from diazoacetic ester reactions.

Complex **1c** is significant in this regard since it appears to be afforded equal opportunity to proceed via A or B. Obviously, from the results it prefers A. In comparing **1c** to those used by Casey and Brookhart, it is apparent that their metal complexes have considerably more steric bulk around the metal (structures E and F) than does **1c** which is square planar. It is also important to note that fluorene is unique and ideally suited for this endeavor because it is also planar.[7] Thus, in the transition state leading to the platinacyclobutane complex, the fluorene moiety can exist parallel to the square planar plane thereby offering minimal steric difficulty. It is also significant to add that molecular models do not reveal any obvious disadvantage to reaction via intermediate B.

Acknowledgment. We acknowledge the donors of the Petroleum Research Fund, administered by the American Chemical Society, the National Science Foundation for support of this research, and Johnson–Matthey for the loan of platinum.

(7) If Py_2 is coordinated to the benzylic carbon, it would be sp^3 thus reducing the planarity somewhat. However, by molecular models this is not a consequential deviation.

A Formal 4 + 1 Route to Alkylidene Cyclopentenediones. A Synthetic Application of the Transition-Metal-Catalyzed Terminal Alkyne ⇌ Vinylidene Rearrangement

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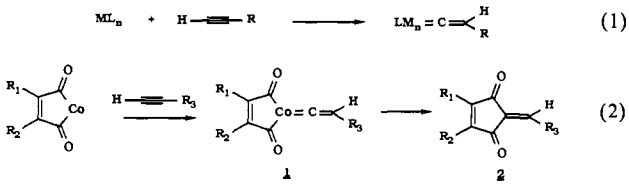
Terminal alkynes react with a wide range of transition-metal catalysts to form metal vinylidene complexes (eq 1).[2] While alkynes participate in numerous metal-catalyzed reactions via 1,2-addition pathways, there are no documented synthetically useful transition-metal-catalyzed reactions of terminal alkynes that proceed via the vinylidene tautomer.[3] We wish to describe a novel reaction of a cobaltacyclopentenedione with terminal alkynes, presumably via the vinylidene tautomer **1**, to provide 5-alkylidene cyclopent-2-ene-1,4-diones **2** (eq 2).[4]



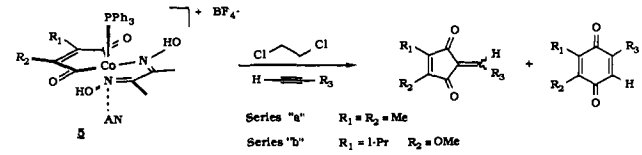
(1) Fellow of the Alfred P. Sloan Foundation, 1983–1988. Camille and Henry Dreyfus Foundation Teacher-Scholar, 1985–1991.

(2) Vinylidene review: Bruce, M. I.; Swincer, A. G. *Adv. Organomet. Chem.* **1983**, *22*, 59.

(3) Synthetic applications of vinylidenes preformed from transition-metal acyls do exist: Barrett, A. B. M.; Sturgess, M. A. *Tetrahedron Lett.* **1986**, *27*, 3811–3814. Barrett, A. G. M.; Brock, C. P.; Sturgess, M. A. *Organometallics* **1985**, *4*, 1903. In addition, there are a few examples from the organometallic literature of reactions that appear to proceed through vinylidene intermediates: Marten, D. F. *J. Chem. Soc., Chem. Commun.* **1980**, 341–342. Chiusoli, G. P.; Salerno, G.; Giroldini, W.; Pallini, L. *J. Organomet. Chem.* **1981**, *219*, C16–C20. Moran, G.; Green, M.; Orpen, A. G. *J. Organomet. Chem.* **1983**, *250*, C15–C20. Buchwald, S. L.; Grubbs, R. H. *J. Am. Chem. Soc.* **1983**, *105*, 5490–5491. Landon, S. J.; Shulman, P. M.; Geoffroy, G. L. J. *J. Am. Chem. Soc.* **1985**, *107*, 6739–6740. Rosenblum, M. *J. Organomet. Chem.* **1986**, *300*, 191–218. We are grateful to referee II for bringing these latter reactions to our attention.

(4) All new compounds were characterized by IR, high field ^1H NMR, and gave satisfactory elemental analysis or high resolution mass spectra.

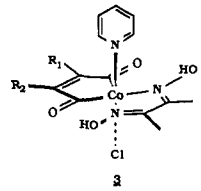
Table I. Formation of 5-Alkylidene Cyclopentenediones from Complexes **5a** and **5b** and Terminal Alkynes[a]



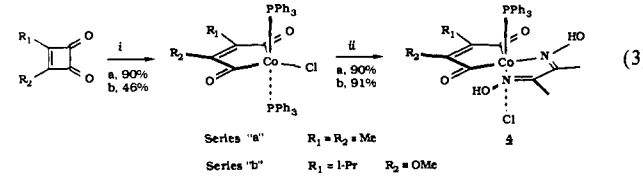
entry	complex	alkyne R_3	product yield	quinone yield
1	**5a**	*n*-Bu	66 (**7**)	08
2	**5a**	$(CH_2)_3Cl$	44 (**8**)	08
3	**5a**	CH_2OCH_3	34	14
4	**5a**	$(CH_2)_3CN$	41	09
5	**5a**	Ph	23	13
6	**5a**	CH_2OAc	30	
7	**5a**	C_6H_{11}	80	
8	**5a**	$(CH_2)_{12}CH_3$	74	10
9	**5b**	*n*-Bu	72	
10	**5b**	C_6H_{11}	75	04[b]

[a] 1.5 equiv of alkyne in dichloroethane at 70 °C for 36 h. [b] Only one isomer of the quinone was detected.

Maleoylcobalt complexes **3** have been shown to react with a complete variety of alkynes (terminal, internal, electron deficient, electron rich) to form quinones.[5] During our attempts to vary

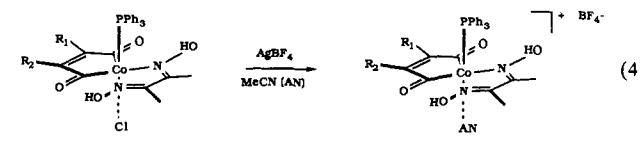


the reactivity and selectivity of the maleoylcobalt complexes through ligand variations, we prepared the PPh_3-substituted system **4a**, by the route shown in eq 3, and examined its reaction with



a. (i) 1.5 equiv $ClCo(PPh_3)_3$, PhH, 50 °C, 8 h; (ii) 1 equiv dimethylglyoxime in CH_3CN, room temperature, 24 h.
b. (i) 1.5 equiv $ClCo(PPh_3)_3$, PhH, 60 °C, 48 h; (ii) 1 equiv dimethylglyoxime in CH_3CN, room temperature, 24 h.

alkynes. In contrast to the quinone formation from **3** which proceeds readily at 80 °C with most alkynes and most rapidly with terminal alkynes, **4a** was unreactive toward terminal alkynes. Ionization of the Cl ligand, a technique that facilitated the reaction of **3** with alkynes, was attempted with **4a**. Reaction of **4a** with $AgBF_4$ in CH_3CN led to the isolation of the stable cation **5a** in quantitative yield (eq 4). On treatment of **5a** with 1-hexyne in



dichloroethane at 70 °C, a reaction ensued leading to the formation of 5-pentylidene-2,3-dimethylcyclopent-2-ene-1,4-dione (**7**) in 66% yield (Table I, entry 1). Use of 1-deuterio-1-hexyne gave the expected deuterium analogue of **7** in 64% yield. This reaction was extended to other terminal alkynes, and the results are listed in Table I, entries 1–8. Yields were moderate to good with the

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Table II. In Vitro Antitumor Assay of Alkylidene Cyclopentenediones **7** and **8** Compared with Cisplatin and Mitomycin C (IC_{50}, μg/mL)

cell line	cisplatin	mitomycin C	7	8
murine melanoma	7.7	2.5	15.1	11.1
human colon (HCT-116)	4.5	0.50	15.2	15.0
human nasopharyngyl	2.6	0.69	18.6	6.4
human colon (Moser)	6.3	2.2	15.2	17.4
murine lung	7.0	0.75	14.4	17.0
human colon (RCA)			12.5	13.2

lower yields attributed to the sensitivity of the very reactive alkylidene cyclopentenedione core. In some cases small amounts of the corresponding benzoquinone were also isolated. One trend was noted from the data in Table I—alkynes with electron-withdrawing groups attached gave poorer yields of alkylidene cyclopentenediones compared to the other alkynes.

A brief survey was made of the stereoselectivity of the reaction with respect to the geometry of the alkylidene double bond substituents and the substituents on the cyclopentenedione ring. Cationic maleoylcobalt complex **5b**, prepared analogously to **5a** (eq 3 and 4), was treated with 1-hexyne and cyclohexylacetylene to provide the cyclopentenediones shown in Table I, entries 9 and 10. In every case the reaction product proved to be a 1:1 mixture of double bond stereoisomers.

Alkylidene cyclopentenediones have been prepared previously by aldol dehydration and related sequences applied to cyclopentenediones[6] and by rearrangement of alkylidene furanones,[7] and an interesting zwitterionic route from an unsaturated ketene was recently disclosed.[8] The present method is rationalized by coordination of the alkyne to the cationic cobalt of complex **5** in place of the readily lost MeCN ligand. For reasons poorly understood at present, reaction of the alkyne-coordinated complex to give quinone must be slowed significantly for the PPh_3-ligated series **4** relative to the pyridine-ligated complexes **3**. Retardation of the quinone formation allows the slower terminal alkyne to vinylidene tautomerization to proceed, leading to the observed alkylidene cyclopentenedione products.

There has been some interest in the biological properties of alkylidene and arylidene cyclopentenediones with examples of antitumor[9] and anticoagulant[10] properties noted for the latter and fungicidal and bactericidal[11] properties noted for the former. Since the 5-alkylidene-cyclopent-2-ene-1,4-dione ring is very similar to the 5-alkylidene-4-hydroxycyclopent-2-enone core found in a number of very potent antitumor antibiotics of current interest (clavulones (claviridenones),[12] chlorovulones,[13] punaglandins[14]), two of the alkylidene cyclopentenediones of Table I were submitted for in vitro assay of cytotoxicity against six tumor cell lines.[15] The IC_{50} data for 5-pentylidene-2,3-dimethylcyclopent-2-ene-1,4-dione (**7**) and 5-(4-chlorobutylidene)-2,3-dimethylcyclopent-2-ene-1,4-dione (**8**) are shown in Table II with results for the clinically useful anticancer drugs cisplatin and mitomycin C given for comparison. Although subsequent in vivo testing of the two alkylidene cyclopentenediones showed no activity, the cytotoxicity results suggest that further assay of simple structures related to alkylidene cyclopentenediones could provide interesting biological leads.

Acknowledgment. This investigation was supported by PHS Grant No. CA-40157 awarded by the National Cancer Institute, DHHS. The effort of Dr. Suresh Iyer on some aspects of this project is gratefully acknowledged.

Supplementary Material Available: Experimental procedures consisting of the preparation of the cobalt complexes and reactions of the maleoylcobalt complexes **5a** and **5b** with terminal alkynes (13 pages). Ordering information is given on any current masthead page.

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(15) We thank Dr. Terrence Doyle of Bristol-Myers Co. for the antitumor assay of the compounds.

Remarkable Enantioselective 1,4-Addition Reactions of Chiral Allylphosphonyl Anions (Ambident Nucleophiles) with Cyclic Enones (Ambident Electrophiles)

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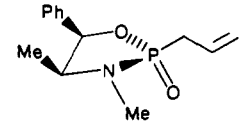
Despite the enormous amount of work on organophosphorus compounds,[1] relatively few studies have concerned asymmetric induction reactions involving chiral substrates of the phosphine oxide type.[2] In the course of our studies on asymmetric induction reactions involving allylic anions with enones,[3] we found that chiral allylphosphonyl anions of **1** and **2** undergo good enantioselective



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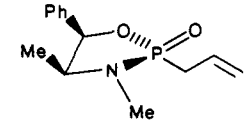

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