N^α-Carbobenzoxyhistidine hydrazide (0.60 g, 2.0 mmoles) was converted to its azide and then added (in ethyl acetate solution) to the above dimethylformamide solution of the free base tetrapeptide at 0°. The ethyl acetate was removed by distillation *in vacuo* at 0°, and the remaining dimethylformamide solution was kept at 0° for 48 hr. The dimethylformamide was removed by distillation *in vacuo* at 40–50° and the residue submitted to purification by countercurrent distribution in the toluene system for 120 transfers. The material in tubes 35–63 ($K = 0.67$) was pooled and evaporated. Crystallization of the protected pentapeptide from methanol yielded 0.73 g (78%), mp 172–174°; $R_{f\mathrm{BAW}}$ 0.85; $[\alpha]^{25}\mathrm{D}$ −32.5° (*c* 1, methanol).

Anal. Calcd for $C_{51}H_{65}O_{10}N_9$ (964.1): C, 63.5; H, 6.80; N, 13.1. Found: C, 63.8; H, 6.96; N, 13.6.

Histidylphenylalanyllysyltryptophanylglycine. The protected pentapeptide (96 mg, 0.10 mmole) was dissolved in 4 cc of 4 *N* hydrogen bromide in glacial acetic acid. After standing at room temperature for 30 min, a large volume of ethyl ether was added to precipitate the hydrogen bromide salt of the free pentapeptide. The ether was decanted and the residue washed twice with fresh ether and then dried *in vacuo* over sodium hydroxide pellets. The dried peptide was dissolved in a small volume of 0.01 *M* ammonium acetate, and applied to a 1.4 × 55 cm column of carboxymethylcellulose previously buffered with 0.01 *M* ammonium acetate. After collecting 40 fractions (4 cc each) a gradient was begun with 0.2 *M* ammonium acetate with a 500-cc mixing chamber. The purified peptide was isolated from tubes 85–120 by lyophilization (three times) to remove ammonium acetate and excess water. The yield of the lysine pentapeptide was 62.5 mg (96%). The ultraviolet absorption of the material revealed a peptide content of 76%, thus making the actual yield of free lysine pentapeptide as 73%. This product gave a single spot, positive to ninhydrin, Pauly, Ehrlich, and chlorine, in paper chromatography, BAW, SBA, and paper electrophoresis at pH 7.0, 400 v, 6 hr ($R_{f\mathrm{Lys}}$ 0.40); $[\alpha]^{25}\mathrm{D}$ −15.4° (*c* 0.3, 0.1 *N* acetic acid).

The lysine pentapeptide (0.5 mg) was dissolved in 0.5 cc of Tris, pH 8.0, buffer (0.01 *M* Mg^{2+}) and 0.005 cc of a leucine aminopeptidase solution (0.14 mg of Worthington No. 5917 in 0.025 cc of water) was added and the digest incubated at 37° for 16 hr. Paper electrophoresis revealed no more pentapeptide. The digest was then directly analyzed for amino acid composition in a Spinco amino acid analyzer. The results in mole ratios were: histidine, 0.98; phenylalanine, 1.03; lysine, 1.00; tryptophan, 1.02; and glycine, 0.88.

Acknowledgments. We wish to thank Miss Ruth Johnson, Mr. Charles Jordan, Jr., Mr. J. D. Nelson, and Miss Jean Putnam for their able technical assistance. This work was supported in part by grants from the National Institutes of Health of the U. S. Public Health Service (GM-02907).

Communications to the Editor

Flash Vacuum Pyrolysis. I. Allylcyclopentadiene from Allyl Phenyl Ether

Sir:

Lossing and co-workers[1] have demonstrated in their comprehensive study of free radicals by mass spectroscopy that pyrolysis of certain normally stable organic molecules at temperatures up to the softening point of quartz (about 1200°), low pressures (about 10^{-3} mm) and short contact times (1–10 msec) can efficiently lead to a wide variety of organic free radicals. While searching for an unequivocal method for generating the succinimidyl radical[2] in an environment suitable for physical and chemical characterization, we realized that pyrolysis at the above conditions, which can serve to define the process of flash vacuum pyrolysis[3] (FVP), had great potential for fundamental studies of the chemical and spectroscopic properties of organic free radicals and other unstable, primary pyrolytic intermediates; the possibility of synthetic utility was also envisioned. In this and the following report[4] we describe the techniques and some preliminary results which have evolved in our investigation of FVP.

Our basic apparatus consists of a tubular oven (*radical gun*) which is housed in a vacuum-tight chamber coupled to a large Pyrex dewar (Figure 1). In the present work the radical gun was constructed from a quartz tube which is tightly and closely coiled with Nichrome wire and then encased with fused quartz. The temperature is measured along the axis by a thermocouple encased in a quartz capillary.

In order to determine whether our apparatus could be used to chemically duplicate results of mass spectrometric experiments, we investigated the FVP of allyl phenyl ether. Lossing and co-workers[5] have shown that the phenoxy radicals initially produced decarbonylate near 900° to give the cyclopentadienyl radical. In our first experiments 0.5 or 1.0 g of allyl phenyl ether was pyrolyzed and the products were immediately quenched on the dewar surface kept at −196° (the distance from the tip of the radical gun to the dewar was about 2.5 cm). The dewar was slowly warmed to room temperature and the volatile products were collected on a vacuum manifold attached to the apparatus. These were isolated by preparative glpc and characterized by modern analytical techniques. The results are summarized by the equation given below and the data given in Table I.

Allylcyclopentadiene[6] (4) had the following properties: parent peak at *m/e* 106; nmr in $CDCl_3$ (TMS)

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[1] (a) F. P. Lossing, P. Kebarle, and J. B. DeSousa, "Advances in Mass Spectrometry," Pergamon Press, London, 1959, p 431; (b) F. P. Lossing, *Ann. N. Y. Acad. Sci.*, **67**, 499 (1957); (c) A. G. Harrison, "Mass Spectroscopy of Organic Ions," Academic Press Inc., New York, N. Y., 1963, p 207.

[2] (a) E. Hedaya, R. L. Hinman, and S. Theodoropulos, *J. Am. Chem. Soc.*, **85**, 3052 (1963); (b) E. Hedaya, R. L. Hinman, L. M. Kibler, and S. Theodoropulos, *ibid.*, **86**, 2727 (1964); (c) E. Hedaya, R. L. Hinman, V. Schomaker, S. Theodoropulos, and L. M. Kyle, in press.

[3] The terms "flash pyrolysis" or "flash heating" have been used to describe experiments where flash lamp emission is converted to heat: L. A. Nelson and N. A. Kuebler, *J. Chem. Phys.*, **37**, 47 (1962).

[4] C. L. Angell, E. Hedaya, and D. McLeod, Jr., *J. Am. Chem. Soc.*, **89**, 4214 (1967).

[5] (a) I. P. Fisher, F. F. Palmer, and F. P. Lossing, *ibid.*, **86**, 2741 (1964); (b) R. F. Pottie and F. P. Lossing, *ibid.*, **85**, 269 (1963); (c) A. G. Harrison, T. R. Horner, H. J. Dauben, Jr., and F. P. Lossing, *ibid.*, **85**, 5593 (1963).

[6] A. Renner, U. S. Patent 3,105,839 (Oct 1, 1963).

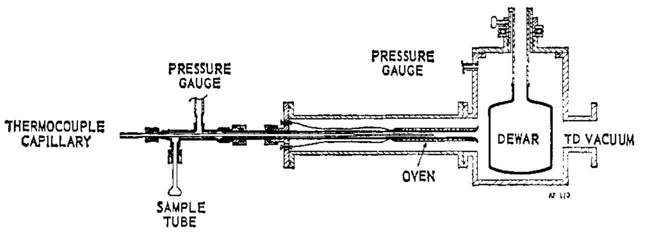

Figure 1. Flash vacuum pyrolysis apparatus.

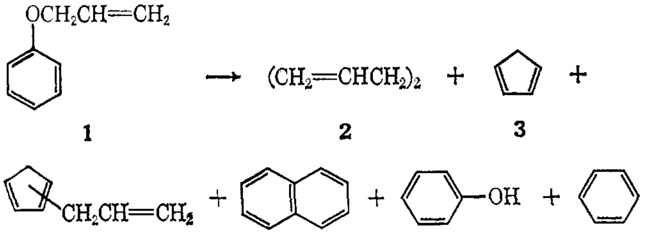

Table I. Flash Vacuum Pyrolysis of Allyl Phenyl Ether

	Temp,		Product distribution[c]							
P, μ[a]	°C	Yield[b]	1	2	3	4	5	6	7	Other[d]
68	954	60.2	1.1	19.1	3.9	55.1	1.2	10.3	1.4	7.9
82	944[e]	24.2	1.9	25.0	9.8	3.2	6.8	28.6	8.2	16.5
62	857	62.6	1.6	22.9	1.7	38.9	1.6	16.7	0.3	16.3
185	750	51.9	2.6	42.6	0.6	16.2	0.5	32.4	1.1	4.0

[a] Approximate average pressure in radical gun; contact times were about 10^{-3} sec. [b] (Grams of volatiles/grams of allyl ether) × 100; does not include carbon monoxide or other noncondensable gases; in general, a small amount of an involatile amorphous residue was also obtained. [c] (Area of peak/total area of peaks) × 100 in gas chromatogram; Apiezon and Carbowax columns were used. [d] (Total area of unknown peaks/total area of peaks) × 100; in general, each unknown represented no more than 5% of the total area. [e] Pyrolysate was condensed in a cold trap about 1 ft from the tip of the radical gun.

2.8–3.2 m, 4.7 m, 5.1 m, and 5.5–6.4 m ppm in an area ratio of 4:1:1:4; infrared 3.25, 3.33, 3.48, 6.09, 6.21, and 14.8 br μ (neat); $\lambda_{\max}^{C_7H_{14}}$ (ϵ) 251 (940), 258 (790), 264 (730), 271 (720), and 278 (630). This material is probably a mixture of 1- and 2-substituted isomers.[7] The other products were characterized by direct comparison of mass, infrared, and nmr spectra and glpc retention times with those of authentic materials.

These data show that the mass spectral results of Lossing can be chemically duplicated in our apparatus on a preparative scale. Furthermore, the allylcyclopentadiene must be formed after condensation of the pyrolysate on the Dewar surface since the yield of this cross-coupling product is drastically reduced when condensation occurs instead in a liquid nitrogen trap located approximately 1 ft from the tip of the radical gun (second row, Table I). The radical-coupling reactions occurring either on condensation, or warming of the dewar surface, or both apparently lead to a statistical distribution of coupling products on the basis of allylcyclopentadiene:biallyl ratio (first row, Table I). The ultimate products resulting from coupling of two cyclopentadienyl radicals may include naphthalene, although more recent experiments[8] suggest that the dihydrofulvalene, which should be the initial product, may polymerize and thus lead in part to formation of nonvolatile residues. The over-all distribution of products indicates that the decarbonylation reaction of phenoxy radicals is an efficient process, as the mass spectral data also indicate. This remarkable reaction[9] was found to be significant at much lower temperatures, and its mechanism is a question of considerable interest.

The absence of Claisen rearrangement at the temperatures investigated here must result from an unfavorable activation entropy ($\Delta S^{\ddagger} = -12$ eu)[10] compared to that for homolysis, which overcomes the activation enthalpy difference which would clearly favor the former process. At 500° the Claisen rearrangement product (2-allylphenol) was detected by glpc.

We are currently investigating the FVP of a variety of phenyl ethers as well as other molecules and have already found that anisole[8] gives substantial yields of methylcyclopentadiene at 950°.

Acknowledgment. The authors are indebted to Dr. F. P. Lossing for important discussions, and also acknowledge the assistance of Mr. W. D. Bird in the construction of apparatus.

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(7) S. McLean and P. Haynes, *Tetrahedron*, 21, 2329 (1965).

(8) E. Hedaya and D. McNeil, unpublished results.

(9) This reaction also occurs when phenols are flash photolyzed in the vapor: G. Porter and B. Ward, *Proc. Chem. Soc.*, 288 (1964).

(10) H. L. Goering and R. R. Jacobson, *J. Am. Chem. Soc.*, **80**, 3277 (1958).

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Flash Vacuum Pyrolysis. II. The Electronic, Vibrational, and Electron Spin Resonance Spectra of the Benzyl Radical

Sir:

In the preceding communication[1] it was demonstrated that flash vacuum pyrolysis (FVP) can be an efficient source of free radicals such that primary, stable reaction products can be isolated on a chemically significant scale. An important aspect of this work is the spectroscopic characterization of some of the free-radical intermediates whose existence has been demonstrated by the extensive research of Lossing and co-workers.[2] One approach suggested by studies[3] of the optical and esr spectra of simple radicals and high-temperature molecules would involve stabilization of the reactive free radicals by isolation in rare gas matrices at low temperatures. We have now found that a variety of reactive organic free radicals which are generated by FVP can in fact be stabilized in rare gas matrices which permits, in the most favorable cases, the observation of their ultraviolet, visible, infrared, and esr spectra *under essentially identical conditions;* such a

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(1) E. Hedaya and D. McNeil, *J. Am. Chem. Soc.*, **89**, 4213 (1967).

(2) (a) F. P. Lossing, P. Kebarle, and J. B. DeSousa, "Advances in Mass Spectrometry," Pergamon Press, London, 1959, p 431; (b) F. P. Lossing, *Ann. N. Y. Acad. Sci.* **67**, 499 (1957); (c) A. G. Harrison, "Mass Spectroscopy of Organic Ions," Academic Press Inc., New York, N. Y., 1963, p 207.

(3) (a) W. Weltner, Jr., *Science*, **155**, 155 (1967); (b) C. K. Jen in "Formation and Trapping of Free Radicals," A. M. Bass and H. P. Broida, Ed., Academic Press Inc., New York, N. Y., 1960.