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Exploratory Studies Probing the Intermediacy of Azomethine Ylides in the Photochemistry of N-Phthaloyl Derivatives of α-Amino Acids and β-Amino Alcohols.

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Abstract: Exploratory photochemical studies with N-phthaloyl derivatives of glutamic acid, aspartic acid, serine, threonine and analogous carboxylic acids and alcohols have been conducted to determine the generality of azomethine ylide forming decarboxylation and retro-aldol fragmentation reactions. Preferences in the competition between these excited state reaction pathways have been determined by studies with phthalimides which contain both α-amino acid and β-aminoethanol groups.

Keywords: Photochemistry, Mechanisms, Imides, Amino acid derivatives

INTRODUCTION

The photochemistry of phthalimides has been the subject of intense investigation in recent years owing to the wide variety of mechanistically and synthetically interesting reactions that these substrates undergo.[1] The studies have demonstrated that phthalimides participate in photoinduced hydrogen-atom abstraction,[2] single-electron transfer,[3] and olefin-cycloaddition[4] processes. In addition, it is now known that N-phthaloyl derivatives of α-amino acids **1** undergo photodecarboxylation reactions to generate the corresponding N-alkylphthalimides **3** (Scheme 1).[5] This unique excited state process, first uncovered by Kanaoka,[5a] and later probed more thoroughly by Griesbeck and his coworkers,[5b] has been the focus of recent studies in our laboratories aimed at elucidating the mechanistic intricacies of and potential relationships between the photochemistry of N-substituted carboxymethyl-, trimethylsilylmethyl-, and β-hydroxyethyl-phthalimides.[6]

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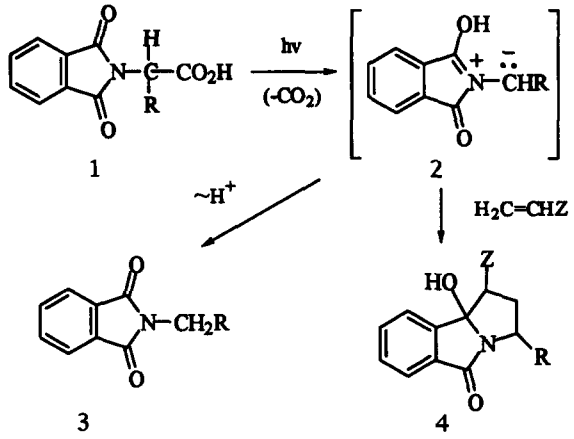
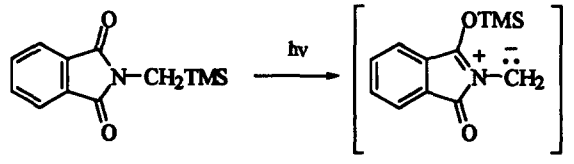
We have found that irradiation of the N-phthaloyl derivatives of glycine, alanine and phenylglycine (**1**, R = H, CH_3 or Ph) in solutions containing electron deficient olefins, such as methyl acrylate, leads to efficient production of benzopyrrolizidines **4** (Scheme 1).[6c]

These and related observations made in our studies with N-silylmethyl-phthalimides and -maleimides[6a,b] suggest that the photodecarboxylation reactions of N-phthaloyl α-amino acids proceed via the intermediary of azomethine ylides **2**. 1,4-Prototropic rearrangement or dipolar cycloaddition reactions of these ylides lead to formation of the respective alkylphthalimide **3** and benzopyrrolizidine **4** products. Support for this proposal has come from recent laser flash photolysis investigations with N-phthaloyl glycine (**1**, R = H).[7] Pulsed irradiation of this substance results in the formation of a 392 nm absorbing transient which has been assigned to the azomethine ylide **2** (R = H). This transient undergoes unimolecular decay in the absence of trapping agents and bimolecular decay in the presence of the dipolarophiles, methyl acrylate and acrylonitrile. The spectroscopic and kinetic properties of this intermediate closely parallel those of the related OTMS ylide **6** which arises by pulsed irradiation of N-(trimethylsilylmethyl)phthalimide (**5**) (Scheme 2).

Scheme 1.



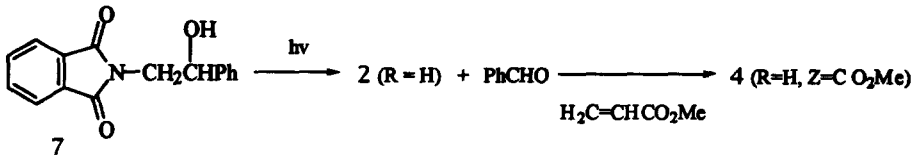
Scheme 2.



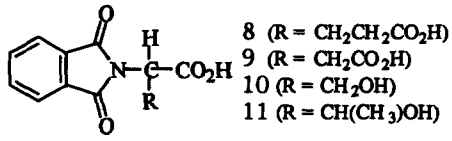
Contemporary studies by Pratt[8] and us[6c] have also uncovered a related reactivity pattern in the photochemistry of N-[(β-hydroxy-β-aryl)ethyl]phthalimides. This is exemplified by the behavior of the β-phenylethanol derivative **7** which upon irradiation in an MeCN solution containing 0.2 M methyl acrylate gives rise to the epimeric cycloadducts **4** (Z = CO_2Me) and benzaldehyde along with N-phenacylphthalimide and N-methylphthalimide (Scheme 3). Based on these findings, we have proposed that the excited states of N-(β-hydroxylethyl)-phthalimides undergo hydrogen atom abstraction to form 1,5-diradicals, which then fragment to

yield the same azomethine ylides, *i. e.*, **2**, that serve as intermediates in the N-phthaloyl α-amino acid photoreactions.

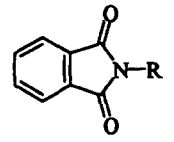
Scheme 3.



The results of the studies described above suggest that three types of seemingly unrelated phthalimide derivatives participate in excited-state reactions in which closely related azomethine ylides serve as key intermediates. In the current effort, we have carried out additional exploratory studies with several N-phthaloyl derivatives of α-amino acids and β-amino alcohols with the aim of assessing the mechanistic proposals outlined above, the generality of the dipolar cycloaddition processes, and preferences in the competition between the decarboxylation and fragmentation reactions in systems that contain both functionalities. For these purposes, we have investigated the photochemistry of N-phthaloyl derivatives of glutamic acid (**8**), aspartic acid (**9**), serine (**10**), threonine (**11**) and closely related carboxylic acid and alcohol analogs **12–14**. Below is presented the results of this effort, which demonstrate the generality of the ylide-forming and trapping reactions, as well as the reactivity profiles of these short-lived intermediates.



8 (R = $CH_2CH_2CO_2H$)
9 (R = CH_2CO_2H)
10 (R = CH_2OH)
11 (R = $CH(CH_3)OH$)

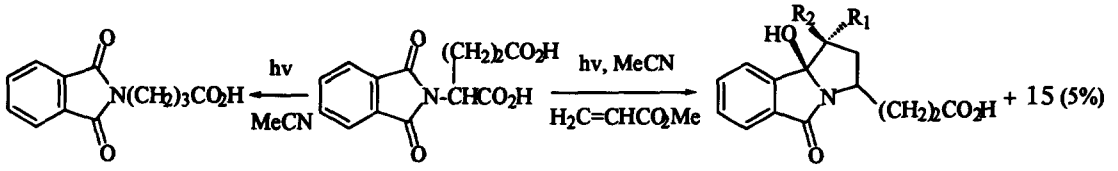


12 (R = CH_2CH_2OH)
13 (R = $CH_2CH(CH_3)OH$)
14 (R = CH_2CH_2Br)

RESULTS AND DISCUSSION

N-Phthaloyl Glutamate. As anticipated based on the precedence found in earlier efforts by Kanaoka,[5a] irradiation of N-phthaloyl glutamic acid (**8**) in MeCN (or 10% D_2O-MeCN) results in efficient (70%) production of N-phthaloyl γ-aminobutyric acid (**15**) (or its γ-D analog) (Scheme 4). When this substrate is irradiated in an MeCN solution containing 90 mM methyl acrylate, the butyric acid derivative **15** is formed (5%) along with the stereoisomeric benzopyrrolizidines **16** and **17** (61%) in a 2:1 ratio. The C-6 stereochemistry in both **16** and **17** is assigned by comparison of ^{1}H- and ^{13}C-NMR data with those of

Scheme 4.



15 (70%)

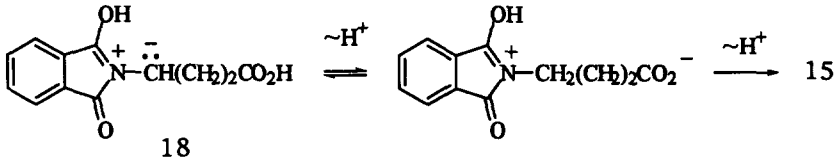
8

16 (R_1 = CO_2Me, R_2 = H)(41%)
17 (R_1 = H, R_2 = CO_2Me) (20%)

benzopyrrolizidine adducts arising by photolysis of N-phthaloyl-alanine and -phenylalanine, which have been characterized by X-ray crystallographic methods.[6c]

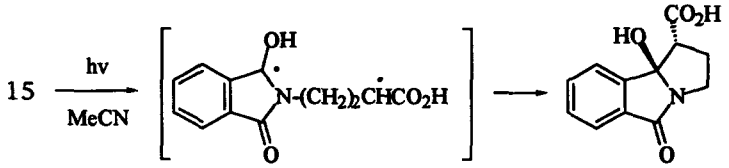
These observations show that the azomethine ylide **18** generated by photodecarboxylation of **8** undergoes dipolar cycloaddition under these conditions at a rate that is faster than 1,4-prototropic shift or proton transfer from the terminal carboxylic acid group. This is an unexpected result since we already demonstrated[7] that intermolecular C-protonation of a related OTMS-ylide by acetic acid occurs with a bimolecular rate constant of $3x10^8\ M^{-1}s^{-1}$ and that dipolar cycloaddition of the same ylide with methyl acrylate is a much slower process (ca. $1x10^7\ M^{-1}s^{-1}$). A possible rationalization for why intermolecular cycloaddition is more facile than terminal carboxylic acid facilitated conversion of ylide **18** to the aminobutyric acid derivative **15** surfaces when consideration is given to the detailed mechanism of the latter process. Accordingly, internal carboxylic acid facilitated conversion of **18** to **15** requires two proton transfer steps, a reversible and highly favorable C-protonation and an unfavorable O-deprotonation (Scheme 5). It is expected that the second step in this process would be slow owing to a ring size governed-entropic barrier.

Scheme 5.



N-phthaloyl γ-aminobutyric acid (**15**) is photochemically reactive under the conditions of its formation from the glutamate derivative **8**. Accordingly, irradiation of an MeCN solution of **15** results in high yielding (72%) production of a substance identified as the benzopyrrolizidine **19** (Scheme 6) on the basis of its spectroscopic similarities to the previously characterized ester derivative **4** (Z = CO_2CH_3).[6c] The efficient formation of **19** by excited-state δ- (not γ-) hydrogen abstraction is likely a result of radical stabilization provided by the terminal carboxyl group. Surprisingly, the one-carbon less homolog **20**, formed by photodecarboxylation of N-phthaloyl aspartate **9**, does not participate in a clean excited-state γ-hydrogen atom abstraction process. Irradiation of **20** in MeCN gives rise instead to a mixture of products, including the benzazepindione **23** (21%), N-ethylphthalimide (32%), and phthalimide (12%) (Scheme 7). While it is clear that N-ethylphthalimide is formed from the excited state of **20** by decarboxylation, the origins of benzazepindione **23** and phthalimide are less certain. These substances could arise by respective cyclization or fragmentation of diradicals produced by excited-state decarboxylation (**21**) or hydrogen atom abstraction (**22**) (Scheme 7). In the former case, cyclization of **22** would give a tricyclic amidol, which by ring opening would

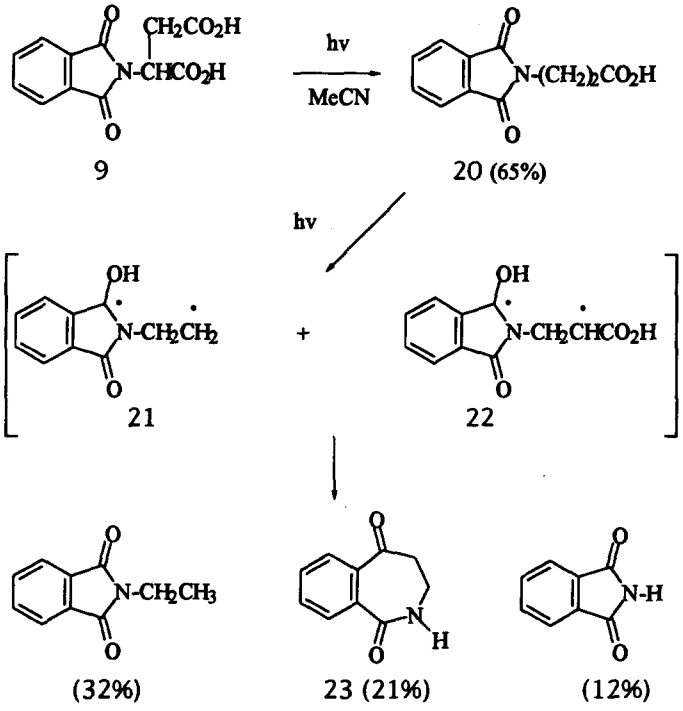
Scheme 6.



19 (72%)

then yield an α-keto acid precursor of **23**.

Scheme 7.



N-(β-Hydroxyethyl)phthalimides. As discussed above (Scheme 3), we have demonstrated by the use of trapping studies that photolysis of the N-phthaloyl phenylethanolamine **7** results in generation of the azomethine ylide **2**.[6c] To evaluate the generality of this process, the photochemistry of the ethanol and propanolamine derivatives **12** and **14** was probed. Photoreaction of **12** in MeCN produces phthalimide, along with its N-methyl and N-vinyl (**24**) derivatives, in respective yields of 10%, 38% and 12% (Scheme 8). That azomethine ylide **2** formation is the predominant excited-state reaction pathway followed in this process is evidenced by the observation that irradiation of **12** in MeCN solutions containing either methyl acrylate or acrylonitrile gives rise to formation of not only phthalimide, N-methylphthalimide and N-vinylphthalimide, but also the corresponding, known[6c] benzopyrrolizidines **27–30**. Analysis of the product ratios (Table 1) suggests that ylide **2**, formed by fragmentation of **12** and trapped by dipolarophile, is an intermediate in formation of N-methylphthalimide but that it is not involved in pathways leading to the phthalimide and its N-vinyl derivative.

Similar results were obtained in parallel studies with the hydroxypropyl phthalimide **13**.[9] The observations (see Table 1) demonstrate that the previously uncovered ylide forming photoreaction of N-(β-hydroxyethyl) phthalimides is ubiquitous. In addition, ylide forming fragmentations of the excited states of these substrates are competitive with excited-state γ-hydrogen abstraction, the latter pathway leading to formation of phthalimide or its N-acetonyl derivative **26**. Finally, the origin of N-vinylphthalimides **24** and **25** in the respective photoreactions of **13** and **14** is not clear at this time. Perhaps relevant to the mechanism(s) of

these photodehydration processes is our observation that irradiation of the β-phthaloyl bromoethane **14** in MeCN leads to exceptionally clean formation of N-vinylphthalimide (**24**).

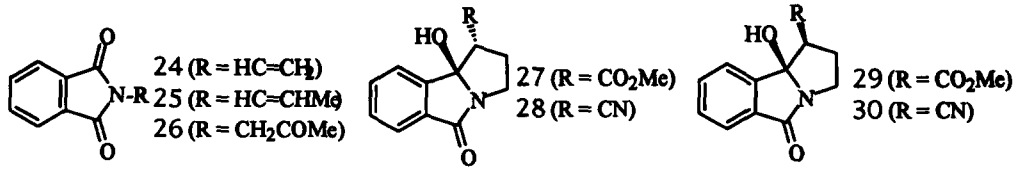
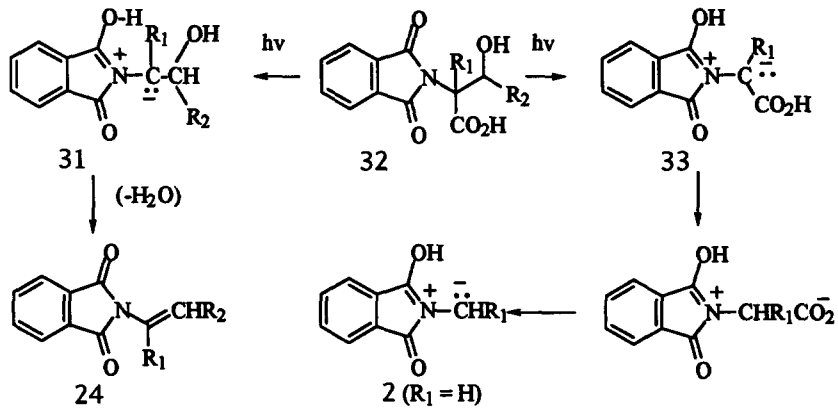


Table 1. Product Yields from Photoreactions of **12** and **13** in MeCN in the Absence and Presence of Methyl Acrylate and Acrylonitrile.

		Products Yields								
		N-Substituted Phthalimides								
Substrate	Additive	N-H	N-CH_3	**24**	**25**	**26**	**27**	**28**	**29**	**30**
12	none	10%	38%	12%	–	–	–	–	–	–
12	CH_2=$CHCO_2Me$	8%	8%	5%	–	–	19%	–	6%	–
12	CH_2=CHCN	10%	6%	6%	–	–	–	25%	–	8%
13	none	10%	38%	–	5%	38%	–	–	–	–
13	CH_2=$CHCO_2Me$	12%	5%	–	0%	30%	22%	–	6%	–
13	CH_2=CHCN	10%	5%	–	0%	25%	–	25%	–	8%

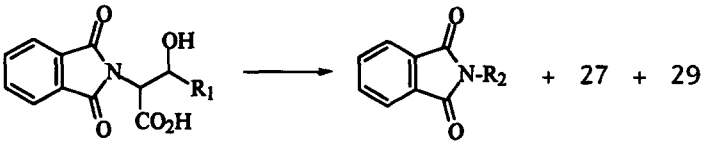
Scheme 8.



N-Phthaloyl Derivatives of Serine and Threonine. The excited states of N-phthaloyl β-hydroxy-α-amino acids **32** can react by two different ylide forming reaction pathways. Photodecarboxylation of these substances would produce β-hydroxy ylides **31** (Scheme 8) while fragmentation via the alcohol function would generate the carboxy-ylides **33**. With the intent of determining the relative efficiencies of these reaction

pathways and probing the reactivity profiles of the resultant ylide intermediates, we have carried out photochemical studies with the N-phthaloyl derivatives for serine (**10**) and threonine (**11**). In a manner similar to that described by Griesbeck and his coworkers[5b] in their earlier studies with these substrates, irradiation of MeCN solutions of **10** and **11** gives rise to mixtures of products dominated by the respective vinylphthalimides, **24** and **25** (Scheme 9). The presence of 64 mM methyl acrylate has little effect on the courses of these processes. In both cases, the benzopyrrolizidines **27** and **29** are formed in low yields at the expense of N-methylphthalimide, but the efficiencies for production of the vinylphthalimides remain high.

Scheme 9.



10 (R_1 = H) —hv, MeCN→ { 24 (R_2 = HC=CH$_2$) (75%); (R_2 = CH_3) (10%); 12 (R_2 = CH_2CH_2OH) (trace) }

11 (R_1 = CH_3) —hv, MeCN→ { 25 (R_2 = HC=$CHCH_3$) (60%); (R_2 = CH_3) (21%); 34 (R_2 = CH_2CO_2H) (trace) }

10 (R_1 = H) —hv, MeCN, H_2C=$CHCO_2Me$→ { 24 (R_2 = HC=CH_2) (70%); (R_2 = CH_3) (trace); 27 (5%) + 29 (trace) }

11 (R_1 = CH_3) —hv, MeCN, H_2C=$CHCO_2Me$→ { 25 (R_2 = HC=CH_2) (60%); (R_2 = CH_3) (trace); 27 (5%) + 29 (trace) }

A reasonable conclusion that can be drawn from these results is that decarboxylation is the predominant reaction pathway followed in the excited-state chemistry of these bifunctional substrates. The β-hydroxy azomethine ylides **31** (Scheme 8) formed in this way appear to undergo rapid β-elimination to yield N-vinylphthalimides, the major products in these photoprocesses. A minor competitive route appears to be fragmentation to produce the a-carboxy ylide **33**. Interestingly, this ylide is not readily trapped by the added dipolarophile, methyl acrylate. This contrasts with the high dipolar cycloaddition reactivity of related C-alkyl substituted ylide intermediates. A plausible rationalization of this behavior is based on the availability of a potentially rapid decay pathway transforming the C-carboxy substituted ylide **33** to its decarboxylated analog **2**. Accordingly, proton transfer from the carboxylic acid function to the ylide carbanionic center would give rise to a zwitterionic intermediate from which loss of CO_2 would be rapid (Scheme 8). Ylide **22**, formed in this manner, would serve as the precursor of N-methylphthalimide and the benzopyrrolizidines **27** and **29**.

SUMMARY

The investigations described above have shown that the azomethine ylide forming photoreactions of N-phthaloyl α-amino acids and N-(β-hydroxyethyl)phthalimides are ubiquitous processes. In addition, by use of studies with bifunctional substrates, we have shown that excited state decarboxylation through the N-phthaloyl α-amino acid functionality is much more efficient process than fragmentation of the β-hydroxyethyl phthalimide moiety. Lastly, while C-alkyl-substituted azomethine ylides derived by irradiation of α-alkyl-substituted α-amino acids are readily trapped by dipolar cycloaddition with methyl acrylate and acrylonitrile, those which arise either by decarboxylation or fragmentation in the excited states of phthalimide derivatives of β-hydroxy α-amino acids (*i.e.*, **31** and **33**, Scheme 8) are short-lived owing to the availability of rapid β-elimination and proton transfer-decarboxylation pathways.

EXPERIMENTAL

General. All reported reactions were run under a dried nitrogen atmosphere. Unless otherwise noted, all reagents were obtained from commercial sources and used without further purification. All Compounds were isolated as oils and shown to be >90% pure by ^1H and/or ^{13}C NMR unless otherwise noted. ^1H NMR and ^{13}C NMR spectra were recorded by using $CDCl_3$ solutions unless otherwise specified and chemical shifts are reported in ppm relative to residual $CHCl_3$ at 7.24 ppm (for ^1H NMR) and 77.0 ppm (for ^{13}C NMR). ^{13}C NMR resonance assignments were aided by the use of the DEPT technique to determine numbers of attached hydrogens and ^1H NMR coupling constants (J-values) are reported in Hz. Infrared spectra were obtained using neat liquids unless otherwise specified and data are reported in units of cm^{-1}. Low (MS) and high (HRMS) mass spectra, reported as *m/z* (relative intensity), were recorded by using electron impact ionization (EI) or chemical ionization (CI). Photochemical reactions were conducted by using an apparatus consisting of a 450-W medium-pressure mercury lamp surrounded by a glass filter and within a quartz, water-cooled well that was purged with O_2-free N_2 both before and during irradiation. Photochemical reaction progress was monitored by gas chromatography, TLC or ^1H NMR.

Irradiation of N-Phthaloyl-L-glutamic Acid (8). A Solution of N-phthaloyl-L-glutamic acid (**8**, 500mg 1.80mmol) in 200mL of CH_3CN was irradiated with Vycor-filtered light under N_2 for 30h (100% conversion of **8**). Concentration of the photolysate gave a residue which was subjected to column chromatography (silica, ethyl actate : hexane = 1 : 2) yielding 295mg (70%) of **15**.

A Solution of **8** (50mg, 0.18mmol) in a solution of 18mL of CH_3CN and 2mL of D_2O was irradiated with Vycor-filtered light under N_2 for 25h (100% conversion of **8**). Concentration of the photolysate gave a residue which was subjected to column chromatography (silica, ethyl acetate : hexane = 1 : 2) yielding 34mg (80%) of **15-D.**

A solution of **8** (500mg, 0.18mmol) and methyl acrylate (1.55g, 18.0mmol) in 200mL of CH_3CN was irradiated with Vycor-filtered light unedr N_2 for 30h (80% conversion of **8**). Concentration of the photolysate gave a residue which was subjected to column chromatography (silica, ethyl acetate: hexane= 1:2) yielding 188mg (41%) of **16**, 92mg (20%) of **17** and 17mg (5%) of **15.**

16; ^1H NMR 2.01-2.15 (m, 2H, $C\underline{H}_2CH_2CO_2H$), 2.51 (s, 1H, OH), 2.62 (t, 2H, J=2.6Hz, $CH_2C\underline{H}_2CO_2H$), 2.54 (dd, 1H, J=13.0 and 7.9Hz, $CHC\underline{H}_2CH$), 2.74 (dd, 1H, J=13.3 and 7.9Hz, $CHC\underline{H}_2CH$),

3.16 (s, 3H, CO_2CH_3), 3.43 (d, 1H, J=6.7Hz, C<u>H</u>(CO_2CH_3)), 4.45-4.62 (m, 1H, C<u>H</u>$CH_2CH_2CO_2H$), 7.42-7.69 (m, 4H, aromatic) ; ^{13}C NMR 32.0 (<u>C</u>$H_2CH_2CO_2H$), 32.3 (CH_2<u>C</u>H_2CO_2H), 38.0 (CH<u>C</u>H_2CH) 51.2 (CO_2<u>C</u>H_3), 51.6 (<u>C</u>H(CO_2CH_3)), 54.6 (<u>C</u>H$CH_2CH_2CO_2H$), 98.0 (C(OH)), 123.3, 130.2, 131.8 and 142.2, (CH, aromatic), 132.7 and 144.0 (C, aromatic), 171.5 (C=O), 172.1 (CO_2Me), 177.6 (CO_2H) ; IR (KBr) 1690 (amide, NCO), 1730 (ester, CO_2Me), 3150-3450 (br, carboxyl OH) ; MS (EI) m/z (rel, intensity) 319 (M^+, 12), 301 (75), 270 (25), 260 (61), 228 (100), 227 (96), 214 (69), 186 (82), 182 (69), 174 (69); HRMS (EI) m/z 319.1040 ($C_{16}H_{17}NO_6$ requires 319.1056).

17; ^1H NMR 2.01-2.25 (m, 2H, C<u>H</u>$_2$$CH_2CO_2H$), 2.51 (t, 2H, J=2.6Hz, CH_2C<u>H</u>$_2$$CO_2H$), 2.71-2.84 (m, 2H, CHC<u>H</u>$_2$CH), 3.17 (s, 1H, OH), 3.86 (s, 3H, CO_2CH_3), 3.71-3.80 (m, 1H, C<u>H</u>(CO_2CH_3)), 4.04-4.10 (m, 1H, C<u>H</u>$CH_2CH_2CO_2H$), 7.45-7.90 (m, 4H, aromatic) ; ^{13}C NMR 31.6 (<u>C</u>$H_2CH_2CO_2H$), 32.1 (CH_2<u>C</u>H_2CO_2H), 36.6 (CH<u>C</u>H_2CH) 50.5 (CO_2<u>C</u>H_3), 52.3 (<u>C</u>H(CO_2CH_3)), 53.3 (<u>C</u>H$CH_2CH_2CO_2H$), 95.4 (C(OH)), 123.6, 130.1, 130.9 and 141.7 (CH, aromatic), 133.1 and 145.9 (C, aromatic), 171.0 (C=O), 172.0 (<u>C</u>O_2Me) 178.1 (CO_2H) ; IR (KBr) 1650 (amide, NCO), 1700 (ester, CO_2Me), 3250-3500 (br, carboxyl OH) ; MS (EI) m/z (rel, intensity) 319 (M^+, 3), 301 (44), 228 (51), 227 (88), 186 (74), 182 (100), 174 (35); HRMS (EI) m/z 319.1046 ($C_{16}H_{17}NO_6$ requires 319.1056).

Irradiation of N-Phthaloylaspartic Acid (9). A solution of N-phthaloylaspartic acid **9** (200mg, 0.76mmol) in 200mL of CH_3CN was irradiated with Vycor-filtered light under N_2 for 30h (90% conversion of **9**). Concentration of the photolysate gave a residue which was subjected to column chromatography (silica, ethyl acetate: hexane= 1:2) yielding 97mg (65%) of **20.**

Irradiation of N-Phthaloylserine (10). A solution of **10** (300mg, 1.28mmol) in 200mL of CH_3CN was irradiated with Vycor-filtered light under N_2 for 10h (90% conversion of **10**). Concentration of the photolysate gave a residue which was subjected to column chromatography (silica, ethyl acetate: hexane= 1:4) yieding 150mg (75%) of N-vinylphthalimide (**24**), 19mg (10%) of N-methylphthalimide and a trace of N-(2-hydroxyethyl)phthalimide (**12**).

A solution of **10** (300mg, 1.28mmol) and methyl acrylate (1.10g, 12.8mmol) in 200mL of CH_3CN was irradiated with Vycor-filtered light under N_2 for 10h (70% conversion of **10**). Concentration of the photolysate gave a residue which was subjected to column chromatography (silica, ethyl acetate: hexane= 1:4) yielding 109mg (70%) of **24**, trace of N-methylphthalimide, 11mg (5%) of **27** and trace of **29**.

Irradiation of N-Phthaloylthreonine (11). A solution of **11** (316mg, 1.27mmol) in 200mL of CH_3CN was irradiated with Vycor-filtered light under N_2 10h (100% conversion of **11**). Concentrarion of the photolysate gave a residue which was subjected to column chromatography (silica, ethyl acetate:hexane= 1:5) yielding 143mg (60%) of N-1-propenylphthalimide (**25**) (E : Z = 3 : 1), 43mg (21%) of N-methylphthalimide and trace of **34**.

A solution of **11** (316mg, 1.27mmol) and methyl acrylate (1.10g, 12.7mmol) in 200mL of CH_3CN was irradiated with Vycor-filtered light under N_2 for 15h (100% conversion of **11**). Concentration of the photolysate gave a residue which was subjected to column chromatography (silica, ethyl acetate : hexane= 1:4) yielding 143mg (60%) of **25** (E : Z = 3 : 1), a trace of N-methylphthalimide, 16mg (5%) of **27** and a trace of **29**.

Irradiation of N-(2-Hydroxyethyl)phthalimide (12). A solution of **12** (500mg, 2.62mmol) in 200mL of CH_3CN was irradiated with Pyrex-filtered light under N_2 for 30h (65% conversion of **12**). Concentration of the photolysate gave a residue which was subjected to column chromatography (silica, ethyl acetate : hexane =

1:2) yielding 104mg (38%) of N-methylphthalimide, 35mg (12%) of N-vinylphthalimide (**24**) and 25mg (10%) of phthalimide.

A solution of **12** (500mg, 2.62mmol) and methyl acrylate (1.39g, 26.2mmol) in 200mL of CH_3CN was irradiaterd with Pyrex-filtered light under N_2 for 30h (55% conversion of **12**). Concentration of the photolysate gave a residue which was subjected to column chromatography (silica, ethyl acetate : hexane = 1:5) yielding 67mg(19%) of **27**, 21mg (6%) of **29**, 19mg (8%) of N-methylphthalimide, 14mg (5%) of **24** and 19mg (8%) of phthalimide.

A solution of **12** (500mg, 2.62mmol) and acrylonitrile (1.39g, 26.2mmol) in 200mL of CH_3CN was irradiaterd with Pyrex-filtered light under N_2 for 30h (60% conversion of **12**). Concentration of the photolysate gave a residue which was subjected to column chromatography (silica, ethyl acetate : hexane = 1:4) yielding 84mg (25%) of **28**, 27mg (8%) of **30**, 15mg (6%) of N-methylphthalimide, 15mg (6%) of **24** and 23mg (10%) of phthalimide.

Irradiation of N-(2-Hydroxypropyl)phthalimide (13). A solution of **13** (550mg, 2.68mmol) in 200mL of CH_3CN was irradiaterd with Pyrex-filtered light under N_2 for 30h (100% conversion of **13**). Concentration of the photolysate gave a residue which was subjected to column chromatography (silica, ethyl acetate : hexane = 1:5) yielding 207mg (38%) of N-acetonylphthalimide (**26**), 164mg (38%) of N-methylphthalimide, 25mg (5%) of N-propenylphthalimide **25** and 39mg (10%) of phthalimide.

A solution of **13** (550mg, 2.68mmol) and methyl acrylate (2.31g, 26.8mmol) in 200mL of CH_3CN was irradiaterd with Pyrex-filtered light under N_2 for 30h (100% conversion of **13**). Concentration of the photolysate gave a residue which was subjected to column chromatography (silica, ethyl acetate : hexane = 1:4) yielding 146mg (22%) of **27**, 40mg (6%) of **29**, 163mg (30%) of **26**, 22mg (5%) of N-methylphthalimide and 47mg (12%) of phthalimide.

A solution of **13** (500mg, 2.68mmol) and acrylonitrile (1.42g, 26.8mmol) in 200mL of CH_3CN was irradiaterd with Pyrex-filtered light under N_2 for 30h (100% conversion of **13**). Concentration of the photolysate gave a residue which was subjected to column chromatography (silica, ethyl acetate : hexane = 1:4) yielding 143mg (25%) of **28**, 45mg (8%) of **30**, 136mg (25%) of **26**, 22mg (5%) of N-methylphthalimide and 39mg (10%) of phthalimide.

Irradiation of N-(2-Bromoethyl)phthalimide (14). A solution of **14** (500mg, 1.98mmol) in 200mL of CH_3CN was irradiaterd with Pyrex-filtered light under N_2 for 30h (80% conversion of **14**). Concentration of the photolysate gave a residue which was subjected to column chromatography (silica, ethyl acetate : hexane = 1:5) yielding 192mg (70%) of **24.**

Irradiation of N-Phthaloyl-γ-aminobutyric Acid (15). A solution of **15** (200mg, 0.86mmol) in 200mL of CH_3CN was irradiated with Vycor-filtered light under N_2 for 9h (100% conversion of **15**). Concentration of the photolysate gave a residue which was subjected to column chromatography (silica, ethyl acetate) yielding 144mg (72%) of **19**. mp 245-246 °C; ^{1}H NMR 2.69-2.73 (m, 2H, $NC\underline{H}_2$), 3.15 (s, 1H, OH), 3.30-3.51 (m, 2H, $HO_2CC\underline{H}_2$), 3.30-3.51 (m, 1H, $C\underline{H}CCO_2H$), 7.53-7.78 (m, 4H, aromatic), 8.55 (s, 1H, CO_2H); ^{13}C NMR 34.2 ($\underline{C}H_2$), 41.0 ($\underline{C}H_2N$), 51.7 ($\underline{C}HCO_2H$), 79.4 ($\underline{C}OH$), 128.2, 129.5, 131.6 and 132.7 (CH, aromatic), 132.5 and 136.7 (C, aromatic), 169.4 (amide, NCO), 172.9 (CO_2H) ; IR (KBr) 1640 (NCO), 1710 (CO_2H) ; MS (EI) m/z (rel. intensity) 233 (M^+, 6), 215 (38), 187 (34), 174 (100), 159 (69), 130 (57), 103 (83), 77 (65); HRMS (EI) m/z 233.0686 ($C_{12}H_{11}NO_4$ requires 233.0688).

Irradiation of N-Phthaloyl-β-aminopropionic Acid (20). A solution of **20** (200mg, 0.91mmol) in 200mL of CH_3CN was irradiated with Vycor-filtered light under N_2 for 20h (95% conversion of **20**). Concentration of the photolyzate gave a residue which was subjected to column chromatography (silica, ethyl acetate:hexane = 1:1) yielding 48mg (32%) of N-ethylphthalimide, 32mg (21%) of benzazepinedione **23** and 15mg (12%) of phthalimide.

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9. The photochemistry of this substrate has been described previously (ref. 5b).