(50 mL) afforded 0.400 g (80%) of **15**: mp 249–250 °C (C_2H_5OH); IR (KBr) ν_{max} 1709, 1600 cm^{-1}; ^{1}H NMR (Me_2SO-d_6) δ 2.68 (2 H, t, CH_2), 3.04 (2 H, t, $\mathbf{H_2}CCO_2H$), 7.34–7.56 (3 H, m, Ar H), 7.86 (1 H, s, Ar H), 7.96–8.12 (3 H, m, Ar H), 8.50 (2 H, d, Ar H); UV (anhydrous C_2H_5OH) λ_{max} 376 nm (ϵ 3800), 357 (4400), 340 (3200), 325 (1900), 255 (200 000), 247 (90 000).

Anal. Calcd for $C_{17}H_{14}O_2$: C, 81.60; H, 5.60. Found: C, 81.33; H, 5.84.

5-(2-Anthryl)pentanoic Acid (16). Ester **6** (0.548 g, 2 mmol) was hydrogenated over 10% Pd/C in anhydrous C_2H_5OH (50 mL), and the product obtained was boiled with *o*-chloranil (0.590 g, 1.2 mmol) for 3 h under N_2. Hydrolysis of the product from the above reaction with 10 alcoholic KOH solution (20 mL) afforded 0.410 g (71%) of acid **16**: mp 191–192 °C (C_2H_5OH); IR (KBr) ν_{max} 1695, 1575 cm^{-1}; ^{1}H NMR ($DCCl_3$) δ 1.6 (4 H, m, CH_2) 2.2–2.3 (2 H, m, CH_2), 2.82 (2 H, m, CH_2), 7.3–7.5 (3 H, m, Ar H), 7.72 (1 H, m, Ar H), 7.88 (3 H, m, Ar H), 8.00–8.32 (2 H, m, Ar H); UV (anhydrous C_2H_5OH) λ_{max} 377 nm (ϵ 5400), 358 (6100), 341 (4400), 327 (2500), 291 (700), 254 (237 000), 249 (88 900).

Anal. Calcd for $C_{19}H_{18}O_2$: C, 82.01; H, 6.44. Found: C, 82.13; H, 6.56.

3-(9-Anthryl)propanoic Acid (22).[20] Hydrogenation of acid **20** (0.496 g, 2 mmol) over 10% Pd/C (50 mg) in anhydrous C_2H_5OH (20 mL) afforded 0.450 g (90%) of acid **22**: mp 188–190 °C (C_2H_5OH–H_2O, lit.[20] mp 191–192 °C); IR (KBr) 1695, 1600 cm^{-1}; ^{1}H NMR ($DCCl_3$) δ 2.78–2.96 (2 H, br t, CH_2), 3.8–4.0 (2 H, br t, CH_2), 7.40–7.55 (5 H, m, Ar H); 7.9–8.1 (2 H, m, Ar H), 8.2–8.4 (2 H, m, Ar H); UV (anhydrous C_2H_5OH) λ_{max} 386 nm (ϵ 5000), 361 (5180), 347 (380), 332 (1450), 256 (95 700).

5-(9-Anthryl)pentanoic Acid (23). Hydrogenation of acid **21** (0.556 g, 2 mmol) in anhydrous C_2H_5OH (30 mL) over 10% Pd/C (70 mg) afforded 0.440 g (79%) of acid **23**: mp 112–113 °C (ether–petroleum ether); IR (KBr) ν_{max} 1695, 1613 cm^{-1}; ^{1}H NMR ($DCCl_3$) δ 1.70–1.98 (4 H, d, CH_2), 2.42 (2 H, m, CH_2), 3.58 (2 H, m, CH_2), 7.16 (1 H, s, Ar H), 7.26–7.60 (4 H, m, Ar H), 7.94–8.20 (2 H, m, Ar H), 8.10–8.32 (1 H, m, Ar H), 11.14 (1 H, s, CO_2H); UV (anhydrous C_2H_5OH) λ_{max} 387 nm (ϵ 8830), 382 (4640), 367 (8990), 348 (5420), 331 (2490), 318 (1020), 257 (169 000), 250 (80 900), 236 (21 600), 223 (6700).

Anal. Calcd for $C_{19}H_{18}O_2$: C, 82.01; H, 6.44. Found: C, 81.87; H, 6.65.

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Registry No. 1, 2143-81-9; **2**, 1099-45-2; **3**, 42997-19-3; **5**, 75802-25-4; **6**, 75802-26-5; **7**, 75802-27-6; **8**, 75802-28-7; **9**, 75802-29-8; **10**, 75802-30-1; **11**, 75802-31-2; **12**, 75802-32-3; **13**, 75802-33-4; **14**, 75802-34-5; **15**, 75802-35-6; **16**, 75802-36-7; **17**, 642-31-9; **18**, 75802-37-8; **19**, 75802-38-9; **20**, 5335-33-1; **21**, 75802-39-0; **22**, 41034-83-7; **23**, 75802-40-3; [6-(methoxycarbonyl)hexa-2,4-dien-1-yl]triphenylphosphonium bromide, 75802-41-4.

Desiccant Efficiency in Solvent and Reagent Drying. 5. Amines[1-4]

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The use of amines in synthesis can be divided into three principal areas: (i) as basic agents for the promotion of dehydroeliminations, (ii) as nucleophiles in simple displacements, and (iii) as precursors of various metalated derivatives. Because of strong N–H hydrogen bonding, in all these uses, water present in the amine system may exert damaging, i.e., yield lowering, effects by interfering with absolute basicity and nucleophilicity[6] and/or reacting either as free water or hydroxide ion with unstable intermediates or sensitive products.[7] However, despite the existence of an arsenal of desiccants, the presence of water in these systems continues to be a problem for the synthetic chemist. This is because the recommended agents for removal of water and polar impurities[9] from other solvent and reagent types[1-4] may not be suitable for amines. Therefore the radiotracer method for water assay previously developed by us[10] has now been applied to obtain quantitative data on the drying of some representative amines.

The Pyridine Group. For pyridine, and indeed generally for the amine class, the traditionally recommended siccatives are the alkali and alkali earth hydroxides and oxides.[11] Thus, literature prescriptions commonly advocate distillation from KOH,[12a,b] standing over BaO,[12c] or distillation from CaH_2,[13] the employment of the latter procedure reportedly yielding samples containing 18–20 ppm of residual water. The use of Al_2O_3 has also been occasionally reported.[14] Our results for pyridine obtained by application of the radiotracer technique are summarized in Table I. The results are largely self-explanatory, and as can be seen, a horizontal line drawn under the entry for KOH sharply demarcates *serious desiccants* from those which are less efficaceous. Surprisingly perhaps, alumina is seen to be rather unimpressive; however, this ineffectiveness in the drying of polar reagents has been noted previously.[1,3] It is also worth noting that the use of sodium is to be avoided; it is not particularly efficient and contributes to material loss by a wasteful side reaction which produces bipyridyls.

Alkylated derivatives of pyridine are more basic and often less nucleophilic than pyridine itself, and these attributes are considered advantageous in synthesis. We therefore thought it of interest to compare the difficulty

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[1] Part 1: D. R. Burfield, K. H. Lee, and R. H. Smithers, *J. Org. Chem.*, **42**, 3060 (1977).

[2] Part 2: D. R. Burfield, G. H. Gan, and R. H. Smithers, *J. Appl. Chem. Biotechnol.*, **28**, 23 (1978).

[3] Part 3: D. R. Burfield and R. H. Smithers, *J. Org. Chem.*, **43**, 3966 (1978).

[4] Part 4: D. R. Burfield and R. H. Smithers, *J. Chem. Technol. Biotechnol.*, in press.

[5] Abstracted in part from the Final Year Project of Andrew S. C. Tan, 1978–1979.

[6] As is well-known, solvation effects play a vital part in determining both basicity and nucleophilicity; see, for example, C. Reichardt "Solvent Effects in Organic Chemistry", Verlag Chemie, Weinheim, Germany, 1979, pp 55–60, 148–155.

[7] In a pertinent example from our own laboratories, the literature preparation of methyl diphenylphosphinite calls for reaction between chlorodiphenylphosphine and methanol in the presence of pyridine and gives a reported yield of 52%.[8] In our hands, the use of rigorously dried pyridine and methanol increased the yield to 75%.

[8] A. E. Arbuzov and K. V. Nikonorov,, *Zh. Obsch. Khim.*, **18**, 2008 (1948).

[9] D. R. Burfield and R. H. Smithers, *Chem. Ind.* (*London*), 240 (1980).

[10] D. R. Burfield, *Anal. Chem.*, **48** 2285 (1976).

[11] See, for example: (a) D. Todd "Experimental Organic Chemistry", Prentice-Hall Inc., NJ, 1979; (b) R. S. Monson, "Advanced Organic Synthesis", Academic Press, New York, 1971; (c) J. A. Riddick and W. B. bunger, "Organic Solvents", 3rd ed., Wiley-Interscience, New York, 1970.

[12] See, for example: (a) G. A. Olah and M. Watkins, *Org. Synth.*, **58**, 75 (1978); (b) W. H. F. Sasse, "Organic Synthesis", Collect. Vol. V, Wiley, New York, 1973, p 102; (c) R. F. Evans, H. C. Brown, H. C. Van der Plas, *ibid.*, p 977.

[13] D. Jerchel and E. Bauer, *Angew. Chem.*, **68**, 61 (1956).

[14] D. N. Glew and N. S. Rath, *Can. J. Chem.*, **49**, 837 (1971).

Table I. Desiccant Efficiency in the Drying[a,b] of a Pyridine[c] Series

	residual water content,[d] ppm			
desiccant	pyridine	2-methylpyridine	2,6-dimethylpyridine	2,4,6-trimethylpyridine
CaH_2	39 (14)[e]	84	248 (138)[e]	132
CaC_2	44 (10)[e]	71	519	8
BaO	101	27	360	33
4A sieves	106 (0.3)[f]		268 (126)	
3A sieves	117	55	200 (128)	47
benzene azeotrope	125	40	207	390
KOH powder	152	176	325	27
Na	388			
CaO	962		935	
silica gel	926			
Al_2O_3	1306			

[a] Static drying modes unless specified otherwise. [b] Water content assayed by the radiotracer technique. [c] Desiccant loading 5% w/v; initial water content 2500 ppm (0.25% w/w). [d] 24-h drying times unless specified otherwise. [e] 168-h drying time. [f] Sequentially dried sample, 24 h.

of drying of some of the more commonly used alkylated derivatives. A survey of the literature revealed that although the alkylpyridines are usually subjected to similar drying procedures as pyridine itself, fractionation alone and fractionation from BF_3 (!) have been advocated for 2-methylpyridine[15] and 2,6-dimethylpyridine,[16] respectively. The results summarized in Table I exhibit a clear-cut trend; whereas one alkyl group at the 2-position gives results of similar overall order to pyridine, when N is flanked by two such groups (as in the lutidine) there is a marked increase in difficulty of drying, with 2–10-fold greater water levels being observed. Interestingly, the final member of series, the collidine, gave rise to some of the lowest residual water levels recorded. Not only is 2,4,6-trimethylpyridine the most basic of the series examined,[17] it is also the easiest example to dry. Clearly then, there seems to be no relation between increasing basicity and drying difficulty, and instead this property appears to be determined by the interplay of water-solubility factors and of steric crowding about the N atom. Thus, for 2,6-dimethylpyridine, an infinitely water-miscible base, an obvious speculation is that the two flanking methyl groups present a serious impediment to the close approach of a siccative to the water-coordinating site. For trimethylpyridine, a drop in residual water concentrations is paralleled by a corresponding large decrease in water solubility.[18]

Triethylamine. Triethylamine, commonly used as a mild base in dehydrohalogenations, has been dehydrated by the alkaline earth oxides,[11c,19a] KOH,[19b] CaH_2,[19c] and molecular sieves[19d] as well as by alumina and sodium metal.[11c] The results summarized in Table II require little comment beyond the fact that, despite being considerably more basic than the pyridines, triethylamine ($pK_b = 3.1$) appears very much easier to dehydrate.

Table II. Desiccant Efficiency in the Drying[a] of Various Amines[b]

	residual water content,[c] ppm		
desiccant	Et_3N[d]	$(Me_2CH)_2NH$[e]	$NH_2(CH_2)_3NH_2$[e]
KOH powder	37 (23)[f]	750[g]	1370 (3700)[g]
4A sieves	33 (28)[h]	<25	<25
3A sieves	34	<25	<25
CaH_2	68 (34)[f]	150[i]	500[i]
Na	83	<25	150
BaO	89 (53)[f]	50	1100
CaC_2	98 (80)[f]	<25[i]	<25[i]
CaO	165 (56)[f]		
Al_2O_3	223 (223)[j]		
silica gel	451		
$CaSO_4$			>2500

[a] Static drying modes unless specified otherwise. [b] Desiccant loading 5% w/v, initial water content 2500 ppm (0.25% w/w). [c] 24-h drying times unless specified otherwise. [d] Water content assayed by the radiotracer method. [e] Water content assayed by the near-IR method. [f] 168-h drying time. [g] Aged desiccant used. [h] Sequentially dried sample. [i] Stirred samples. [j] 72-h drying time.

Diisopropylamine. Diisopropylamine is the precursor of lithium diisopropylamide, a powerful highly hindered base which is freely soluble in many organic solvents and which has achieved prominence in synthesis[20] in the continuing search for potent bases of low nucleophilicity. Curiously, drying prescriptions for the parent amine are infrequently mentioned, but desiccation with KOH and storage over CaH_2 is probably a typical expedient.[21] Because this drying problem was not amenable to investigation using the radiotracer method, due to interference by isotopic exchange, the near-IR method[1,6,22] was applied and yielded the results summarized in Table II. In view of the high water solubility (~40%) and basicity (pK_b = 2.9) of this amine, it may seem surprising that dehydration is so facile. However, an examination of models of the water–amine complex suggests that the avoidance of steric congestion between the water molecule and the adjacent methyl groups can only occur with the imposition of severe entropy constraints, with the probable result that the equilibrium between complex and free amine lies largely to the left.

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(15) L. A. Walter, "Organic Syntheses", Collect. Vol. III, Wiley, New York, 1955, p 757.

(16) A. N. Sharpe and S. Walker, *J. Chem. Soc.* 2974 (1961).

(17) The relevant pK_b values for pyridine, 2-methylpyridine, 2,6-dimethylpyridine, and 2,4,6-trimethylpyridine are 8.8, 8.0, 7.3, and 6.6, respectively.

(18) While pyridine itself, as well as its mono- and dialkyl derivatives, is essentially completely water miscible, the solubility of the trimethylated pyridine is only about 3%. See *Beilsteine, 4th ed.*, **20**, 164 (1953).

(19) (a) R. Breslow and J. Posner, "Organic Syntheses", Collect. Vol. V, Wiley, New York, 1973, p 514; (b) H. Rinderknecht and M. Gutenstein, *ibid*, p 822; (c) M. E. Jung and C. A. McCombs, *Org. Synth.*, **58**, 163 (1978); (d) T. J. Atkins, R. E. Richman, and W. F. Oettle, *ibid.*, **58**, 87 (1978).

(20) For usage see, for example: (a) B. M. Trost, C. D. Shuey, F. DiNinno, Jr., and S. S. McElvain, *J. Am. Chem. Soc.*, **101**, 1284 (1979); (b) R. A. Olofson and C. M. Dougherty, *ibid.*, **95**, 582 (1973).

(21) D. Enders, R. Pieter, B. Renger, and D. Seebach, *Org. Synth.*, **58**, 113 (1978).

(22) R. L. Meeker, F. Critchfield, and E. T. Bishop, *Anal. Chem.*, **34**, 1510 (1962).

1,3-Propanediamine. This is another example of an amine which has sprung to prominence in synthesis because of unique reactions brought about by a derivative, in this case its monopotassium salt.[23] Desiccation has been achieved by vacuum distillation alone,[24a] distillation from alkali metal mirrors,[24b] or distillation from KOH.[24c] Our results using the near-IR method are displayed in Table II and indicate that, not surprisingly, this amine with two coordinating centers is one of the more difficult examples to dry. It is worth noting that freshly ground KOH gives a drier sample than aged material stored in a desiccator, although as may be seen, in comparison with several other siccatives, e.g., CaC_2 or sieves, KOH is not particularly good. In addition, although seldom recommended for use in these situations, $CaSO_4$ (Drierite) was investigated in view of some of the more extravagant claims which have been made on its behalf.[25] As may be seen, the results are rather dismal.

Desiccation of Amines. General Recommendations. Perhaps not surprisingly, the results from this study lend support to the current usage of molecular sieves and CaH_2 as *serious* and widely applicable siccatives for amines. Apart from this, it is fitting to draw attention to the high efficiency of CaC_2 in these studies, which, though infrequently prescribed as a desiccant, is often seen to surpass CaH_2 in potency and is more desirable than the hydride from consideration of cost and safety in storage. On the other hand, the performance of alumina is uniformly disappointing and it cannot be advocated as a serious desiccant for amines.

Experimental Section

Details of the water assay techniques as well as the source, activation, and handling of most of the desiccants have already been described.[1-4] Determination of water content by the near-IR method[22] was carried out on a Varian Cary 17 Instrument. Calcium carbide was of industrial grade and was crushed in a mortar immediately prior to use. Appropriate venting was provided for desiccants producing gases, e.g., CaC_2, CaH_2.

Amines were of laboratory reagent grade and purified by standard methods.[11c] The pyridines and triethylamine were stood over KOH for 24 h, decanted, fractionated, and stored in dark bottles over 20% w/v 3A molecular sieves. Pyridine had bp 115–116 °C, 2-methylpyridine 128–129 °C, 2,6-dimethylpyridine 145–146 °C, and 2,4,6-trimethypyridine 176–178 °C. Et_3N had bp 89–89.5 °C. Diisopropylamine was first allowed to stand over 20% w/v 3A molecular sieves, decanted, stirred overnight with CaH_2, fractionated, and finally stored as above, bp 84 °C. 1,3-Propanediamine was mixed with 20% v/v benzene, fractionated, stirred overnight with CaH_2, and fractionated again, bp 135–136 °C.

Acknowledgment. We thank the Department of Chemistry, University of Malaya, for support of this work and Miss Lim Siew Heong for her able technical assistance.

Registry No. Pyridine, 110-86-1; 2-methylpyridine, 109-06-8; 2,6-dimethylpyridine, 108-48-5; 2,4,6-trimethylpyridine, 108-75-8; Et_3N, 121-44-8; $(Me_2CH)_2NH$, 108-18-9; $NH_2(CH_2)_3NH_2$, 109-76-2; CaH_2, 7789-78-8; CaC_2, 75-20-7; BaO, 1304-28-5; benzene, 71-43-2; KOH, 1310-58-3; Na, 7440-23-5; CaO, 1305-78-8; Al_2O_3, 1344-28-1; $CaSO_4$, 7778-18-9.

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[23] Potassium 3-aminopropylamide possesses the singular property of bringing about the conversion internal alkyne → 1-alkyne in essentially quantitative yields. See C. A. Brown and A. Yamashita, *J. Am. Chem. Soc.*, **97**, 891 (1975).

[24] (a) A. Gero, *J. Am. Chem. Soc.* **76**, 5159 (1954); (b) L. R. Dalton, J. L. Dye, E. M. Fielden, and E. J. Hart, *J. Phys. Chem.*, **70**, 3358 (1966); (c) K. C. Badri and L. Y. Goh, *Inorg. Chim. Acta*, in press.

[25] W. A. Hammond, "Drierite", the W. A. Hammond Drierite Company, Xenia, OH.

Trapping of Intermediates in the Thermolysis of α-Azidochalcone. Insight into the "Zwittazido Cleavage" Reaction

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The "zwittazido cleavage" reaction (Scheme I) has recently been the subject of considerable study[1] because this novel rearrangement possesses both interesting mechanistic and advantageous synthetic characteristics. Although a large amount of work with cyclic and acyclic ketoazides has been reported,[1,2] the mechanism of this reaction is still somewhat obscure, especially the question of whether a concerted or stepwise process (or both) occurs.

In the rearrangement of cyclic keto vinyl azides opportunity exists for an intramolecular ring closure following an initial ring cleavage (Scheme I). In acyclic systems formation of azirines, indoles, or rearranged cyano ketones can take place.[2] In transformation **1**→**2**, the reaction has been postulated to occur via intermediate **3**. An alternate pathway would involve a cleavage to ions **4** and **5**, which may recombine to **2** (Scheme II).

Our interest in the chemistry of vinyl azides[3] led us to investigate this reaction and to show that even in the acyclic case cleavage can occur and that the intermediates can be trapped with alcohols or amines.

Thermolysis of α-azidochalcone (**1**) in *o*-dichlorobenzene for 24 h produced α-cyano-α-phenylacetophenone (**2**) in 70% yield. When the reaction was carried out in the presence of 10 equiv of either ethanol or benzyl alcohol, the yield of **2** decreased while ethyl benzoate (**6**) and benzyl benzoate (**7**), respectively, were isolated. Thermolysis with 10 equiv of benzylamine yielded *N*-benzylbenzamide (**8**). In all three trapping experiments, considerable quantities of **2** were also obtained along with benzyl cyanide (**9**) and polymeric materials. The results are recorded in Table I.

The formation of compounds **6–9** indicates that at least part of the thermolysis of the acyclic α-azidochalcone proceeds by a cleavage mechanism as shown in Scheme II which allows for an acyclic cation intermediate **4** to react with the alcohols and amine. Protonation of **5** leads to benzyl cyanide (**9**).

We showed that the azido ketone **1** did not react with ethanol in boiling toluene to produce ethyl benzoate.[4] Furthermore, no ethyl benzoate (**6**) was detected by GC when either the cyano ketone **2** or the crude mixture resulting from heating **1** in *o*-DCB was subjected to trapping reaction conditions.[5]

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[1] H. W. Moore, *Acc. Chem. Res.*, **12**, 125 (1979), and references cited there in.

[2] D. Knittel, Hemetsberger, R. Leipert, and H. Weidman, *Tetrahedron Lett.*, 1459 (1970).

[3] For instance (a) G. L'Abbé, and A. Hassner, *Angew. Chem., Int. Ed. Engl.*, **10**, 98, (1971); (b) A. Hassner, E. S. Ferdinandi, and R. J. Isbister, *J. Am. Chem. Soc.*, **92**, 1672 (1970); (c) A. Hassner, *Acc. Chem. Res.*, **4**, 9 (1971).

[4] Azidochalcone (**1**) reacts with nucleophiles such as sodium sulfide or ylides at the azide rather than at the carbonyl function; B. A. Belinka, Jr., and A. Hassner, *J. Org. Chem.*, **44**, 4712 (1979), and unpublished results in this laboratory; G. Mathys, S. Toppet, and G. L'abbé, *Chem. Ind.* (*London*), **6**, 278 (1975).

[5] G. L'abbé and A. Hassner, *J. Org. Chem.*, **36**, 258 (1971).