilbenyl DPPs

To synthesise the *trans*-stilbene-4-carbonitrile required for the *trans*-stilbenyl DPPs, both mono- and di-substituted, it was decided to utilise a variant of a literature procedure[41] involving a modification of the Wadsworth-Emmons reaction. This involved reacting diethyl benzylphosphonate with 4-cyanobenzaldehyde in the presence of 15-crown-5 (a crown ether), with sodium hydride as base in dry THF.

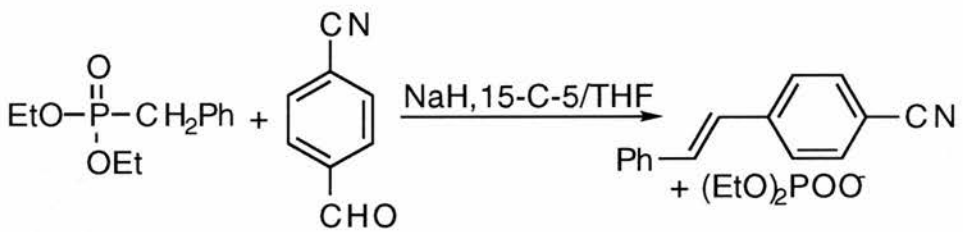

Fig. 3.40 Synthesis of *trans*-stilbene-4-carbonitrile.

Initial attempts followed the exact literature procedure. This required that a mixture of the 4-cyanobenzaldehyde and diethyl benzylphosphonate in THF be added dropwise to a stirred, cooled slurry of the sodium hydride in THF with the crown ether. With this method, however, the reported vigorous evolution of hydrogen along with an orange colour developing did not occur. The yields of stilbene were also much lower than expected, and so a slight modification was developed. The diethyl benzylphosphonate was added first to the sodium hydride/THF slurry, stirred for several hours at room temperature and then the 4-cyanobenzaldehyde was added. This produced the expected evolution of hydrogen, the colour change and a much better yield of the desired *trans*-stilbene-4-carbonitrile, with almost no *cis*-isomer produced.

The mechanism is typical for a Wadsworth-Emmons reaction. The initial reaction occurs between the sodium hydride and the diethyl benzylphosphonate, generating hydrogen gas and the carbanion.

Fig. 3.41 Initial synthesis of ylide.

This carbanion then reacts with the 4-cyanobenzaldehyde, giving the oxaphosphetane intermediate that immediately rearranges to the desired *trans*-stilbene-4-carbonitrile and the phosphate ester.

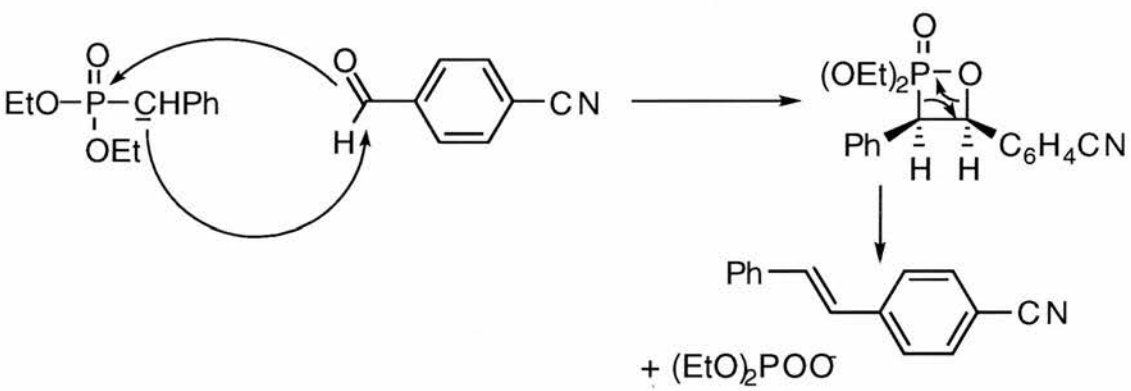

Fig. 3.42 Reaction of carbanion with 4-cyanobenzaldehyde.

The selectivity towards the *trans*-isomer can be explained in terms of the preference of Wadsworth-Emmons olefin syntheses to generate the *trans*-olefin, especially if the newly formed double bond is conjugated with existing double bonds. Clearly in this case, with two phenyl rings in conjugation, the *trans* isomer would be expected to predominate.

A possible reason for the initial conditions being unsuccessful is that the carbanion may not be very soluble in THF, and so is produced in very low quantities, due to an equilibrium reaction between the ylide and the phosphonate being set up. This would lead to a very low concentration of the carbanion in the THF solution initially, and so prevent reaction occurring. The 4-cyanobenzaldehyde present in the reaction could then be susceptible to side reactions, leading to lower yields. If the carbanion concentration is allowed to build up over a period of time then the addition of the 4-cyanobenzaldehyde may allow rapid formation of the stilbene, with fewer side reactions.

Once the required *trans*-stilbene-4-carbonitrile had been synthesised, it was then necessary to react it to form the mono-*trans*-stilbenyl DPP pigment. Before attempting this, a synthesis of diphenyl DPP was attempted, to gain familiarity with the DPP synthesis techniques before risking the valuable stilbene-4-carbonitrile. This was achieved using benzonitrile, diethyl succinate and sodium tert-amyloxide in refluxing tert-amyl alcohol. A modest yield of scarlet diphenyl DPP resulted. For the mono-*trans*-stilbenyl DPP a variant of the standard DPP synthesis was used. The nitrile was reacted with ethyl 2-phenyl-5-ketopyrrole-3-carboxylate in the presence of sodium tert-amyloxide in refluxing tert-amyl alcohol[5].

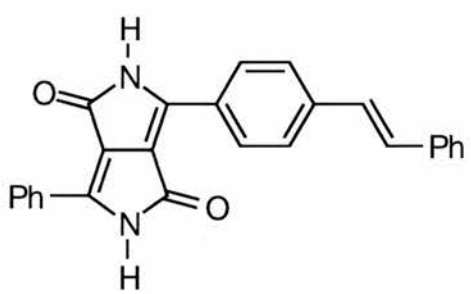

Fig. 3.43 Mono-*trans*-stilbenyl DPP.

The mono-*trans*-stilbenyl DPP pigment was synthesised in modest yield as a deep burgundy powder. This material was less soluble than diphenyl DPP, being only very slightly soluble in most common organic solvents, the best solubility being in acetic acid.

The di-*trans*-stilbenyl DPP pigment was synthesised by using the standard DPP pigment synthesis method. This gave a modest yield of a deep purple/black solid. This was found to be even less soluble than the mono-*trans*-stilbenyl DPP, having very low solubility in most organic solvents, though acetic acid proved to be the best.

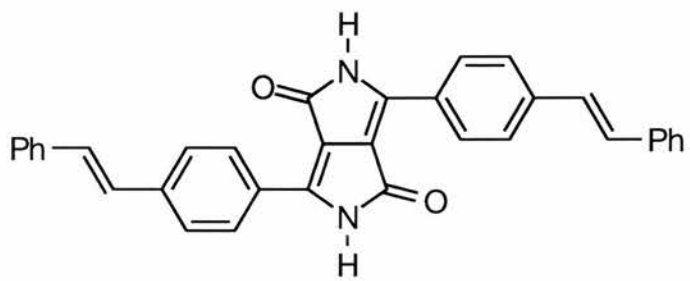

Fig. 3.44 Di-*trans*-stilbenyl DPP.

Evidently, the presence of the supposedly mobile aromatic rings of the *trans*-stilbenyl groups do not interfere greatly with the crystal packing of the pigment. The solubility is, in fact, reduced further from that of diphenyl DPP. Therefore, it appears that *trans*-stilbenyl groups do not offer any real hope of supplying the desired properties of latent DPP pigments. Because of this it was decided to attempt to synthesise *cis*-stilbene containing DPPs. Since *cis*-stilbenes are certainly not planar, due to the steric interference of the two adjacent phenyl rings, it was suggested that the presence on a DPP pigment of either one or two *cis*-stilbenyl groups instead of the more planar *trans*-stilbenyl group would increase the solubility of the *cis*-stilbenyl DPP pigment in various media compared to the *trans*.

3.09d Synthesis of *cis*-stilbenyl DPPs

The previous method of synthesising stilbenes had produced only the *trans*-isomer in moderate yield. A method of stilbene synthesis generating a high proportion of the *cis*-isomer had to be found. Research into this area indicated a variety of methods, the most promising[42] being to react benzyltriphenylphosphonium chloride with aqueous sodium hydroxide to generate the ylide which then reacts with 4-cyanobenzaldehyde in dichloromethane (DCM) to form the stilbene-carbonitrile with a high proportion as the desired *cis*-isomer.

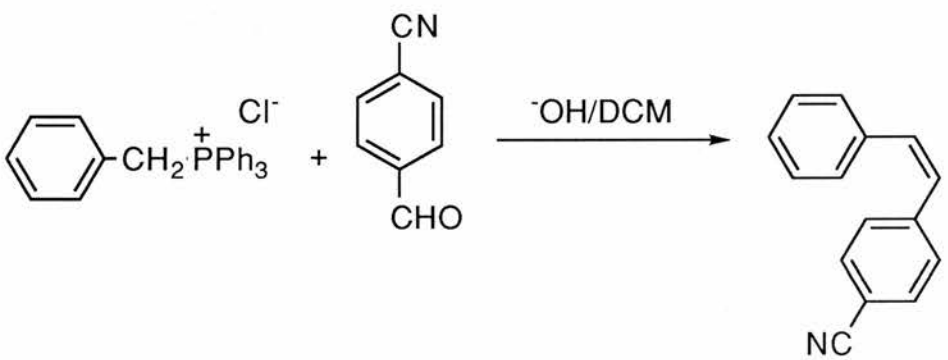

Fig. 3.45 Synthesis of *cis*-stilbene-4-carbonitrile.

Although the synthetic method found was not for the *cis*-stilbene-4-carbonitrile itself, being a method of synthesising *cis*-stilbene, it was thought that the presence of the nitrile on the benzaldehyde would not unduly affect the reaction. Furthermore, although nitriles are unstable to base over long periods, being hydrolysed slowly to acid salts, the rapid Wittig reaction would allow swift work-up before too much decomposition had occurred.

The triphenylphosphonium chloride was deprotonated by the sodium hydroxide to form the ylide as expected. This ylide then reacted with the benzaldehyde-4-carbonitrile to form the oxaphosphetane, which rearranged to form the two expected stilbene-4-carbonitriles, both *cis* and *trans*, and triphenyl phosphine oxide.

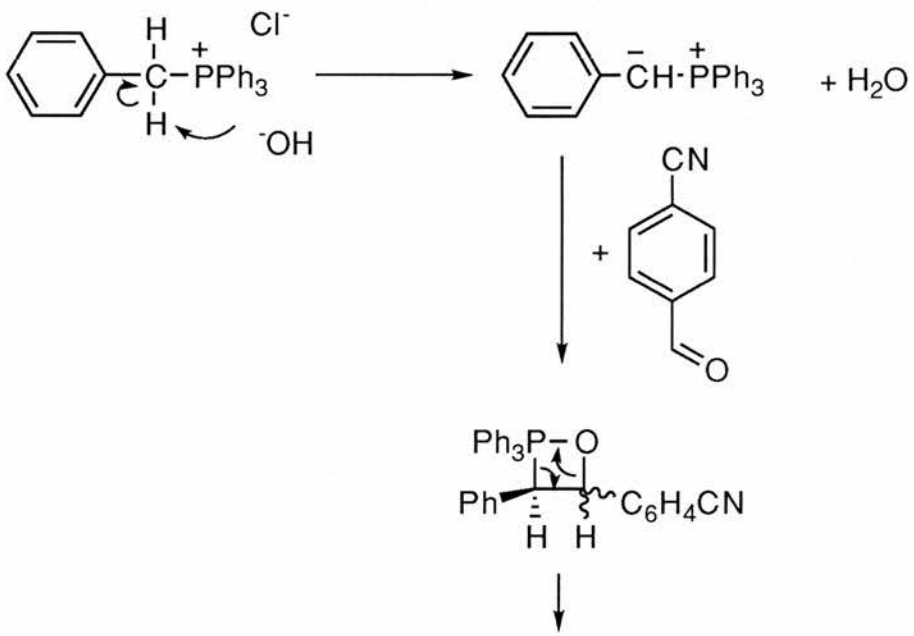

Fig. 3.46 Mechanism of *cis* and *trans*-stilbene-4-carbonitrile synthesis.

The overall yield of this reaction was good, giving a good ratio of the *cis* to *trans*-isomer. The purity of the materials, after column chromatography was also excellent.

Once the *cis*-stilbene-4-carbonitrile had been synthesised it was necessary to synthesise the mono and di-*cis*-stilbenyl DPP pigments. This was done using the same procedures as for the *trans* isomers, with the lactam ester ethyl 2-phenyl-5-ketopyrrole-3-carboxylate being used for the mono-*cis*-stilbenyl DPP, diethyl succinate being used for the di-*cis*-stilbenyl DPP.

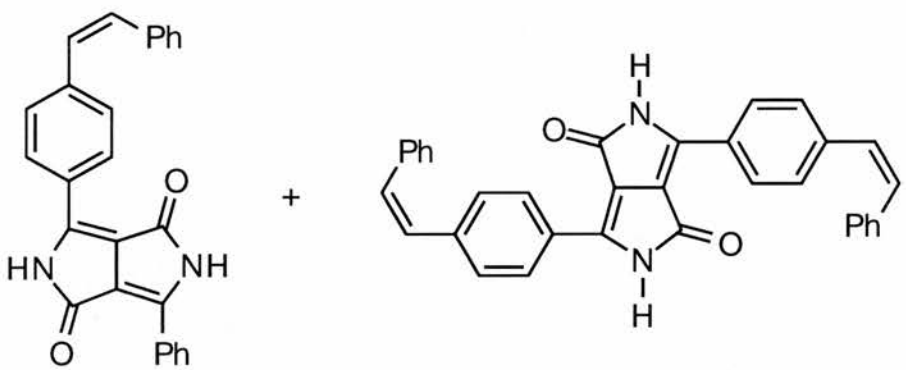

Fig. 3.47 Mono and di-*cis*-stilbenyl DPP pigments.

The yields in both cases were significantly lower than the *trans* isomers. This is possibly due to a steric effect of the slightly overlapping aromatic rings interfering with the nucleophilic attack by the enolate ion.

The solubilities of the mono- and di-stilbenyl DPPs in various solvents were much better than those of the equivalent *trans* DPPs, though still not high. Again, the highest solubility was in acetic acid.

3.09e Synthesis of phenanthryl DPP

Since the aim of this particular work was to convert partially soluble stilbenyl DPPs to hopefully less soluble phenanthryl DPPs *via* photochemical methods it was decided to synthesise a final product, monophenanthryl DPP, before the attempt to photocyclise the stilbenyl DPPs in order to assess the spectral properties. This was achieved by the photocyclisation of *trans*-stilbene-4-carbonitrile to phenanthrene-3-carbonitrile, followed by the incorporation of the phenanthryl group into a DPP by previously established procedures.

A literature procedure[43] was initially followed for the synthesis of phenanthrene from *trans*-stilbene, again in order to gain familiarity with the procedure before risking the valuable stilbene-4-carbonitrile. A dilute solution of *trans*-stilbene in cyclohexane with a catalytic amount of iodine was exposed to UV light to effect the reaction, which was followed by ^{1}H NMR.

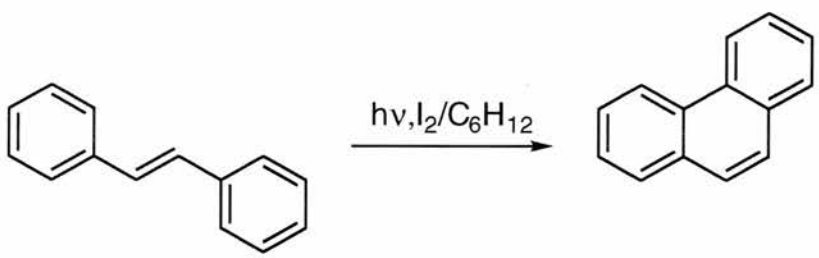

Fig. 3.48 Scheme of photocyclisation of *trans*-stilbene.

The overall yield of this reaction, after purification of the phenanthrene, was over 90%, which was encouraging for the further work concerning the synthesis of phenanthrene-3-carbonitrile from stilbene-4-carbonitrile.

The *trans*-stilbene is initially photoisomerised to the *cis* isomer, which then undergoes conversion of a 1,3,5-hexatriene to a dihydrophenanthrene containing a cyclohexadiene ring. This cyclohexadiene then undergoes hydrogen extraction by either I_2 or dissolved O_2 to form phenanthrene and HI/H_2O. In the case of the I_2, only a catalytic quantity is required due to most of the HI being oxidised back to I_2 and H_2O by dissolved atmospheric O_2.

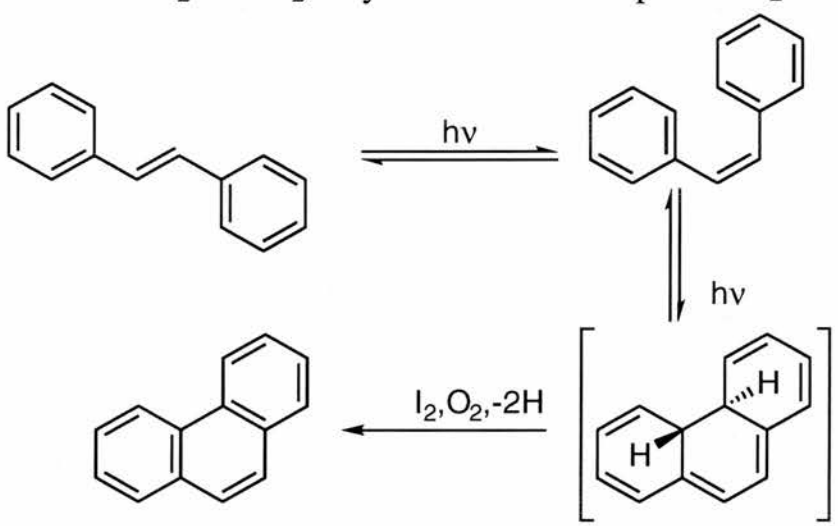

Fig. 3.49 Mechanism of stilbene photocyclisation.

The synthesis of phenanthrene-3-carbonitrile was conducted using essentially identical conditions to the unsubstituted phenanthrene, with the reaction being done at low concentration in cyclohexane with a catalytic amount of iodine. The yield of this reaction was also good, giving enough of the phenanthrene to proceed further with the DPP pigment synthesis.

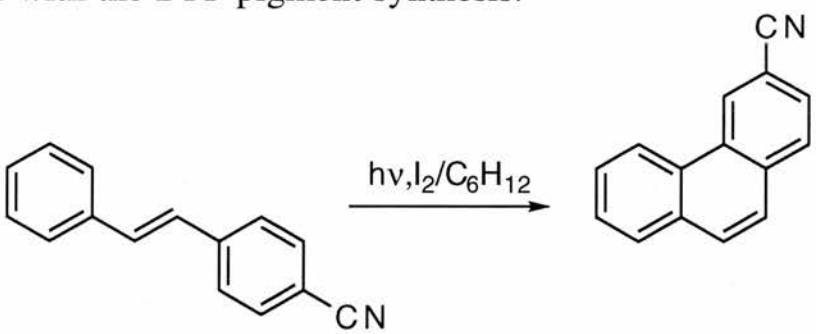

Fig. 3.50 Synthesis of phenanthrene-3-carbonitrile.

The monophenanthryl DPP was synthesised *via* the standard method to give a modest yield of a bright scarlet material.

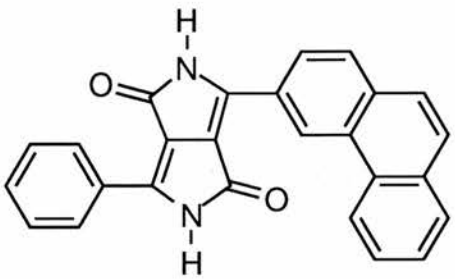

Fig. 3.51 Mono phenanthryl DPP

This was then found to be much more soluble than the mono *trans*-stilbene DPP in organic solvents, especially acetic acid. This indicated that the hoped for reduction in solubility of the immobile planar phenanthryl group as opposed to the more mobile *trans*-stilbenyl group did not occur.

It was, however, decided to continue with the attempted photochemical conversion of the mono-*trans*-stilbenyl to the monophenanthryl DDP in order to demonstrate the possibility of photochemical rearrangements upon DPP pigments in future work.

3.09f Attempted photochemistry of stilbenyl DPPs

Since it had been determined that the solubilities in most organic solvents of the DPP pigments synthesised were not very high, it was necessary to use acetic acid as a solvent for the photochemical reaction. Although acetic acid is not wholly UV transparent it was hoped that it would permit enough of the UV light through to permit the photochemical reaction of the *trans*-stilbenyl group. The reaction conditions used were similar to those used previously, with a dilute solution of the mono-*trans*-stilbenyl DPP in stirred, warm acetic acid containing a catalytic amount of iodine. However, after only one hour of illumination with UV light, the characteristic orange colour of the mono-*trans*-stilbenyl DPP in solution in acetic acid had faded completely, leaving almost no trace of coloured material in the reaction vessel. Removal of the acetic acid at this stage yielded a small amount of brown residue which by TLC gave a continuous trace from baseline to solvent front. This indicated that the mono-*trans*-stilbenyl DPP, far from rearranging to the monophenanthryl DPP, was unstable to the reaction conditions, and therefore had decomposed into a complex mixture of products. The mono-*cis*-stilbenyl DPP was also found to be unstable to visible light while in solution, which indicated the instability of these DPPs in solution to light in general. The reaction scheme involving the synthesis of stilbenyl DPPs to undergo photochemical reactions was therefore abandoned.

The results showed that any method of activation of latent DPP pigments would probably have to involve thermal rather than photochemical processes, as DPP pigments seem to be too unstable to light in solution for any photochemical method to be of practical use.

4) CONCLUSION

It was found that the thermal Diels-Alder reaction between furans and DMAD, followed by aromatisation of the resulting oxabicyclo adducts by either low valence titanium or by concentrated sulphuric acid gave good overall yields of aromatic products of interest in pigment synthesis. Furthermore, the phenol containing compounds resulting from the acid treatment could easily be alkylated in high yields by treatment with mild base and haloalkanes.

The synthesis of a latent DPP pigment met with less success. It was found that in the case of the norbornadiene analogues the nitrile containing prearomatic compounds were inaccessible, due to thermal instability. Furthermore, it was later found that the norbornadiene-type structure envisaged as a precursor to aromatic groups is unstable to the highly basic and nucleophilic DPP forming conditions. This would seem to preclude the formation of DPPs containing these groups by normal methods.

The synthesis of *cis* and *trans*-stilbenyl DPPs was more successful, mono and di-substituted pigments being synthesised. However, the very low solubility of these compounds in most organic solvents was generally inadequate for the desired purpose. It also proved not to be possible to photocyclise them to phenanthryl group containing DPPs in solution, due to the low stability of the DPP to light while in solution.

5) EXPERIMENTAL

Melting points were obtained on an Electrothermal 9100 digital melting point apparatus and are uncorrected. ^{1}H NMR spectra were obtained with a Varian Gemini 200 MHz NMR spectrometer. ^{13}C NMR spectra were obtained on the same Varian Gemini machine operating at 50 MHz. IR spectra were obtained on a Perkin-Elmer 1710 Infrared Fourier transform spectrometer. UV/VIS spectra were obtained on a Philips PU 8730 UV/VIS scanning spectrophotometer.

Phthalate esters experimental

Dimethyl acetylenedicarboxylate

To 255 cm^3 cooled methanol was added in portions, with cooling, 56 cm^3 (1.02 moles) concentrated sulphuric acid. To this cooled solution was added 50 g (0.33 moles) commercial acetylenedicarboxylic acid, mono potassium salt. The mixture was allowed to react, with slow stirring, for four days. The liquid was decanted off the solid layer, which was washed with 250 cm^3 water. The solutions were combined, and washed with 5 x 250 cm^3 portions of diethyl ether. The ether portions were combined with the initial decanted solution, and the combined ether portions were washed with 200 cm^3 water, 150 cm^3 saturated sodium hydrogen carbonate solution, and finally 200 cm^3 water. The solution was dried with calcium chloride, filtered, and the ether removed under reduced pressure. The resulting yellow oil was purified by distillation at 90°C/18 mmHg to give a pale yellow oil. Yield 30.3 g (65 %). ^{1}H NMR ($CDCl_3$) δ_H 3.82 (6H, s, 2 x CO_2Me), identical to an authentic sample.

2-n-Butylfuran

10.25 g (0.15 moles) Furan was added dropwise to a stirred solution of 15 cm^3 10 molar (0.15 moles) commercial n-butyl lithium (in hexanes) in 65 cm^3 tetrahydrofuran at -15°C. The mixture was allowed to warm to room temperature, and stirred for 24 hrs. 16.15 cm^3 (0.15 moles) Dry commercial n-butyl bromide was then added dropwise and the resulting mixture stirred for a further 24 hrs. The resulting brown mixture was then poured on to ~100 g crushed ice and the crude product extracted with 4 x 25 cm^3 diethyl ether. The diethyl ether portions were combined, and the solvent evaporated off under reduced pressure, resulting in a brown/orange oil. This crude product was then diluted with dichloromethane and eluted through a silica column to remove coloured polar impurities. After removal of the dichloromethane the resulting orange oil was then passed through a second column using petroleum ether b.p.40-60°C as eluant, giving a very pale yellow liquid, b.p. 136-7°C Authentic b.p. 138°C[44]. Yield 8.79 g (47 %).^{1}H NMR ($CDCl_3$) δ_H 1.95 (3H, t, 7 Hz, CH_2-Me), 1.38 (2H. sex, 7 Hz, CH_2-CH_2-Me), 1.61 (2H, quin, 7 Hz, CH_2-CH_2-CH_2), 2.62 (2H, t, 7 Hz, furyl-CH_2-CH_2), 5.98 (1H, d, 4 Hz, furyl H), 6.30 (1H, dd, 4 Hz + 1 Hz, furyl H), 7.30 (1H, d, 1 Hz, furyl H), ^{1}H NMR data identical to ref. 44.

2-n-Decylfuran

10.25 g (0.15 moles) Furan was added dropwise to a stirred solution of 15 cm^3 10 molar (0.15 moles) commercial n-butyl lithium (in hexanes) in 65 cm^3 tetrahydrofuran at -15°C. The mixture was allowed to warm to room temperature, and stirred for 24 hrs. 31.12 cm^3 (0.15 moles) Dry commercial n-decyl bromide was then added dropwise and the resulting mixture stirred for a further 24 hrs. The

resulting brown mixture was then poured on to ~100 g crushed ice and the crude product extracted with 4 x 25 cm^3 diethyl ether. The diethyl ether portions were combined, and the solvent evaporated off under reduced pressure, resulting in a brown/orange oil. This crude product was then diluted with petroleum ether b.p.40-60°C and eluted through a silica column to remove coloured polar impurities to give a clear, very pale yellow liquid. Yield 29.43 g (94 %).^{1}H NMR ($CDCl_3$) 0.90 (3H, t, 7 Hz, CH_2-Me), 1.20-1.40 (14H, m, 7 x CH_2), 1.63 (2H, quin, 7 Hz, furyl-CH_2-CH_2-CH_2), 2.62 (2H, t, 7 Hz, furyl-CH_2-CH_2), 5.98 (1H, d, 4 Hz, furyl H), 6.28 (1H, dd, 4 Hz + 1 Hz, furyl H), 7.31 (1H, d, 1 Hz, furyl H), ^{1}H NMR data identical to ref. 44.

Dimethyl 7-oxabicyclo[2.2.1]hepta-2,5-diene-2,3-dicarboxylate

6.15 cm^3 (7.1 g) (0.05 moles) Dimethyl acetylenedicarboxylate (DMAD) and 3.64 cm^3, (3.4 g), (0.05 moles) commercial furan were heated together in a sealed tube at 100°C for 10 hours. Some crystals appeared on the unheated part of the tube and the reaction mixture turned to a brown oil. No further purification was necessary. Yield 10.14 g (97 %). ^{1}H NMR ($CDCl_3$) δ_H 3.82 (6H, s, 2 x CO_2Me), 5.68 (2H, s, 2 x allyl H), 7.21 (2H, s, 2 x vinyl H), ^{1}H NMR data identical to ref. 16.

Dimethyl 1-methyl-7-oxabicyclo[2.2.1]hepta-2,5-diene-2,3-dicarboxylate

6.15 cm^3 (7.1 g) (0.05 moles) Dimethyl acetylenedicarboxylate (DMAD) and 4.57 cm^3, (4.18 g), (0.05 moles) commercial 2-methylfuran were heated together in a sealed tube at 100°C for 10 hours. Some crystals appeared on the unheated part of the tube and the reaction mixture turned to a pale brown oil. No further purification

was necessary. Yield 11.10 g (98 %). ^{1}H NMR ($CDCl_3$) δ_H 1.80 (3H, s, allyl-Me), 3.80 (3H, s, CO_2Me), 3.85 (3H, s, CO_2Me), 5.60 (1H, d, 3 Hz, allyl H), 6.98 (1H, d, 6 Hz, vinyl H), 7.20 (1H, dd, 3 Hz + 6 Hz, vinyl H), ^{1}H NMR data identical to ref. 16.

Dimethyl 1-n-butyl-7-oxabicyclo[2.2.1]hepta-2,5-diene-2,3-dicarboxylate

6.15 cm^3 (7.1 g) (0.05 moles) Dimethyl acetylenedicarboxylate (DMAD) and (6.20 g) (0.05 moles) 2-n-butylfuran were heated together in a sealed tube at 100°C for 10 hours. The reaction mixture turned to an orange-brown oil. Unreacted material was removed under vacuum. No further purification was necessary. Yield 9.25 g (70 %). ^{1}H NMR ($CDCl_3$) δ_H 0.9 (3H, t, 7 Hz, CH_2-Me), 1.38 (4H, m, CH_2-CH_2-CH_2-Me), 2.15 (2H, t, 7 Hz, allyl-CH_2-CH_2), 3.78 (3H, s, CO_2Me), 3,85 (3H, s, CO_2Me), 5.63, (1H, d, 3 Hz, allyl H), 7.00 (1H, d, 6 Hz, vinyl H), 7.18 (1H, dd, 3 Hz + 6 Hz, vinyl H).

Dimethyl 1-n-decyl-7-oxabicyclo[2.2.1]hepta-2,5-diene-2,3-dicarboxylate

6.15 cm^3 (7.1 g) (0.05 moles) Dimethyl acetylenedicarboxylate (DMAD) and (10.41 g) (0.05 moles) 2-n-decylfuran were heated together in a sealed tube at 100°C for 10 hours. Some crystals appeared on the unheated part of the tube and the reaction mixture turned orange. The product was purified by column chromatography using 10% diethyl ether, 90% petroleum ether b.p.40-60 °C as eluant, giving a yellow oil. Yield 14.5g (85%). ^{1}H NMR ($CDCl_3$) δ_H 0.88 (3H, t, 7 Hz, CH_2-Me), 1.20-1.50 (16H, m, 8 x CH_2), 2.12 (2H, t, 7 Hz, allyl-CH_2-CH_2), 3.77 (3H, s, CO_2Me), 3.85 (3H, s, CO_2Me), 5.62

(1H, d, 3 Hz, allyl H), 6.99 (1H, d, 6 Hz, vinyl H), 7.17 (1H, dd, 3 Hz + 6 Hz, vinyl H).

Dimethyl 1-n-dodecyl-7-oxabicyclo[2.2.1]hepta-2,5-diene-2,3-dicarboxylate and Dimethyl 1,4-di-n-dodecyl-7-oxabicyclo[2.2.1]hepta-2,5-diene-2,3-dicarboxylate

0.62 cm^3 (0.72 g) (0.0056 moles) Dimethyl acetylene-dicarboxylate (DMAD) and 1.86 g of a mixture of 2-n-dodecylfuran and 2,5-di-n-dodecylfuran were heated together at 100°C in an open tube for 10 hrs, giving a brown oil. This was subject to column chromatography using 20% diethyl ether, 80% petroleum ether b.p.40-60 °C , giving two fractions of yellow oil. Yield (of monodocecyl adduct) 0.40g. ^1H NMR ($CDCl_3$) δ_H 0.89 (3H, t, 7 Hz, CH_2-Me), 1.20-1.50 (20H, m, 10 x CH_2), 2.24 (2H, t, 7 Hz, allyl-CH_2-CH_2), 3.78 (3H, s, CO_2Me), 3.85 (3H, s, CO_2Me), 5.65 (1H, d, 3 Hz, allyl H) 6.99 (1H, d, 6 Hz, vinyl H), 7.17 (1H, dd, 3 Hz + 6 Hz, vinyl H). Yield (of didodecyl adduct) 1.08 g. ^1H NMR ($CDCl_3$) δ_H 0.89 (6H, t, 7 Hz, 2 x CH_2-Me), 1.20-1.50 (40H, m, 20 x CH_2), 2.15 (4H, t, 7 Hz, 2 x allyl-CH_2-CH_2), 3.78 (6H, s, 2 x CO_2Me), 6.92 (2H, s, 2 x vinyl H).

Dimethyl 3-hydroxyphthalate

To a cooled, stirred solution of 3.0 g (0.0143 moles) dimethyl 7-oxabicyclo[2.2.1]hepta-2,5-diene-2,3-dicarboxylate in 50 cm^3 dichloromethane was added dropwise 0.85 cm^3 (0.015 moles) concentrated sulphuric acid. The initial yellow solution turned red/brown upon addition of the acid, and after one hour the solution had turned deep red/black. The mixture was stirred at room temperature for 50 hours, then 50 cm^3 water was added to dilute the

acid. The mixture was extracted twice with 50 cm^3 dichloromethane, the solvent evaporated off, and the product purified by column chromatography using diethyl ether/petroleum ether b.p.40-60 °C as eluant to give a pale yellow oil. Authentic m.p 67-68°C[44]. Yield 0.54 g (18%). ^1H NMR ($CDCl_3$) δ_H 3.90 (3H, s, CO_2Me), 3.93 (3H, s, CO_2Me), 6.96 (1H, d, 8 Hz, 4-aryl H), 7.10 (1H, d, 8 Hz, 6-aryl H), 7.45 (1H, t, 8Hz, 5-aryl H), 10.60 (1H, s, phenol H).

Dimethyl 6-hydroxy-3-methylphthalate

To a cooled, stirred solution of 3.0 g (0.0134 moles) dimethyl 1-methyl-7-oxabicyclo[2.2.1]hepta-2,5-diene-2,3-dicarboxylate in 50 cm^3 dichloromethane was added dropwise 0.85 cm^3 (0.015 moles) concentrated sulphuric acid. The initial yellow solution rapidly turned red/brown upon addition of the acid, and after ten minutes the reaction mixture was deep brown. The reaction was stirred for 30 minutes then 50 cm^3 water was added to dilute the acid. The mixture was then extracted twice with 50 cm^3 dichloromethane, the solvent evaporated off, and the product purified by column chromatography using diethyl ether/petroleum ether b.p.40-60 °C as eluant to give a pale yellow oil which solidified upon standing to give a pale yellow crystalline material, m.p. 66-67°C. Authentic m.p. 67-68 °C[45]. Yield 2.00 g (67%).^1H NMR ($CDCl_3$) δ_H 2.22 (3H, s, aryl-Me), 3.91 (3H, s, CO_2Me), 3.93 (3H, s, CO_2Me), 6.98 (1H, d, 8 Hz, 5-aryl H), 7.30 (1H, d, 8 Hz, 4-aryl H), 10.78 (1H, s, phenol H).

Dimethyl 3-n-butyl-6-hydroxyphthalate

To a cooled, stirred solution of 3.24 g (0.0122 moles) dimethyl 4-n-butyl-7-oxabicyclo[2.2.1]hepta-2,5-diene-2,3-dicarboxylate in 50 cm^3 dichloromethane was added dropwise 0.85 cm^3 (0.015 moles)

concentrated sulphuric acid. The initial yellow solution quickly turned red, then brown upon addition of the acid, and after ten minutes the reaction mixture was deep brown. The reaction was stirred for half an hour then 50 cm^3 water was added to dilute the acid. The mixture was then extracted twice with 50 cm^3 dichloromethane, the solvent evaporated off, and the product purified by column chromatography using diethyl ether/petroleum ether b.p.40-60 °C as eluant to give a yellow oil. Yield 2.00g (62%). ^1H NMR ($CDCl_3$) δ_H 0.92 (3H, t, 7 Hz, CH_2-Me), 1.35 (2H, sex, 7 Hz, CH_2-CH_2-Me), 1.55 (2H, quin, 7 Hz, CH_2-CH_2-CH_2), 2.43 (2H, t, 7 Hz, aryl-CH_2-CH_2), 3.91 (3H, s, CO_2Me), 3.93 (3H, s, CO_2Me), 6.99 (1H, d, 8 Hz, aryl H), 7.47 (1H, d, 8 Hz, aryl H), 10.82 (1H, s, phenol H).

Dimethyl-3-n-decyl-6-hydroxyphthalate

To a cooled, stirred solution of 5.00 g (0.0143 moles) dimethyl 7-oxabicyclo[2.2.1]-4-n-decylhepta-2,5-diene-2,3-dicarboxylate in 50 cm^3 dichloromethane was added dropwise 0.85 cm^3 (0.015 moles) concentrated sulphuric acid. The initial yellow solution quickly turned red, then brown upon addition of the acid, and after ten minutes the reaction mixture was deep brown. The reaction was stirred for approximately half an hour then 50 cm^3 water was added to dilute the acid. The mixture was extracted twice with 50 cm^3 dichloromethane, the solvent evaporated off, and the product purified by column chromatography using diethyl ether/petroleum ether b.p.40-60 °C as eluant to give a pale yellow oil which crystallised upon standing to give a low melting (< 20°C) waxy solid. Yield 4.02 g (80%). ^1H NMR ($CDCl_3$) δ_H 0.85 (3H, t, 7 Hz, CH_2-Me), 1.20-1.40 (14H, m, 7 x CH_2), 1.56 (2H, quin, 7 Hz, aryl-CH_2-CH_2-CH_2), 2.43 (2H, t, aryl-CH_2-CH_2),

3.91 (3H, s, CO_2Me), 3.93 (3H, s, CO_2Me), 7.00 (1H, d, 8 Hz, 5-aryl H), 7.38 (1H, d, 8 Hz, 4-aryl H), 10.82 (1H, s, phenol H).

4,6-Di-n-dodecyl-3-hydroxyphthalic anhydride

To a cooled, stirred solution of 0.50 g (0.00914 moles) dimethyl 1,4-di-n-dodecyl-7-oxabicyclo[2.2.1]hepta-2,5-diene-2,3-dicarboxylate in 50 cm^3 dichloromethane was added dropwise 0.50 cm^3 (~0.010 moles) concentrated sulphuric acid. The initial yellow solution rapidly turned brown upon addition of the acid, and after a few minutes the reaction mixture was deep brown. The reaction was stirred for 45 minutes then 25 cm^3 water was added to dilute the acid. The mixture was extracted twice with 25 cm^3 dichloromethane, the solvent evaporated off, and the product purified by column chromatography using diethyl ether/petroleum ether b.p.40-60 °C as eluant to give a yellow oil which crystallised on standing to give a pale yellow waxy solid. m.p. 41-43°C. Yield 0.30 g (66%). ^1H NMR ($CDCl_3$) δ_H 0.86 (6H, t, 7 Hz, 2 x CH_2-Me), 1.05-1.40 (36H, m, 18 x CH_2), 1.60 (4H, m, 2 x aryl-CH_2-CH_2-CH_2), 2.73 (2H, t, 7 Hz, aryl CH_2-CH_2), 2.94 (2H, t, 7 Hz, aryl-CH_2-CH_2), 7.38 (1H, s, aryl H). High res. MS (EI): found m/z = 500.385651; expected $M^{+\cdot}$ for $C_{32}H_{52}O_4$ = 500.386561.

Dimethyl 6-methoxy-3-methylphthalate

To a solution of 0.50 g (0.00223 moles) dimethyl 6-hydroxy-3-methylphthalate in 5 cm^3 acetone was added 0.46 g (0.00268 moles) potassium carbonate and one drop of water. Some slight effervescence occurred. The mixture was heated under reflux for 30 minutes, and the colour of the mixture changed from very pale yellow to pale brown. 0.167 cm^3 (0.00268 moles) methyl iodide were then added,

and the mixture heated under reflux for 12 hours, while being monitored by TLC. The pale brown colour faded slightly during this time. The acetone was then evaporated off under reduced pressure, ~25 cm^3 diethyl ether added, and the slurry washed with water. The ether fraction was collected and the ether evaporated under reduced pressure, leaving a clear, slightly yellow oil. The oil was distilled at 135°C/0.6 mBar, to give a colourless oil which crystallised upon standing to give white crystals, m.p.46-7°C. Yield 0.44 g (84%).^{1}H NMR ($CDCl_3$) δ_H 2.38 (3H, s, aryl-Me), 3.85 (3H, s, OMe), 3.87 (3H, s, OMe), 3.89 (3H, s, OMe), 6.95 (1H, d, 8 Hz, 5-aryl H), 7.25 (1H, d, 8 Hz, 4-aryl H). High res. MS (EI): found m/z = 238.084771; expected $M^{+\cdot}$ for $C_{12}H_{14}O_5$ = 238.084124.

Dimethyl 6-n-butoxy-3-methylphthalate

To a solution of 0.50 g (0.00223 moles) dimethyl 6-hydroxy-3-methylphthalate in 5 cm^3 acetone was added 1.00 g (0.0072 moles) potassium carbonate and one drop of water. Some slight effervescence occurred. The mixture was heated under reflux for 30 minutes, and the colour of the mixture changed from very pale yellow to pale brown. A small amount (~1mg) of sodium iodide and 0.48 cm^3 (0.00446 moles) n-butyl bromide were then added, and the mixture heated under reflux for 12 hours, while being monitored by TLC. The pale brown colour faded slightly during this time. The acetone was then evaporated off under reduced pressure, ~25 cm^3 diethyl ether added, and the slurry washed with water. The ether fraction was collected and the ether evaporated under reduced pressure, leaving a clear, slightly yellow oil. The oil was distilled at 155°C/0.6 mBar, to give a pale yellow oil. Yield 0.55 g (90%). ^{1}H NMR ($CDCl_3$) δ_H 0.93 (3H, t, 7 Hz, CH_2-Me), 1.46 (2H, sex, 7 Hz, CH_2-CH_2-Me), 1.71 (2H,

quin, 7 Hz, aryl-O-CH_2-$\underline{CH_2}$-CH_2), 2.34 (3H, s, aryl-Me), 3.82 (3H, s, CO_2Me), 3.84 (3H, s, CO_2Me), 3.98 (2H, t, 7 Hz, aryl-O-$\underline{CH_2}$-CH_2), 6.92 (1H, d, 8 Hz, 5-aryl H), 7.20 (1H, d, 8 Hz, 4-aryl H). High res. MS (EI):found *m/z* = 280.130327; expected $M^{+\cdot}$ for $C_{15}H_{20}O_5$ = 280.131074.

Dimethyl 6-isopropoxy-3-methylphthalate

To a solution of 0.50 g (0.00223 moles) dimethyl 6-hydroxy-3-methylphthalate in 5 cm^3 acetone was added 1.00 g (0.0072 moles) potassium carbonate and one drop of water. Some slight effervescence occurred. A small amount (~1mg) of sodium iodide and 0.42 cm^3 (0.00446 moles) isopropyl bromide were then added, and the mixture heated under reflux for 12 hours, while being monitored by TLC. The initial pale yellow colour of the solution changed to pale brown, which then faded slightly during this time. The acetone was then evaporated off under reduced pressure, ~25 cm^3 diethyl ether added, and the slurry washed with water. The ether fraction was collected and the ether evaporated under reduced pressure, leaving a clear, slightly yellow oil. The oil was distilled at 140°C/0.5 mbar to give a colourless oil. Yield 0.49 g (82%).^{1}H NMR ($CDCl_3$) δ_H 1.3 (6H, d, 7 Hz, 2 x aryl-O-isopropyl CH_3), 2.38 (3H, s, aryl-Me), 3.85 (3H, s, CO_2Me), 3.87 (3H, s, CO_2Me), 4.50 (1H, sept, 7 Hz, aryl-O-isopropyl CH), 6.97 (1H, d, 8 Hz, 5-aryl H), 7.20 (1H, d, 8 Hz, 4-aryl H), High res. MS (EI):found *m/z* = 266.115846; expected $M^{+\cdot}$ for $C_{14}H_{18}O_5$ = 266.115424.

Dimethyl 3-n-butyl-6-methoxyphthalate

To a solution of 0.50 g (0.00188 moles) dimethyl 3-n-butyl-6-hydroxyphthalate in 5 cm^3 acetone was added 1.00 g (0.0072 moles)

potassium carbonate and one drop of water. Some slight effervescence occurred. 0.21 cm^3 (0.00331 moles) methyl iodide were then added, and the mixture heated under reflux for 12 hours, while being monitored by TLC. The initial pale yellow colour of the solution changed to pale brown, which then faded slightly during this time. The acetone was then evaporated off under reduced pressure, ~25 cm^3 diethyl ether added, and the slurry washed with water. The ether fraction was collected and the ether evaporated under reduced pressure, leaving a clear, slightly yellow oil. The oil was distilled at 150°C/0.6 mBar to give a colourless oil. Yield 0.3 g (57%). ^1H NMR ($CDCl_3$) δ_H 0.90 (3H, t, 7 Hz, CH_2-Me), 1.20-1.65 (4H, m, CH_2-CH_2-CH_2-Me), 2.67 (2H, t, 7 Hz, aryl-CH_2-CH_2), 3.85 (3H, s, OMe), 3.86 (3H, s, OMe), 3.87 (3H, s, OMe), 6.98 (1H, d, 8 Hz, 5-aryl H), 7.27 (1H, d, 8 Hz, 4-aryl H). High res. MS (EI):found m/z = 280.130643; expected $M^{+\cdot}$ for $C_{15}H_{20}O_5$ = 280.131074.

Dimethyl 3-n-decyl-6-methoxyphthalate

To a solution of 0.50 g (0.00188 moles) dimethyl 3-n-decyl-6-hydroxyphthalate in 5 cm^3 acetone was added 1.00 g (0.0072 moles) potassium carbonate and one drop of water. Some slight effervescence occurred. 0.405 g (0.00285 moles) methyl iodide were then added, and the mixture heated under reflux for 12 hours, while being monitored by TLC. The initial pale yellow colour of the solution changed to pale brown, which then faded slightly during this time. The acetone was then evaporated off under reduced pressure, ~25 cm^3 diethyl ether added, and the slurry washed with water. The ether fraction was collected and the ether evaporated under reduced pressure, leaving a clear slightly yellow oil which crystallised upon standing to give a pale yellow crystalline solid, m.p. 45-47°C. Yield

0.50 g (96%). ^{1}H NMR ($CDCl_3$) δ_H 0.88 (3H, t, 7 Hz, CH_2-Me), 1.20-1.40 (14H, m, 7 x CH_2), 1.51 (2H, quin, 7 Hz, aryl-CH_2-CH_2), 2.64 (2H, t, 7 Hz, aryl-CH_2-CH_2), 3.84 (3H, s, OMe), 3.85 (3H, s, OMe), 3.87 (3H, s, OMe), 6.98 (1H, d, 8 Hz, 5-aryl H), 7.25 (1H, d, 8 Hz, 4-aryl H). High res. MS (EI):found *m/z* = 364.224036; expected $M^{+\cdot}$ for $C_{21}H_{32}O_5$ = 364.224974.

Dimethyl 6-hexadecoxy-3-methylphthalate

To a solution of 0.50 g (0.00188 moles) dimethyl 6-hydroxy-3-methylphthalate in 5 cm^3 acetone was added 1.00 g (0.0072 moles) potassium carbonate and one drop of water. Some slight effervescence occurred. 1.18 g (0.00335 moles) hexadecyl iodide were then added, and the mixture heated under reflux for 12 hours, while being monitored by TLC. The initial pale yellow colour of the solution changed to pale brown, which then faded slightly during this time. The acetone was then evaporated off under reduced pressure, ~25 cm^3 diethyl ether added, and the slurry washed with water. The ether fraction was collected and the ether evaporated under reduced pressure, leaving a clear yellow oil which crystallised upon standing to give a pale yellow crystalline solid that was recrystallised from acetone/water. m.p. 38-39.5°C. Yield 0.83 g (83%). ^{1}H NMR ($CDCl_3$) δ_H 0.89 (3H, t, 7 Hz, CH_2-Me), 1.20-1.50 (26H, m, 13 x CH_2), 1.73 (2H, quin, aryl-CH_2-CH_2-CH_2), 2.38 (3H, s, aryl-Me), 3.87 (3H, s, CO_2Me), 3.89 (3H, s, CO_2Me), 3.98 (2H, t, 7 Hz, aryl-CH_2-CH_2), 6.92 (1H, d, 8 Hz, 5-aryl H), 7.21 (1H, d, 8 Hz, 4-aryl H). High res. MS (EI):found *m/z* = 448.317683; expected $M^{+\cdot}$ for $C_{27}H_{44}O_5$ = 448.318875.

Dimethyl 3-n-butyl-6-(3-phenyl-n-propoxy)phthalate

To a solution of 0.50 g (0.00188 moles) dimethyl 3-n-butyl-6-hydroxyphthalate in 5 cm^3 acetone was added 1.00 g (0.0072 moles) potassium carbonate and one drop of water. Some slight effervescence occurred. A small amount (~1mg) of sodium iodide and 0.42 cm^3 (0.00282 moles) 1-bromo-3-phenylpropane were then added, and the mixture refluxed for 12 hours, while being monitored by TLC. The initial pale yellow colour of the solution changed to pale brown, which then faded slightly during this time. The acetone was then evaporated off under reduced pressure, ~25 cm^3 diethyl ether added, and the slurry washed with water. The ether fraction was collected and the ether evaporated under reduced pressure, leaving a clear yellow oil. This was distilled at 155°C/0.06 mBar to give a pale yellow oil. Yield 0.41 g (57%). ^1H NMR ($CDCl_3$) δ_H 0.91 (3H, t, 7 Hz, CH_2-Me), 1.35 (2H, sex, 7 Hz, CH_2-CH_2-Me), 1.52 (2H, quin, 7 Hz, CH_2-CH_2-CH_2), 2.18 (2H, quin, 7 Hz, aryl-CH_2-CH_2-CH_2-O-aryl), 3.67 (2H, t, 7 Hz, aryl-CH_2-CH_2-CH_2-Me), 2.70 (2H, t, 7 Hz, aryl-CH_2-CH_2-CH_2-O-aryl), 3.89 (3H, s, CO_2Me), 3.71 (3H, s, CO_2Me), 3.98 (2H, t, 7 Hz, aryl-O-CH_2-CH_2), 6.91 (1H, d, 8 Hz, 5-aryl H), 7.15-7.35 (6H, m, aryl H). High res. MS (EI):found m/z = 384.192785; expected $M^{+\cdot}$ for $C_{23}H_{28}O_5$ = 384.193674.

Dimethyl 3-methoxyphthalate

To a solution of 0.53 g (0.002 moles) dimethyl 3-hydroxyphthalate in 5 cm^3 acetone was added 1.00 g (0.0072 moles) potassium carbonate and one drop of water. Some slight effervescence occurred. 0.57 g (0.004 moles) methyl iodide were then added, and the mixture refluxed for 12 hours, while being monitored by TLC. The initial pale yellow colour of the solution changed to pale brown,

which then faded slightly during this time. The acetone was then evaporated off under reduced pressure, ~25 cm^3 diethyl ether added, and the slurry washed with water. The ether fraction was collected and the ether evaporated under reduced pressure, leaving a clear yellow oil. This was purified by column chromatography using diethyl ether/petroleum ether b.p.40-60 °C as eluant to give a colourless oil that crystallised upon standing. m.p. 76.5-77°C. Authentic m.p. 77-78°C[46]. Yield 0.40 g (90%). ^1H NMR ($CDCl_3$) δ_H 3.87 (3H, s, CO_2Me), 3.89 (3H, s, CO_2Me), 3.97 (3H, s, aryl-O-Me), 7.12 (1H, d, 8 Hz, 4-aryl H), 7.42 (1H, t, 8 Hz, 6-aryl H), 7.60 (1H, d, 8 Hz, 5-aryl H). High res. MS (EI):found *m/z* = 224.069286; expected $M^{+\cdot}$ for $C_{11}H_{12}O_5$ = 224.068474.

Dimethyl 6-benzyloxy-3-n-decylphthalate

To a solution of 0.50 g (0.00188 moles) dimethyl 3-n-decyl-6-hydroxyphthalate in 5 cm^3 acetone was added 1.00 g (0.0072 moles) potassium carbonate and one drop of water. Some slight effervescence occurred. A small amount (~1mg) of sodium iodide and 0.5 g (0.0028 moles) benzyl bromide were then added, and the mixture refluxed for 4 hours, while being monitored by TLC. The initial pale yellow colour of the solution changed to pale brown, which then faded rapidly during this time. The acetone was then evaporated off under reduced pressure, ~25 cm^3 diethyl ether added, and the slurry washed with water. The ether fraction was collected and the ether evaporated under reduced pressure, leaving a clear yellow oil which was distilled at 155°C, 0.06 mBar to give a clear, pale yellow oil. Yield 0.38 g (60%). ^1H NMR ($CDCl_3$) δ_H 0.89 (3H, t, 7 Hz, CH_2-Me), 1.20-1.40 (14H. m, 7 x CH_2), 1.51 (2H, quin, 7 Hz, aryl-CH_2-CH_2-CH_2), 2.64 (2H, t, 7 Hz, aryl-CH_2-CH_2), 3.87 (3H, s, CO_2Me), 3.89 (3H, s,

CO_2Me), 5.14 (2H, s, aryl-CH_2-O), 6.98 (1H, d, 8 Hz, 5-aryl H), 7.21 (1H, d, 8 Hz, 4-aryl H), 7.30-7.45 (5H, m, aryl H). High res. MS (EI):found *m/z* = 440.257340; expected $M^{+\cdot}$ for $C_{27}H_{36}O_5$ = 440.256275.

Dimethyl 3-methylphthalate

15.20 cm^3 (0.13 moles) Titanium tetrachloride was added dropwise, under nitrogen, with stirring to 40 cm^3 dry tetrahydrofuran. An immediate vigorous reaction occurred, producing a bright yellow solid which was slightly soluble in the THF. To this thick slurry was added dropwise with stirring a suspension of 2.00 g (0.52 moles) lithium aluminium hydride in 60 cm^3 dry THF, followed by 1.88 g (0.0018 m triethylamine. The reaction mixture immediately changed colour from yellow to black. The mixture was refluxed at 65°C for 30 minutes, and then cooled to room temperature. 4.44 g (0.02 moles) dimethyl 1-methyl-7-oxabicyclo[2.2.1]hepta-2,5-diene-2,3-dicarboxylate in 20 cm^3 THF was added. The reaction mixture was stirred for 24 hours then poured into 400 cm^3 20 % potassium carbonate solution. The resulting purple/black sludge was filtered and the filter cake extracted with dichloromethane. Exposure to air led to the filter cake rapidly turning from deep violet to white. The filtrate was extracted with 3 x 100 cm^3 dichloromethane, the DCM fractions combined and dried with magnesium sulphate. The DCM was removed under reduced pressure, and the residue distilled at 95°C/0.2 mBar to give a pale yellow oil. Authentic b.p.92-94°C/0.2 mBar[16]. Yield 2.5 g (61 %).^{1}H NMR ($CDCl_3$) δ_H 2.32 (3H, s, aryl-Me), 3.76 (3H, s, CO_2Me), 3.82 (3H, s, CO_2Me), 7.30-7.45 (2H, m, aryl H), 7.80 (1H, dd, 2 Hz + 8 Hz, 5-aryl

H), identical to ref. 16. High res. MS (EI):found *m/z* = 208.073972; expected $M^{+\cdot}$ for $C_{11}H_{12}O_4$ = 208.073559.

Dimethyl 3-n-butylphthalate

15.20 cc (0.13 moles) Titanium tetrachloride was added dropwise, under nitrogen, with mechanical stirring to 40 cm^3 dry tetrahydrofuran. An immediate vigorous reaction occurred, producing a bright yellow solid which was slightly soluble in the THF. To this thick slurry was added dropwise with mechanical stirring a suspension of 2.00 g (0.52 moles) lithium aluminium hydride in 60 cm^3 dry THF, followed by 1.88 g (0.0018 m triethylamine. The reaction mixture immediately changed colour from yellow to black. The mixture was refluxed at 65°C for 30 minutes, and then cooled to room temperature. 4.44 g (0.02 moles) dimethyl 1-n-butyl-7-oxabicyclo[2.2.1]hepta-2,5-diene-2,3-dicarboxylate in 20 cm^3 THF was added. The reaction mixture was stirred for 24 hours then poured into 400 cm^3 20 % potassium carbonate solution. The resulting purple/black sludge was filtered and the filter cake extracted with dichloromethane. Exposure to air led to the filter cake rapidly turning from deep violet to white. The filtrate was extracted with 3 x 100 cm^3 dichloromethane, the DCM fractions combined and dried with magnesium sulphate. The DCM was removed under reduced pressure, and the residue distilled at 95°C/0.07 mBar to give a pale yellow oil. Yield 2.90 g (58 %). ^1H NMR ($CDCl_3$) δ_H 0.91 (3H, t, 7 Hz, CH_2-Me), 1.36 (2H, sex, 7 Hz, CH_2-CH_2-Me), 1.60 (2H, quin, 7 Hz, aryl-CH_2-CH_2-CH_2), 2.61 (2H, t, 7 Hz, aryl-CH_2-CH_2), 3.89 (3H, s, CO_2Me), 3.95 (3H, s, CO_2Me), 7.42 (2H, m, aryl H), 7.84 (1H, dd, 2 Hz + 8 Hz, 5-aryl H). High res. MS (EI):found *m/z* = 250.121177; expected $M^{+\cdot}$ for $C_{14}H_{18}O_4$ = 250.120509.

Dimethyl 3-n-decylphthalate

7.60 cc (0.065 moles) Titanium tetrachloride was added dropwise, under nitrogen, with mechanical stirring to 20 cm^3 dry tetrahydrofuran. An immediate vigorous reaction occurred, producing a bright yellow solid which was slightly soluble in the THF. To this thick slurry was added dropwise with mechanical stirring a suspension of 1.00 g (0.26 moles) lithium aluminium hydride in 30 cm^3 dry THF, followed by 0.94 g (0.0009 m triethylamine. The reaction mixture immediately changed colour from yellow to black. The mixture was refluxed at 65°C for 30 minutes, and then cooled to room temperature. 3.50 g (0.01 moles) dimethyl 1-n-decyl-7-oxabicyclo[2.2.1]hepta-2,5-diene-2,3-dicarboxylate in 10 cm^3 THF was added. The reaction mixture was stirred for 24 hours then poured into 200 cm^3 20 % potassium carbonate solution. The resulting purple/black sludge was filtered and the filter cake extracted with dichloromethane. Exposure to air led to the filter cake rapidly turning from deep violet to white. The filtrate was extracted with 3 x 50 cm^3 dichloromethane, the DCM fractions combined and dried with magnesium sulphate. The DCM was removed under reduced pressure, and the residue distilled at 150°C/0.04 mBar to give a very pale yellow oil. Yield 2.0 g (60 %). ^1H NMR ($CDCl_3$) δ_H 0.89 (3H, t, 7 Hz, CH_2-Me), 1.20-1.45 (14H, m, 7 x CH_2), 1.60 (2H, quin, 7 Hz, aryl-CH_2-CH_2-CH_2), 2.60 (2H, t, 7 Hz, aryl-CH_2-CH_2), 3.89 (3H, s, CO_2Me), 3.94 (3H, s, CO_2Me), 7.35-7.50 (2H, m, 2 x aryl H), 7.85 (1H, dd, 2 Hz + 8 Hz, 5-aryl H). High res. MS (EI):found *m/z* = 334.213793; expected $M^{+\cdot}$ for $C_{20}H_{30}O_4$ = 334.214410.

Coumalic acid

To a stirred mixture of 50 g (0.37 moles) malic acid and 43 cm^3 concentrated sulphuric acid was added 3 x 13 cm^3 oleum, 20-30% SO_3, at 45 minute intervals. Some effervescence occured as the malic acid dissolved, giving a pale brown solution. The solution was heated at 95°C for 2 hours. During this time, much gas was given off, and the colour of the mixture turned deeper yellow-brown. The solution was allowed to cool slightly, then poured on to 200 g cruched ice. The mixture was allowed to stand for 24 hours, after which a yellow-brown precipitate had formed. The mixture was filtered, the precipitate washed with 3 x 13 cm^3 ice cold water and dried to give 11.05 g pale brown crude material. This was dissolved in 100 cm^3 methanol, boiled with 1 g activated charcoal, filtered hot and allowed to recrystallise, giving very pale yellow crystals, m.p. 202-4°C (decomposes) Authentic m.p. 203-205°C[18] (decomposes). Yield 7.42 g (29%). ^1H NMR (D_6 Acetone) δ_H 6.39 (1H, dd, 1 Hz + 10 Hz, 3-vinyl H), 7.85 (1H, dd, 3 Hz + 10 Hz, 2-vinyl H), 8.47 (1H, dd, 1 Hz + 3 Hz, 6-vinyl H). A repeat of the above experiment, identical but for the cooling of the reaction mixture in an ice bath to 5-10°C before quenching over crushed ice yielded an immediate yellow-brown precipitate, which after filtering gave 19.10 g yellow-brown crystalline solid. This was purified by sublimation under vacuum to give a pure white crystalline solid, m.p.203-205°C (decomposes). Yield 13.70 g (53 %).

Coumalonitrile

To 1.01 g (0.00723 moles) coumalic acid was added 5 cm^3 purified thionyl chloride. The mixture was refluxed for ~1 hour, after which time the acid had dissolved, giving a clear, brown solution. The

thionyl chloride was distilled off under reduced pressure, leaving a brown mass, which after short-path distillation at 90-95°C/0.01 mBar, gave 1.00 g (0.0063 moles) pale yellow coumaloyl chloride. This was quickly placed in an open-topped flask along with 0.8 g (0.0083 moles) sulphamide and heated at 120°C for 3 hours. An acidic gas was evolved over this time. After cooling, a reddish-brown glassy mass remained. This was dissolved in 50 cm^3 water, washed with 3 x 50 cm^3 dichloromethane, the pH of the water phase was adjusted to pH 4-5 with sodium hydrogen carbonate, then extracted with 2 x 50 cm^3 dichloromethane. The DCM extracts were combined, washed with 100 cm^3 saturated sodium chloride solution, dried with magnesium sulphate, filtered then the solvent removed under reduced pressure to give a pale yellow crystalline material, m.p. 98-99°C Authentic m.p. 98-99°C[20]. Yield 0.63 (82%). ^1H NMR ($CDCl_3$) δ_H 6.42 (1 H, dd, 1 Hz + 10 Hz, 3-vinyl H), 7.34 (1 H, dd, 3 Hz + 10 Hz, 2-vinyl H), 8.04 (1 H, m, 6-vinyl H).

1,2-Dimethyl trimellitate

0.85 g (0.006 moles) Dimethyl acetylenedicarboxylate and 0.7 g (0.005 moles) coumalic acid were heated together in an open tube at 170-180°C for 5 minutes. A strong evolution of gas occurred, along with the dissolution of the coumalic acid. Upon final disappearance of the coumalic acid gas evolution ceased immediately. The resulting yellow oil was purified by column chromatography.giving a very pale yellow solid which was recrystallised from benzene, giving a white solid, m.p. 115-116°C. Authentic m.p. 115.5-117°C[47]. Yield 0.56 g (47%).^1H NMR (D_6 Acetone) δ_H 3.95 (6H, s, 2 x CO_2Me), 7.79 (1H, d, 8 Hz, 4-aryl H), 8.28 (1H, d, 8 Hz, 5-aryl H), 8.50 (1H, s, 3-aryl H), 10.08 (1H, s, CO_2H).

Dimethyl 4-cyanophthalate

0.15 g (0.0011 moles) Dimethyl acetylenedicarboxylate and 0.12 g (0.001 moles) coumalonitrile were heated together in an open tube at 170-180°C for 5 minutes. A strong evolution of gas occured. The resulting yellow oil was purified by column chromatography using diethyl ether/petroleum ether 4060 as eluant, giving a pale brown oil. This was distilled at 140°C/2.5 mBar to give a colourless, clear oil. Authentic m.p. 50-51°C[48]. Yield 0.17 g (78 %). ^{1}H NMR ($CDCl_3$) δ_H 3.94 (6H, s, 2 x CO_2Me), 7.74 -7.88 (2H, m, aryl H), 8.07 (1H, s, 3-aryl H). FT-IR (KBr plate) cm^{-1} 2957 (sharp, medium, C-H stretch), 2237 (sharp, medium, C≡N stretch), 1736 (strong, aryl ester C=O stretch), 1497 (strong, aromatic C=C stretch).

Latent DPP pigment experimental

Coumalin

2.00 g (0.0014 moles) Coumalic acid was sublimed at 180-210°C/8 x10^{-2} torr. The resulting vapour was then passed through a furnace at 700°C and a liquid nitrogen trap. Recovery of the resulting oil followed by column chromatography using diethyl ether/petroleum ether b.p. 40-60 °C as eluant gave a clear, slightly yellow oil, which was purified by distillation at 90°C/18mmHg. Authentic b.p.110°C/26mmHg[25]. Yield 1.10 g (80%). ^{1}H NMR ($CDCl_3$) δ_H 6.20-6.40 (2H, m, vinyl H), 7.30 (1H, m, 2-vinyl H), 7.50 (1H, m, 6-vinyl H).

Diisopropyl 1,2-dihydropyridazine-1,2-dicarboxylate (Failed)

A mixture of 0.50 g (0.0052 moles) coumalin and 1.05 g (0.0052 moles) diisopropyl azodicarboxylate in 5 cm^3 toluene was

heated to reflux. A steady effervescence of gas (found to be CO_2, by passing through saturated $Ca(OH)_2$ soln.) occurred, along with a steady darkening of the reaction mixture. The temperature was maintained until the gas evolution had ceased. TLC examination of the reaction mixture showed a complex mixture of products, and ^1H NMR spectroscopy at this stage indicated none of the desired product had been synthesised. The experiment was abandoned.

Polyethyl phosphate (PEP)

50 g (0.18 moles) phosphorus pentoxide, 100 cm^3 dry chloroform and 50 cm^3 sodium-dried diethyl ether were heated under reflux for 24 hours at 60°C. After this time most of the phosphorus pentoxide had dissolved. The mixture was filtered through glass wool and the solvent evaporated to give a viscous pale yellow oil, setting into a gel at ~0°C. Yield 72.6 g (95%). FT-IR (KBr plate) cm^{-1} 2992 (sharp, weak, C-H stretch), 1481 + 1447 (sharp, weak, C-H deformations), 1397 + 1373 (sharp, weak, C-H symmetrical deformations), 1275 (broad, strong, P=O), 1035 (broad, strong, P-O-alkyl), 920 (broad, strong, P-O-P).

3-Phenylpropynonitrile

A mixture of 2.92 g (0.02 moles) phenylpropiolic acid, 12 g PEP and 10 cm^3 chloroform in a three-necked flask was cooled to 0°C. Ammonia gas was flushed through the flask and a balloon containing ~0.5 l ammonia gas attached. The mixture was mechanically stirred for 30 minutes at 0-5°C, with the ammonia containing balloon being replaced when necessary, then for 90 minutes at 20°C. The mixture became very viscous. the balloon was removed and a further 20 g PEP added. The mixture was then stirred

at 80°C for several hours, then stirred with 300 cm^3 25% sodium carbonate, washed with 3 x 80 cm^3 toluene, dried with sodium sulphate, filtered and the solvent evaporated. The residual oil was distilled at 50°C/0.1 mBar to give a pale yellow solid, m.p. 36.5°C. Authentic m.p. 38-40°C[29]. Yield 0.80 g (31 %). FT-IR (KBr plate) cm^{-1} 3067 (sharp, weak, aryl-H stretch), 2271 (sharp, strong, C≡N stretch), 2144 (sharp, medium, C≡C stretch), 1595 + 1575 + 1490 (sharp, medium, aryl C=C stretch), 759 + 688 (sharp, strong, mono-substituted aryl-H bending).

Diisopropyl 1,2,3,6-tetrahydropyridazine-1,2-dicarboxylate

Buta-1,3-diene gas was bubbled through a solution of 5.0 g (0.025 moles) diisopropyl azodicarboxylate in 3 cm^3 toluene at 50°C until the orange colour of the diisopropyl azodicarboxylate faded. The toluene was removed under reduced pressure, leaving a very pale yellow oil. This was purified by distillation at 111°C/0.1 mBar to give a colourless oil. Yield 5.70 g (90%). ^1H NMR ($CDCl_3$) δ_H 1.25 (12H, d, 7 Hz, 4 x O-isopropyl CH_3), 3.75 (2H, m, allyl H), 4.44 (2H, m, allyl H), 4.97 (2H, sept, 7 Hz, 2 x O-isopropyl CH), 5.79 (2H, s, vinyl H).

Diisopropyl 4,5-dimethyl-1,2,3,6-tetrahydropyridazine-1,2-dicarb-oxylate

A mixture of 2.03 g (0.025 moles) 2,3-dimethylbuta-1,3-diene and 5.0 g (0.025 moles) diisopropyl azodicarboxylate in 3 cm^3 toluene was heated at 50°C until the orange colour of the diisopropyl azodicarboxylate faded. The toluene was removed under reduced pressure, leaving a pale yellow oil. This was purified by distillation at 120°C/0.1 mBar to give a very pale yellow oil which crystallised upon

standing to give a waxy solid, m.p. 52-4°C. Yield 4.92 g (70%). ^{1}H NMR ($CDCl_3$) δ_H 1.25 (12H, d, 7 Hz, 4 x isopropyl CH_3), 1.63 (6H, s, 2 x vinyl-Me), 3.60 (2H, m, allyl H), 4.20 (2H, m, allyl H), 4.97 (2H, sept, 7 Hz, 2 x isopropyl CH).

Diisopropyl 4-methyl-1,2,3,6-tetrahydropyridazine-1,2-dicarboxylate

A mixture of 0.68 g (0.01 moles) 3-methylbuta-1,3-diene and 1.01 g (0.005 moles) diisopropyl azodicarboxylate in 3 cm^3 toluene was heated at 50°C until the orange colour of the diisopropyl azodicarboxylate faded. The toluene was removed under reduced pressure, leaving a colourless oil. Yield 1.35 g (100%). ^{1}H NMR ($CDCl_3$) δ_H 1.23 (12H, d, 6 Hz, 4 x isopropyl CH_3), 1.69 (3H, s, vinyl-Me), 3.69 (2H, m, allyl H), 4.30 (2H, m, allyl H), 4.92 (2H. sept, 6 Hz, isopropyl CH), 5.43 (1H, s, vinyl H). The experiment repeated with 1.0 g (0.014 moles) 3-methylbuta-1,3-diene and 2.5 g (0.012 moles) diisopropyl azodicarboxylate gave 3.49 g (99 % yield).

Diisopropyl 3-methyl-1,2,3,6-tetrahydropyridazine-1,2-dicarboxylate

A mixture of 1.36 g (0.02 moles) 90 % penta-1,3-diene (*cis* + *trans*) and 1.01 g (0.005 moles) diisopropyl azodicarboxylate in 3 cm^3 toluene was heated at 50°C until the orange colour of the diisopropyl azodicarboxylate faded. The toluene was removed under reduced pressure, leaving a colourless oil. Yield 1.35 g (100%). ^{1}H NMR ($CDCl_3$) δ_H 1.20-1.40 (15H, m, 4 x isopropyl CH_3 + allyl-Me), 3.69 (1H, m, allyl H), 4.42 (1H, m, allyl H), 4.71 (1H, m, allyl H), 4.92 (2H, m, 2 x isopropyl CH), 5.72 (2H, m, 2 x vinyl H). The experiment repeated with 2.2 g (0.028 moles) 90 % penta-1,3-diene (*cis* + *trans*) and 2.5 g (0.012 moles) diisopropyl azodicarboxylate gave 3.49 g (99 % yield).

Diisopropyl 1,2-dihydropyridazine-1,2-dicarboxylate

A solution of 3.52 g (0.02 moles) N-bromosuccinimide and 4.26 g (0.017 moles) diisopropyl 1,2,3,6-tetrahydropyridazine-1,2-dicarboxylate in 700 cm^3 carbon tetrachloride was refluxed for two hours until the NBS had dissolved. The mixture was filtered to remove the insoluble succinimide by-product, and the carbon tetrachloride distilled off. The resulting brown oil, the crude monobromide was then dissolved in 40 cm^3 dry toluene, then heated to reflux. At the first sign of reflux 2.5 cm^3 (0.0214 moles) 2,6-lutidine was added and the mixture refluxed for five minutes. A precipitation of white solid occurred during this time. The mixture was quickly cooled, diluted with 50 cm^3 diethyl ether and washed with 2 x 50 cm^3 dilute HCl, 50 cm^3 saturated NaCl, dried with $MgSO_4$, and the solvent removed. The resulting brown oil was purified by column chromatography using diethyl ether/petroleum ether as eluant to give an off-white crystalline material. m.p. 87-88°C. Yield 0.8 g (20 %). ^1H NMR ($CDCl_3$) δ_H 1.29 (12H, d, 7 Hz, 4 x isopropyl CH_3), 5.01 (2H, sept, 7 Hz, 2 x isopropyl CH), 5.63 (2H, m, vinyl H), 6.71 (2H, m, vinyl H).

Diisopropyl 4,5-dimethyl-1,2-dihydropyridazine-1,2-dicarboxylate (Failed)

A solution of 4.00 g (0.023 moles) N-bromosuccinimide and 4.90 g (0.017 moles) diisopropyl 4,5-dimethyl-1,2,3,6-tetrahydropyridazine-1,2-dicarboxylate in 800 cm^3 carbon tetrachloride was refluxed for two hours until the NBS had dissolved. Some brown colouration of the solution occurred. The mixture was filtered to remove any of the insoluble succinimide by-product, and the carbon tetrachloride distilled off. The resulting brown oil, the

presumed crude monobromide was then dissolved in 40 cm^3 dry toluene, then heated to reflux. At the first sign of reflux 3.0 cm^3 (0.025m) 2,6-lutidine was added and the mixture refluxed for five minutes. No white precipitation occurred during this time. The mixture was quickly cooled, diluted with 50 cm^3 diethyl ether and washed with 2 x 50 cm^3 dilute HCl, 50 cm^3 saturated NaCl, dried with $MgSO_4$, and the solvent removed. ^1H NMR spectroscopy at this stage indicated only the presence of the diisopropyl 4,5-dimethyl-1,2,3,6-tetrahydropyridazine-1,2-dicarboxylate starting material, and that none of the desired diisopropyl 4-methyl-1,2-dihydropyridazine-1,2-dicarboxylate had been formed. The experiment was abandoned.

Diisopropyl 4-methyl-1,2-dihydropyridazine-1,2-dicarboxylate (Failed)

A solution of 1.06 g (0.006 moles) N-bromosuccinimide and 1.35 g (0.005 moles) diisopropyl 4-methyl-1,2,3,6-tetrahydropyridazine-1,2-dicarboxylate in 200 cm^3 carbon tetrachloride was refluxed for two hours until the NBS had dissolved. Some brown colouration of the solution occurred. The mixture was filtered to remove the insoluble succinimide by-product, and the carbon tetrachloride distilled off. The resulting brown oil, the presumed crude monobromide was then dissolved in 10 cm^3 dry toluene, then heated to reflux. At the first sign of reflux 0.70 cm^3 (0.006 moles) 2,6-lutidine was added and the mixture refluxed for five minutes. No white precipitation occurred during this time. The mixture was quickly cooled, diluted with 50 cm^3 diethyl ether and washed with 2 x 50 cm^3 dilute HCl, 50 cm^3 saturated NaCl, dried with $MgSO_4$, and the solvent removed. ^{1}HNMR spectroscopy at this stage indicated none of the desired diisopropyl-4-methyl-1,2-

dihydropyridazine-1,2-dicarboxylate had formed. The experiment was abandoned.

Diisopropyl 3-methyl-1,2-dihydropyridazine-1,2-dicarboxylate

A solution of 1.06 g (0.006 moles) N-bromosuccinimide and 1.35 g (0.005 moles) diisopropyl 3-methyl-1,2,3,6-tetrahydropyridazine-1,2-dicarboxylate in 200 cm^3 carbon tetrachloride was refluxed for two hours until the NBS had dissolved. Some brown colouration of the solution occurred. The mixture was filtered to remove the insoluble succinimide by-product, and the carbon tetrachloride distilled off. The resulting brown oil, the crude monobromide was then dissolved in 10 cm^3 dry toluene, then heated to reflux. At the first sign of reflux 0.70 cm^3 (0.006 moles) 2,6-lutidine was added and the mixture refluxed for five minutes. A precipitation of some white solid occurred during this time. The mixture was quickly cooled, diluted with 50 cm^3 diethyl ether and washed with 2 x 50 cm^3 dilute HCl, 50 cm^3 saturated NaCl, dried with $MgSO_4$, and the solvent removed. The resulting brown oil was purified by column chromatography using diethyl ether/petroleum ether b.p. 40-60 °C as eluant to give a yellow oil. Yield 0.40 g (30 %). ^1H NMR ($CDCl_3$) δ_H 1.20-1.30 (15H, m, 4 x isopropyl CH_3 + vinyl-Me), 4.98 (2H, m, 2 x isopropyl CH), 5.50-5.70 (2H, m, vinyl H), 6.79 (1H, m, vinyl H).

Diisopropyl 4,5-dimethyl-6-isopropoxy-1,2,3,6-tetrahydropyridazine-1,2-dicarboxylate

To a solution of 3.55 g (0.012 moles) diisopropyl 4,5-dimethyl-1,2,3,6-tetrahydropyridazine-1,2-dicarboxylate in 50 cm^3 dichloromethane was added dropwise a solution of 1 cm^3 (0.019

moles) bromine in 25 cm^3 DCM over 1 hour. At the end of this period the excess bromine and DCM were removed under reduced pressure. The crude dibromide was dissolved in ~50 cm^3 isopropanol and a freshly prepared solution of 0.87 g (0.037 moles) sodium isopropoxide in 50 cm^3 isopropanol was added slowly with stirring. The mixture was stirred for 90 hours, after which a white precipitate had formed. The isopropanol was removed under reduced pressure, 50 cm^3 diethyl ether and 50 cm^3 dilute HCl were added and the mixture shaken to dissolve the precipitate. The ethereal layer was separated, washed with 2 x 50 cm^3 water, dried with magnesium sulphate and the diethyl ether removed. The residual brown oil was purified by column chromatography using diethyl ether/petroleum ether as eluant to give a pale yellow oil which crystallised upon standing. This yellow solid was recrystallised from diethyl ether/petroleum ether b.p. 40-60 °C to give colourless plates. m.p. 82.5-83°C. Yield 2.3g (56 %). ^1H NMR ($CDCl_3$) δ_H 1.10-1.21 (18H, m, 6 x isopropyl CH_3), 1.57 (3H, s, vinyl-Me), 1.66 (3H, s, vinyl-Me), 3.49 (1H, m, allyl H), 4.01 (1H, m, isopropyl CH), 4.19 (1H, m, allyl H), 4.89 (2H, m, 2 x isopropyl CH), 5.37 (1H, s, allyl H).

Diisopropyl 6-isopropoxy-4-methyl-1,2,3,6-tetrahydropyridazine-1,2-dicarboxylate and Diisopropyl 3-isopropoxy-4-methyl-1,2,3,6-tetrahydropyridazine-1,2-dicarboxylate

To a solution of 3.50 g (0.012 moles) diisopropyl 4-methyl-1,2,3,6-tetrahydropyridazine-1,2-dicarboxylate in 15 cm^3 dichloromethane was added dropwise a solution of 0.70 cm^3 (0.0133 moles) bromine in 10 cm^3 DCM over 1 hour. At the end of this period the excess bromine and DCM were removed under reduced pressure. The crude dibromide was dissolved in ~50 cm^3 isopropanol

and a freshly prepared solution of 0.63 g (0.027 moles) sodium isopropoxide in 50 cm^3 isopropanol was added slowly with stirring. The mixture was stirred for 48 hours, after which a white precipitate had formed. The isopropanol was removed under reduced pressure, 50 cm^3 diethyl ether and 50 cm^3 dilute HCl were added and the mixture shaken to dissolve the precipitate. The ethereal layer was separated, washed with 2 x 50 cm^3 water, dried with magnesium sulphate and the diethyl ether removed. The residual brown oil was purified by column chromatography using diethyl ether/petroleum ether as eluant to give a pale yellow oil which was distilled at 120-125°C, 0.3 mBar to give a very pale yellow oil. Yield 1.70 g (43 %). ^1H NMR spectroscopy indicated a mixture of two products. ^1H NMR ($CDCl_3$) δ_H 1.10-1.30 (18H, m, 6 x isopropyl CH_3), 1.78 (3H, vinyl-Me), 3.62 (1H, m, allyl H), 4.05 (1H, sept, 7 Hz, isopropyl CH), 4.42 (1H, m, allyl H), 4.94 (2H, sept, 7 Hz, 2 x isopropyl CH), 5.54 (1H, m, vinyl H). The experiment was abandoned at this stage.

<u>Diisopropyl 6-isopropoxy-3-methyl-1,2,3,6-tetrahydropyridazine-1,2-dicarboxylate and Diisopropyl 3-isopropoxy-3-methyl-1,2,3,6-tetrahydropyridazine-1,2-dicarboxylate</u>

To a solution of 3.50 g (0.012 moles) diisopropyl 3-methyl-1,2,3,6-tetrahydropyridazine-1,2-dicarboxylate in 15 cm^3 dichloromethane was added dropwise a solution of 0.70 cm^3 (0.0133 moles) bromine in 10 cm^3 DCM over 1 hour. At the end of this period the excess bromine and DCM were removed under reduced pressure. The crude dibromide was dissolved in ~50 cm^3 isopropanol and a freshly prepared solution of 0.63 g (0.027 moles) sodium isopropoxide in 50 cm^3 isopropanol was added slowly with stirring. The mixture was stirred for 48 hours, after which a white precipitate

had formed. The isopropanol was removed under reduced pressure, 50 cm^3 diethyl ether and 50 cm^3 dilute HCl were added and the mixture shaken to dissolve the precipitate. The ethereal layer was separated, washed with 2 x 50 cm^3 water, dried with magnesium sulphate and the diethyl ether removed. The residual brown oil was purified by column chromatography using diethyl ether/petroleum ether as eluant to give a pale yellow oil. Yield 1.98 g (50 %). ^1H NMR spectroscopy indicated a mixture of two products. ^1H NMR ($CDCl_3$) δ_H 1.00-1.35 (21H, m, 6 x isopropyl CH_3 + allyl-Me), 3.95 -4.22 (1H, m, isopropyl CH), 3.53-3.83 (1H, m, allyl H), 4.96 (2H, sept, 7 Hz, 2 x isopropyl CH), 5.67-6.00 (3H, m, 2 x vinyl H + allyl H). The experiment was abandoned at this stage.

Diisopropyl 4,5-dimethyl-1,2-dihydropyridazine-1,2-dicarboxylate (Failed)

To a solution of 0.60 g (0.0014 moles) diisopropyl 4,5-dibromo-4,5-dimethyl-1,2,3,6-tetrahydropyridazine-1,2-dicarboxylate in 20 cm^3 tetrahydrofuran was added dropwise 2.0 cm^3 (0.002m) 1.0 m potassium t-butoxide in THF. The mixture was stirred at room temperature for 48 hours, followed by 6 hours at reflux after which no observable reaction had occurred, The experiment was abandoned.

Diisopropyl 7,8-diaza-2-cyano-3-phenylbicyclo[2.2.2]octa-2,5-diene-7,8-dicarboxylate (Failed)

0.20 g (0.00084 moles) diisopropyl 1,2-dihydropyridazine-1,2-dicarboxylate and 0.10 g (0.00079 moles) 3-phenylpropynonitrile were dissolved in 3 cm^3 toluene, and warmed to reflux. The mixture was monitored by TLC. After 48 hours the reaction mixture had

darkened slightly though no other evidence for reaction was present. The experiment was abandoned.

Diisopropyl 7,8-diaza-2-cyano-4-methyl-3-phenylbicyclo[2.2.2]octa-2,5-diene-7,8-dicarboxylate (Failed)

0.20 g (0.00075 moles) Diisopropyl 3-methyl-1,2-dihydropyridazine-1,2-dicarboxylate and 0.10 g (0.00079 moles) 3-phenylpropynonitrile were dissolved in 3 cm^3 toluene, and warmed to reflux. The mixture was monitored by TLC. After 48 hrs the reaction mixture had darkened slightly though no other evidence for reaction was present. The experiment was abandoned.

Bicyclo[2,2,2]octa-2,5-diene-2-carboxylic acid (Failed)

A mixture of 1.0 g (0.014 moles) propiolic acid, 1.50 g (0.018 moles) cyclohexa-1,3-diene and 5 cm^3 1,4-dioxane was refluxed at 100°C for 12 hours. After this time, the initial yellow colour had darkened slightly. the reaction mixture was poured into 40 cm^3 water, whereupon a brown oil separated. This oil was collected and boiled with petroleum ether b.p. 60-80 °C for 1 hour, during which time the oil gradually solidified into a whitish solid, m.p. 122-123°C Authentic m.p. 78-80°C[31]. ^{1}HNMR spectroscopy proved the substance to be benzoic acid, m.p. 123°C. A repeat of the reaction with tetrahydrofuran added to the reaction mixture to reduce the reflux temperature to 80°C and with extraction of the oil with diethyl ether followed by column chromatography also failed to generate any of the desired product. The experiment was abandoned.

Bicyclo(2,2,1]hepta-2,5-diene-2-carboxylic acid

To 0.90 g (0.0127 moles) propiolic acid was added 1.68 g (0.025 moles) freshly distilled cyclopentadiene. The initially cold solution became warm over a period of ten minutes. After the reaction mixture had been allowed to react and cool for one hour the excess cyclopentadiene was evaporated off, leaving a white, crystalline material which decolourised steadily over 12 hours. The resulting brown crystalline material was crushed, washed with diethyl ether, the solution filtered, and the solvent removed to give an off-white crystalline material, m.p. 91-2°C. Authentic m.p. 93-4°C[32]. Yield 1.00 g (58 %). ^{1}H NMR ($CDCl_3$) δ_H 2.13 (2H, m, CH_2), 3.74 (1H, m, tertiary allyl H), 3.84 (1H, m, tertiary allyl H), 6.80 (1H, m, vinyl H), 6.94 (1H, m, vinyl H), 7.68 (1H, m, vinyl H).

Bicyclo[2,2,1]hepta-2,5-diene-2-carbonitrile

A mixture of 1.00 g (0.0073 moles) bicyclo[2,2,1]hepta-2,5-diene-2-carboxylic acid, 8 g PEP and 10 cm^3 chloroform in a three-necked flask was cooled to 0°C. Ammonia gas was flushed through the flask and a balloon containing ~0.5 l ammonia gas attached. The mixture was mechanically stirred for 30 minutes at 0-5°C, with the ammonia containing balloon being replaced if necessary then for 90 minutes at 20°C. The mixture became very viscous, the balloon was removed and a further 20 g PEP added. The mixture was then stirred at 80°C for several hours, then stirred with 200 cm^3 25% sodium carbonate, washed with 3 x 50 cm^3 toluene, dried with sodium sulphate, filtered and the solvent evaporated. The residual oil was purified by column chromatography, giving a clear pale yellow oil, rapidly discolouring Yield 0.20 g (23 %). ^{1}H NMR ($CDCl_3$) δ_H 2.19

(2H, m, CH_2), 3.82 (2H, m, 2 x tertiary allyl CH), 6.76 (1H, m, vinyl H), 6.90 (1H, m, vinyl H), 7.64 (1H, d, 5 Hz, vinyl H).

Diisopropyl benzylphosphonate

A mixture of 10.41 g (0.05 moles) triisopropyl phosphite and 8.55 g (0.05 moles) benzyl bromide were heated at 150 °C for 90 minutes. The mixture evolved isopropyl bromide over this time. After the reaction had ceased the isopropyl bromide was distilled from the reaction mixture. The reaction mixture was then subjected to short path distillation at 100 °C/0.1 mBar, giving a colourless, clear oil. Yield 9.75 g (76 %). ^{1}H NMR ($CDCl_3$) δ_H 1.17 (6H, d, 7 Hz, isopropyl CH_3), 1.28 (6H, d, 7 Hz, isopropyl CH_3), 3.11 (2H, d, 23 Hz, P-$\underline{CH_2}$-Ph), 4.60 (2H, m, P-O-isopropyl CH), 7.20-7.32 (5H, m, aryl H), ^{1}H NMR identical to authentic sample.

Diethyl benzylphosphonate

A mixture of 8.31 g (0.05 moles) triethyl phosphite and 9.41 g (0.055 moles) benzyl bromide were heated at 150 °C for 90 minutes. The mixture evolved ethyl bromide over this time. After the reaction had ceased the ethyl bromide was distilled from the reaction mixture. The reaction mixture was then subjected to short path distillation at 100 °C/0.1 mBar, giving a colourless, clear oil. Yield 10.84 g (95 %). ^{1}H NMR ($CDCl_3$) δ_H 1.23 (6H, t, 7 Hz, 2 x CH_2-$\underline{Me}$), 3.15 (2H, d, 21 Hz, P-$\underline{CH_2}$Ph), 4.00 (4H, quin, 7 Hz, 2 x P-O-$\underline{CH_2}$-Me), 7.20-7.40 (5H, m, aryl H), ^{1}H NMR identical to authentic sample.

Trans-stilbene-4-carbonitrile (Failed)

A solution of 1.31 g (0.01 moles) 4-cyanobenzaldehyde and 2.56 g (0.01 moles) diisopropyl benzylphosphonate in 20 cm^3 dry

THF was added to a stirred slurry of 0.44 g (0.011 moles) sodium hydride and 0.06 g 15-crown-5 in 40 cm^3 dry THF. No initial reaction occurred, however, over the course of five hours the mixture changed colour to wine red and then red/black. The mixture was poured into 200 cm^3 water then extracted with 3 x 50 cm^3 diethyl ether, the combined extracts being washed with 2 x 40 cm^3 of a 10 % soln. of sodium metabisulphite, 2 x 40 cm^3 saturated NaCl soln. The solution was dried with $MgSO_4$ and the solvent was evaporated to give a semi-solid mass. ^{1}HNMR indicated only starting material present. The experiment was abandoned.

Trans-stilbene-4-carbonitrile

A solution of 1.31 g (0.01 moles) 4-cyanobenzaldehyde, 2.29 g (0.01 moles) diethyl benzylphosphonate in 20 cm^3 dry THF was added to a stirred slurry of 0.44 g (0.011 moles) sodium hydride and 0.06 g 15-crown-5 in 40 cm^3 dry THF. No initial reaction occurred, however, over the course of four hours the mixture changed colour to wine red and then red/black. The mixture was poured onto 200 cm^3 water then extracted with 3 x 50 cm^3 diethyl ether, the combined extracts being washed with 2 x 40 cm^3 of a 10 % soln. of sodium metabisulphite, 2 x 40 cm^3 saturated NaCl soln. The solution was dried with $MgSO_4$, the solvent was evaporated to give a semi-solid mass, which was then purified by column chromatography using diethyl ether/petroleum ether b.p.40-60 °C as eluant to give a white, powdery material, m.p. 112-115 °C. Authentic m.p. 115°C[49]. Yield 0.50 g (25 %). ^{1}H NMR ($CDCl_3$) δ_H 7.09 (1H, d, 17 Hz, vinyl H), 7.23 (1H, d, 17 Hz, vinyl H), 7.23-7.70 (9H, m, aryl H). FT-IR (KBr disc) cm^{-1} 2226 (sharp, medium, C≡N stretch), 1602 (strong, aromatic C=C stretch), 1504 (strong, aromatic C=C stretch).

Trans-stilbene-4-carbonitrile

A solution of 2.29 g (0.01 moles) diethyl benzylphosphonate in 20 cc dry THF was added to a stirred slurry of 0.44 g (0.011 moles) sodium hydride and 0.06 g 15-crown-5 in 40 cm^3 dry THF. No immediate reaction occurred, however, after two hours stirring at room temperature a slight yellow colour had developed. A solution of 1.31 g (0.01 moles) 4-cyanobenzaldehyde in 20 cm^3 dry THF was then added. Much gas was evolved at this stage and the reaction mixture developed an orange precipitate. The mixture was poured onto 200 cm^3 water then extracted with 3 x 50 cm^3 diethyl ether, the combined extracts being washed with 2 x 40 cm^3 of a 10 % soln. of sodium metabisulphite and 2 x 40 cm^3 saturated NaCl soln. The solution was dried with $MgSO_4$ and the solvent was evaporated to give a semi-solid mass, which was then purified by column chromatography using diethyl ether/petroleum ether b.p. 40-60 °C as eluant to give a white, powdery material, m.p. 111-114°C. Authentic m.p. 115°C[49]. Yield 0.95 g (46 %). ^1H NMR ($CDCl_3$) δ_H 7.10 (1H, d, 16 Hz, vinyl H), 7.25 (1H, d, 16 Hz, vinyl H), 7.25-7.70 (9H, m, aryl H). FT-IR (KBr disc) cm^{-1} 2227 (sharp, medium, C≡N stretch), 1605 (strong, aromatic C=C stretch), 1505 (strong, aromatic C=C stretch).

Cis-stilbene-4-carbonitrile

To a cooled mixture of 2.62 g (0.02 moles) 4-cyanobenzaldehyde, 7.86 g (0.02 moles) benzyltriphenylphosphonium chloride and 10 cm^3 dichloromethane was added slowly, with vigorous stirring, 10 cm^3 of 50 % NaOH solution in water. The temperature rose upon addition, and it was necessary to cool the reaction vessel. An orange colour developed. After 10 minutes the organic layer was separated, washed with 3 x 50 cm^3 water, dried

with $MgSO_4$ and the solvent evaporated. A solid crystalline mass remained. This mixture was separated by column chromatography using diethyl ether/petroleum ether b.p. 40-60 °C as eluant, giving a clear, colourless oil which solidified upon standing to give a colourless crystalline material, m.p. 40-43°C. Authentic m.p. 44°C[50].Yield 1.95 g (47 %). ^{1}H NMR ($CDCl_3$) δ_H 6.58 (1H, d, 12 Hz, vinyl H), 6.78 (1H, d, 12 Hz, vinyl H), 7.10-7.61 (9H, m, aryl H). A by-product of this reaction was 1.15 g (28 %) of the *trans* isomer, identical by ^{1}HNMR spectroscopy to a previously synthesised sample.

Phenanthrene

A solution of 0.41 g (0.0023 moles) *trans*-stilbene and 0.03 g (0.0005 moles) iodine in 230 cm^3 cyclohexane was prepared. This was exposed, with stirring and under air, to UV light from an immersed water-cooled 40 W mercury vapour lamp for 6 hours during which time some acidic vapour was given off. After this time the colour of the iodine had faded somewhat. The solvent was then evaporated, and the phenanthrene purified by column chromatography using diethyl ether/petroleum ether b.p. 40-60 °C as eluant. The pale brown solid was further purified by distillation at 115°C/0.05 mBar to give an off white solid, m.p. 97-100°C. Authentic m.p. 97-100°C[44]. Yield 0.36 g (88 %). ^{1}H NMR ($CDCl_3$) δ_H 7.62 (4H, m, aryl H), 7.76 (2H, s, aryl H), 7.91 (2H, dd, 2 Hz + 7 Hz, aryl H), 8.72 (2H, dd, 2 Hz + 8 Hz, aryl H).

Phenanthrene-3-carbonitrile

A solution of 0.47 g (0.0023 moles) *trans*-stilbene-4-carbonitrile and 0.03 g (0.0005 moles) iodine in 230 cm^3 cyclohexane was prepared. This was exposed, with stirring and under air, to UV

light from an immersed water-cooled 40 W mercury vapour lamp for 6 hours during which time some acidic vapour was given off. After this time the colour of the iodine had faded somewhat. The solvent was then evaporated, giving a pale green solid. This was purified by column chromatography using diethyl ether/petroleum ether b.p. 40-60 °C as eluant, followed by further purification by distillation at 170°C/0.5 mBar, giving an off-white solid, m.p 93-6°C. Authentic m.p. 102°C[51]. Yield 0.24 g (51 %). ^{1}H NMR ($CDCl_3$) δ_H 7.50-7.82 (4H, m, aryl H), 7.82-8.02 (3H, m, aryl H), 8.57 (1H, d, 8 Hz, aryl H), 9.02 (1H, s, aryl H).

Diphenyl DPP pigment

To 50 cm^3 dry tert-amyl alcohol was added 0.76 g (0.033 moles) sodium metal. This was allowed to dissolve at reflux under nitrogen. To the resulting clear, colourless solution was added portionwise, over 30 minutes, a mixture of 1.13 g (0.005 moles) benzonitrile, 1.00 g (0.0075 m) diethyl succinate and 10 cm^3 dry tert-amyl alcohol. The reaction mixture turned yellow, pink, then progressively deeper red. The mixture was heated under reflux for 8 hours. After this time the mixture was allowed to cool, then added portionwise to a cooled solution of 5 cm^3 concentrated HCl soln. in 20 cm^3 methanol. A bright scarlet precipitate formed immediately. The precipitate was filtered, washed with methanol then water and finally dried to give a bright scarlet powder. Yield 0.34 g (24 %). FT-IR (KBr disc) cm^{-1} 3150 (sharp, weak, N-H stretch), 1650 (strong, C=O amide stretch), 1616 (sharp, medium, aromatic C=C stretch), 1570 (sharp, medium, aromatic C=C stretch).

Mono-*trans*-stilbenyl DPP pigment

To 10 cm^3 dry tert-amyl alcohol was added 0.14 g (0.0061 moles) sodium metal. The mixture was heated under reflux under nitrogen for several hours. After this time the sodium had dissolved, giving a colourless, clear solution. 0.45 g (0.0022 moles) *trans*-Stilbene-4-carbonitrile was added, followed by 0.37 g (0.0016 moles) ethyl 2-phenyl-5-ketopyrrole-3-carboxylate in 15 cm^3 dry tert-amyl alcohol, added dropwise over 30 minutes. The mixture was heated under reflux for six hours, during which time the reaction mixture turned deep purple/red. The reaction mixture was then allowed to cool, and stirred at room temperature for 16 hours. The reaction mixture was then poured slowly into a mixture of 5 cm^3 conc. HCl soln. in 20 cm^3 methanol. A deep red precipitate was formed immediately. The precipitate was filtered, washed with methanol then water and finally dried to give a deep red powder. Yield 0.57 g (66 %). FT-IR (KBr disc) cm^{-1} 3125 (sharp, weak, N-H stretch), 1640 (strong, C=O amide stretch), 1600 (sharp, medium, aromatic C=C stretch).

Mono-*cis*-stilbenyl DPP pigment

To 10 cm^3 dry tert-amyl alcohol was added 0.1 g (0.0043 moles) sodium metal. The mixture was heated under reflux under nitrogen for several hours. After this time the sodium had dissolved, giving a colourless, clear solution. 0.20 g (0.001 moles) *cis*-Stilbene-4-carbonitrile was added, followed by 0.16 g (0.00073 moles) ethyl 2-phenyl-5-ketopyrrole-3-carboxylate in 15 cm^3 dry tert-amyl alcohol, added dropwise over 30 minutes. The mixture was heated under reflux for six hours, during which time the reaction mixture turned deep purple/red. The reaction mixture was then allowed to cool, and

stirred at room temperature for 16 hours. The reaction mixture was then poured slowly into a mixture of 5 cm^3 conc. HCl soln. in 20 cm^3 methanol. A deep red precipitate was formed immediately. The precipitate was filtered, washed with methanol then water and finally dried to give a deep red powder. Yield 0.03 g (10 %). FT-IR (KBr disc) cm^{-1} 3137 (sharp, weak, N-H stretch), 1641 (strong, C=O amide stretch), 1600 (sharp, medium, aromatic C=C stretch).

Di-*trans*-stilbenyl DPP pigment

To 40 cm^3 dry tert-amyl alcohol was added 0.76 g (0.033 moles) sodium metal. This was allowed to dissolve at reflux under nitrogen. To the resulting clear, colourless solution was added portionwise, over 30 minutes a mixture of 1.00 g (0.005 moles) *trans*-stilbene-4-carbonitrile, 0.42 g (0.0024 m) diethyl succinate and 10 cm^3 dry tert-amyl alcohol. The reaction mixture turned deep purple/black. The mixture was heated under reflux for 8 hours, then cooled and stirred at room temperature for 16 hours. After this time the mixture was allowed to cool, then added portionwise to a cooled solution of 5 cm^3 concentrated HCl soln. in 20 cm^3 methanol. A deep purple/black precipitate formed immediately. The precipitate was filtered, washed with methanol then water and finally dried to give a deep purple/black powder. Yield 0.25 g (21 %). FT-IR (KBr disc) cm^{-1} 3027 (sharp, weak, N-H stretch), 1646 (strong, C=O amide stretch), 1598 (sharp, medium, aromatic C=C stretch).

Di-*cis*-stilbenyl DPP pigment

To 20 cm^3 dry tert-amyl alcohol was added 0.38 g (0.017 moles) sodium metal. This was allowed to dissolve at reflux under

nitrogen. To the resulting clear, colourless solution was added portionwise, over 30 minutes a mixture of 0.51 g (0.0025 moles) *trans*-stilbene-4-carbonitrile, 0.21 g (0.0012 m) diethyl succinate and 10 cm^3 dry tert-amyl alcohol. The reaction mixture turned deep red. The mixture was heated under reflux for 8 hours. After this time the mixture was allowed to cool and then stirred for 14 hours. The mixture was then added portionwise to a cooled solution of 5 cm^3 concentrated HCl soln. in 20 cm^3 methanol. A deep red precipitate formed immediately. The precipitate was filtered, washed with methanol then water and finally dried to give a deep purple/black powder. Yield ~0.01 g (~2 %). FT-IR (KBr disc) cm^{-1} 3133 (sharp, weak, N-H stretch), 1641 (strong, C=O amide stretch), 1600 (sharp, medium, aromatic C=C stretch).

Monophenanthryl DPP pigment

To 10 cm^3 dry tert-amyl alcohol was added 0.07 g (0.003 moles) sodium metal. The mixture was heated under reflux under nitrogen for several hours. After this time the sodium had dissolved, giving a colourless, clear solution. 0.20 g (0.001 moles) phenanthrene-3-carbonitrile was added, followed by 0.16 g (0.00073 moles) ethyl 2-phenyl-5-ketopyrrole-3-carboxylate in 10 cm^3 dry tert-amyl alcohol, added dropwise over 30 minutes. The mixture was heated under reflux for six hours, during which time the reaction mixture turned deep red. The reaction mixture was then allowed to cool, and stirred at room temperature for 16 hours. The reaction mixture was then poured slowly into a mixture of 5 cm^3 conc. HCl soln. in 20 cm^3 methanol. A red precipitate was formed immediately. The precipitate was filtered, washed with methanol then water and finally dried to give a red powder. Yield 0.17 g (60 %). FT-IR (KBr

disc) cm^{-1} 3145 (sharp, weak, N-H stretch), 1646 (strong, C=O amide stretch), 1614 (sharp, medium, aromatic C=C stretch).

Monobicyclo[2,2,1]hepta-2,5-dienyl DPP pigment (Failed)

To 10 cm^3 dry tert-amyl alcohol was added 0.1 g (0.0043 moles) sodium metal. The mixture was heated under reflux under nitrogen for several hours. After this time the sodium had dissolved, giving a colourless, clear solution. 0.15 g (0.00128 moles) bicyclohepta-2,5-diene-2-carbonitrile was added, followed by 0.21 g (0.001 moles) ethyl 2-phenyl-5-ketopyrrole-3-carboxylate in 15 cm^3 dry tert-amyl alcohol, added dropwise over 30 minutes. The mixture was heated under reflux for six hours, during which time the reaction mixture turned brown. Further stirring at room temperature for 12 hrs led to no further change in colour. The reaction mixture was then poured slowly into a mixture of 5 cm^3 conc. HCl soln. in 20 cm^3 methanol. No red/purple precipitate or solution developed at this stage. The experiment was abandoned.

Monophenanthryl DPP pigment (Failed)

A solution of 10 mg ($3x10^{-5}$ moles) mono-*trans*-stilbenyl DPP and 0.03 g (0.0005 moles) iodine in 230 cm^3 warm acetic acid was prepared. This was exposed, with stirring and under air, to UV light from an immersed water-cooled 40 W mercury vapour lamp for 1 hour during which time the initial orange colour of the solution faded to pale yellow. Removal of the solvent at this time, gave a brown tar, which by TLC indicated a complex mixture. The experiment was abandoned.

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