

Minor planets and related objects. XX. Polarimetric evidence for the albedos and compositions of 94 asteroids

B. Zellner and J. Gradie

Lunar and Planetary Laboratory, University of Arizona, Tucson, Arizona 85721

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New observations of asteroids bring the total to 94 for which useful polarimetry has been obtained, and to 52 for which polarimetric albedos and hence diameters can be computed. All asteroids so far observed, ranging over a more than a factor of 50 in diameter, show the polarimetric signatures of microscopically rough or particulate surface textures. Highly repeatable polarizations are found for each well-observed object, with little if any evidence for variation with rotation or aspect. Compositional types identifiable in our sample include 48 asteroids belonging to the broad *S* class, with iron-bearing silicate surfaces resembling ordinary chondrites or stony-iron meteorites; 34 objects of the *C* type, probably corresponding to carbonaceous chondrites; at least three and possibly five *M* asteroids with surfaces rich in free metal; two with high albedos (class *E*) attributable to pure enstatite; and five of other types. The *C* and *S* types are well separated in albedo, with mean $p_V = 0.06$ and 0.18, respectively. We find no simple mixtures of *C* and *S* materials, but distributions of various optical properties suggest that material of both kinds is seen in various stages of reduction toward surfaces of the metallic type.

INTRODUCTION

THE sensitivity of the linear polarization of reflected light to the composition and microstructure of rough surfaces, and the potential applicability of polarization measurements to hundreds of asteroids, makes it one of the most powerful techniques for exploration of the minor-planet population. Preliminary observations of the polarization as a function of solar phase angle for 43 asteroids were reported by Zellner *et al.* (1974). The polarimetry has been most profitably interpreted along with results from spectrophotometric programs (e.g., McCord *et al.* 1970; Chapman *et al.* 1973; McCord and Chapman 1975a, 1975b), which give indications of the composition, and with radiometric results in which the complementarity of absorbed solar and emitted thermal radiation is used to infer albedos and diameters (e.g., Matson 1971; Morrison 1974; Hansen 1976; Morrison and Chapman 1976).

In examining spectrophotometric, polarimetric, and radiometric results for a combined sample of 110 asteroids, Chapman *et al.* (1975) demonstrated that most of the objects could be assigned to broad but distinct *S* and *C* types in which the optically dominant surface minerals are, respectively, ferromagnesian silicates and carbon. In terms of meteoritic materials the dark, relatively colorless *C* asteroids are most easily identified with carbonaceous chondrites and the lighter, more reddish *S* objects with stony irons (Chapman and Salisbury 1973; Johnson and Fanale 1973; McCord and Gaffey 1974). Some doubts about both identifications have been raised by Zellner *et al.* (1975) on the basis of *UBV* colors. Roughly 10% of the asteroid population cannot be classified as *C* or *S* but belong to rarer types.

The principal classes of asteroids differ in their distributions over diameter and orbital parameters in ways which are poorly documented but vital for

understanding their modes of origin (e.g., Chapman 1975). Thus, the secure identification of types for a statistically broad sample of asteroids is essential. As we shall show, the type assignment is often strongly indicated by a single polarimetric observation and usually becomes unassailable when one other parameter, such as the *U-B* color, is available.

In this paper we present and analyze polarimetric observations for a total of 94 asteroids. For many of the objects listed by Zellner *et al.* (1974) we have improved phase coverage or precision. We also make use of polarimetry of 1566 Icarus by Gehrels *et al.* (1970), of several asteroids by Veverka (1971, 1973), of 1685 Toro by Dunlap *et al.* (1973), of 1620 Geographos by Dunlap (1974), and of 433 Eros by Zellner and Gradie (1976). The interpretations are still based primarily on laboratory results which are largely confined to lunar materials and generally of a quality inferior to that of the astronomical data.

I. OBSERVATIONS

Table I gives observations made with the Wollaston polarimeter first described by Gehrels and Teska (1960; see also Coyne and Gehrels 1967). Since January 1973 we use photon counting instead of dc integration, and the polarization modulation is provided by a rapidly spinning superachromatic half-wave plate (Serkowski 1974) above the fixed Wollaston prism. Along with previously unpublished data we incorporate observations from Table III of Zellner *et al.* (1974), with corrections for various small instrumental effects which are now better understood. Thus, the complete listing of our data comprises Tables I and II of Zellner *et al.* and Table I of this paper.

The polarization quantity of interest is $P_r = P_{\text{obs}} \cos 2\theta_r$, where θ_r is the angle between the measured direction of the strongest electric vector and the

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TABLE I. Observations of asteroids with the photon-counting polarimeter. Telescopes are identified by observatory and aperture in meters as in Table II of Zellner *et al.* (1974).

Ast. No.	Date (UT)	Tel.	Filt.	Phase	P%	ϵ_p°	θ_r	$P_r\%$	Ast. No.	Date (UT)	Tel.	Filt.	Phase	P%	ϵ_p°	θ_r	$P_r\%$
1	73 04 06.45	C1.5	B	18.67	.12	.03	-0.0	.12	4	74 06 28.23	C1.5	R	27.62	.41	.04	-4.1	.41
1	73 04 06.46	C1.5	G	18.67	.15	.05	7.5	.15	4	74 06 28.25	C1.5	B	27.62	.43	.02	-6.0	.42
1	73 04 13.44	S2.3	B	17.31	.24	.01	90.9	-.24	4	74 06 30.15	C1.5	R	27.68	.44	.02	-3.0	.44
1	73 04 13.44	S2.3	G	17.31	.21	.02	88.7	-.21	4	74 06 30.18	C1.5	B	27.68	.44	.01	.8	.44
1	73 04 22.37	C1.5	B	15.11	.82	.04	89.3	-.82	4	74 06 30.20	C1.5	U	27.68	.62	.04	-9.3	.59
1	73 04 22.38	C1.5	G	15.11	.76	.03	89.1	-.76	4	74 06 30.22	C1.5	G	27.68	.37	.02	-2.5	.37
1	73 05 02.39	C1.5	G	12.05	1.26	.06	89.4	-1.26	4	74 07 01.23	C1.5	B	27.70	.45	.02	-1.3	.45
1	73 05 02.39	C1.5	U	12.05	1.33	.04	89.5	-1.33	4	74 07 01.23	C1.5	G	27.70	.40	.01	-1.4	.40
1	73 05 08.39	S2.3	U	9.95	1.52	.07	90.3	-1.52	4	74 07 11.15	S2.3	R	27.72	.39	.03	-2.7	.39
1	73 05 08.39	S2.3	G	9.95	1.65	.04	90.3	-1.65	4	74 07 11.18	S2.3	U	27.72	.58	.02	.2	.58
1	73 05 08.40	S2.3	B	9.95	1.71	.03	90.8	-1.71	5	73 08 08.39	S2.3	B	21.81	.34	.15	-21.5	.25
1	73 05 11.28	S2.3	G	8.88	1.67	.02	92.0	-1.66	5	73 08 08.41	S2.3	G	21.81	.28	.20	-17.1	.23
1	73 05 11.29	S2.3	B	8.88	1.67	.04	91.6	-1.67	5	73 08 22.42	S2.3	G	21.22	.22	.14	3.0	.22
1	73 05 13.38	C1.5	B	8.08	1.72	.04	88.9	-1.72	5	73 09 19.45	C1.5	B	16.88	.22	.14	3.6	-.21
1	73 05 13.38	C1.5	G	8.08	1.69	.04	88.6	-1.69	5	73 09 19.48	C1.5	G	16.87	.21	.14	93.4	-.20
1	73 05 14.36	C1.5	B	7.69	1.77	.04	88.3	-1.77	5	73 10 07.30	S2.3	G	11.42	.62	.11	90.2	-.62
1	73 05 14.37	C1.5	G	7.69	1.71	.05	89.0	-1.71	5	73 10 07.31	S2.3	B	11.42	.65	.12	91.3	-.65
1	73 06 02.37	C1.5	B	1.11	.58	.03	89.9	-.58	5	73 12 07.24	S2.3	B	15.89	.37	.08	85.0	-.37
1	73 06 02.38	C1.5	G	1.11	.65	.04	91.0	-.65	5	73 12 07.25	S2.3	G	15.89	.33	.10	87.3	-.33
1	73 06 03.36	C1.5	G	1.30	.71	.03	91.3	-.71	5	73 12 28.26	C1.5	B	21.39	.24	.15	-.3	.24
1	73 06 03.36	C1.5	B	1.30	.69	.02	89.4	-.69	5	73 12 29.23	C1.5	G	21.57	.28	.16	-.9	.28
1	73 06 11.34	S0.5	G	4.33	1.48	.07	90.0	-1.48	5	73 12 29.25	C1.5	B	21.57	.34	.15	-1.9	.34
1	73 06 11.35	S0.5	B	4.33	1.54	.13	89.2	-1.54	5	74 01 29.14	C1.5	B	24.44	.49	.15	-1.3	.49
1	73 06 26.17	C1.5	G	9.96	1.58	.06	89.2	-1.58	5	74 01 29.14	C1.5	G	24.44	.47	.18	-1.4	.47
1	73 06 26.17	C1.5	B	9.96	1.63	.04	89.3	-1.63	5	75 01 12.32	C1.5	B	26.90	.76	.03	-1.4	.76
1	73 06 26.18	C1.5	U	9.97	1.56	.15	89.3	-1.55	5	75 04 01.29	C1.5	B	8.65	.66	.03	88.8	-.66
1	73 08 22.14	C1.5	G	20.60	1.66	.05	1.6	.66	5	75 04 01.31	C1.5	G	8.64	.69	.03	92.0	-.69
1	74 06 07.44	S2.3	G	19.88	.45	.01	2.8	.45	5	75 05 05.32	C1.5	B	9.85	.71	.03	88.6	-.71
1	74 06 07.46	S2.3	U	19.88	.54	.07	11.5	.49	5	75 05 05.33	C1.5	G	9.86	.69	.03	88.8	-.69
1	74 06 12.44	S2.3	U	19.74	.53	.05	2.2	.52	6	73 10 25.49	C1.5	G	24.07	.31	.15	-4.0	.31
1	74 07 11.46	S2.3	U	16.70	.31	.03	85.2	-.30	6	73 12 28.50	C1.5	B	16.42	.38	.08	94.2	-.38
1	74 08 09.40	C1.5	U	9.77	1.56	.05	90.1	-1.56	6	73 12 28.53	C1.5	G	16.41	.40	.08	85.0	-.40
1	74 09 08.34	S2.3	U	5.93	1.56	.02	90.5	-1.56	6	74 01 19.42	C1.5	B	8.44	.82	.07	88.1	-.82
1	74 09 08.36	S2.3	B	5.93	1.69	.01	90.9	-1.69	6	74 01 19.43	C1.5	B	8.43	.84	.06	90.0	-.84
1	74 09 08.36	S2.3	G	5.93	1.69	.01	91.2	-1.69	6	74 02 22.31	C1.5	B	7.76	.77	.02	91.8	-.77
2	73 04 06.40	C1.5	B	14.79	.73	.03	94.1	-.72	6	74 02 22.33	C1.5	G	7.77	.77	.02	91.9	-.77
2	73 04 13.17	S2.3	G	13.97	.84	.03	92.0	-.84	6	74 04 01.20	C1.5	B	19.28	.06	.17	91.8	-.06
2	73 04 13.18	S2.3	B	13.97	.85	.02	91.2	-.85	6	74 04 01.22	C1.5	G	19.28	.13	.04	91.3	-.13
2	73 04 22.34	C1.5	B	13.48	.92	.03	93.9	-.91	6	74 04 22.20	C1.5	B	21.42	.03	.12	17.2	.03
2	73 06 03.32	C1.5	B	17.59	.15	.04	92.1	-.15	6	74 04 22.22	C1.5	G	21.42	.02	.17	-5.3	.02
2	73 06 14.38	C1.5	B	18.82	.10	.03	.8	.10	6	74 04 26.25	C1.5	B	21.56	.11	.11	12.9	.10
2	73 08 07.23	S2.3	G	19.85	.43	.07	-.2	.43	6	75 03 05.51	C1.5	B	18.19	.23	.05	107.0	-.19
2	73 08 22.21	S2.3	G	18.88	.16	.09	11.3	.15	7	73 09 12.44	C1.5	B	32.72	1.59	.06	-.5	1.59
2	73 08 26.22	C1.5	G	18.55	.13	.08	-11.4	.12	7	73 09 12.46	C1.5	G	32.72	1.41	.05	-.2	1.41
2	74 04 22.48	C1.5	G	17.35	.18	.12	84.2	-.17	7	73 09 12.48	C1.5	U	32.72	2.04	.21	.2	2.04
2	74 06 02.28	S2.3	G	15.93	.48	.02	89.7	-.48	7	73 10 06.51	S2.3	G	32.23	1.26	.06	-1.3	1.26
2	74 06 02.30	S2.3	B	15.93	.47	.02	91.6	-.47	7	73 10 06.52	S2.3	U	32.23	1.99	.31	-1.5	1.98
2	74 07 23.30	C1.5	G	10.97	1.26	.03	90.8	-1.26	7	73 10 07.45	S2.3	U	32.15	1.80	.10	.4	1.80
2	74 07 23.32	C1.5	B	10.97	1.26	.02	89.1	-1.26	7	73 10 07.45	S2.3	B	32.15	1.34	.05	.7	1.34
2	74 08 23.23	S2.3	G	12.78	1.02	.01	91.7	-1.02	7	73 10 07.47	S2.3	G	32.15	1.24	.06	1.0	1.24
2	74 08 23.26	S2.3	B	12.78	1.02	.01	92.1	-1.02	7	73 10 07.52	S2.3	R	32.14	1.22	.26	2.7	1.21
3	73 04 06.44	C1.5	B	15.97	.38	.10	120.7	-.18	7	73 10 27.45	S0.5	G	29.32	.90	.16	.7	.90
3	73 04 13.22	S2.3	B	15.12	.53	.13	90.7	-.53	7	73 10 31.25	S0.5	G	28.46	.88	.24	-.3	.88
3	73 05 15.39	C1.5	G	8.79	.76	.16	87.9	-.76	7	73 11 04.39	S2.3	G	27.33	.58	.08	.2	.58
3	73 07 31.29	S2.3	G	16.13	.39	.17	81.8	-.38	7	73 11 04.40	S2.3	B	27.33	.74	.05	-1.6	.74
3	73 08 08.24	S2.3	G	17.09	.30	.11	92.4	-.30	7	73 12 07.28	S2.3	G	13.42	.64	.02	91.1	-.64
3	74 06 07.42	S2.3	G	23.04	.27	.03	1.0	.27	7	73 12 07.29	S2.3	B	13.41	.60	.02	94.2	-.59
3	74 06 07.43	S2.3	B	23.04	.36	.02	2.0	.36	7	73 12 07.30	S2.3	U	13.41	.49	.08	90.9	-.49
3	74 07 01.44	C1.5	G	22.00	.15	.03	14.5	.15	7	73 12 28.34	C1.5	B	1.64	.37	.04	87.9	-.37
3	74 07 01.45	C1.5	B	21.99	.27	.02	7.0	.28	7	73 12 28.34	C1.5	G	1.64	.37	.08	86.2	-.37
3	74 07 11.44	S2.3	G	20.63	.05	.02	9.6	.05	7	74 01 16.40	C1.5	G	11.03	.70	.07	90.1	-.70
3	74 07 11.44	S2.3	B	20.63	.09	.02	9.7	.09	7	74 01 16.41	C1.5	U	11.04	.82	.10	88.8	-.82
3	74 09 08.37	S2.3	G	2.08	.41	.01	91.3	-.41	7	74 01 16.42	C1.5	B	11.04	.70	.05	90.1	-.70
3	74 11 12.14	C1.5	G	25.79	.57	.03	-.1	.57	7	74 01 29.20	C1.5	G	17.00	.38	.04	90.2	-.38
4	73 04 06.14	C1.5	G	20.12	.06	.07	90.2	-.06	7	74 01 29.20	C1.5	B	17.00	.37	.02	86.5	-.37
4	73 04 06.15	C1.5	B	20.12	.03	.03	89.0	-.03	7	74 01 30.30	C1.5	B	17.44	.32	.04	91.3	-.32
4	73 04 13.16	S2.3	G	19.24	.22	.04	90.9	-.22	7	74 01 30.33	C1.5	G	17.44	.31	.06	87.0	-.31
4	73 10 25.51	C1.5	B	17.77	.27	.04	87.2	-.27	7	74 02 02.25	C1.5	U	18.57	.13	.15	99.6	-.13
4	73 10 25.53	C1.5	G	17.77	.25	.07	95.5	-.24	7	74 02 02.27	C1.5	G	18.58	.26	.05	91.3	-.26
4	73 10 27.52	S0.5	G	18.29	.27	.13	89.9	-.27	7	74 02 22.27	C1.5	U	24.11	.88	.10	-8.4	.84
4	73 12 10.54	S2.3	B	23.83	.16	.02	0.0	.16	7	74 02 22.29	C1.5	B	24.11	.42	.02	-.4	.42
4	73 12 10.55	S2.3	G	23.83	.13	.02	-0.0	.13	7	74 02 22.30	C1.5	G	24.12	.32	.03	-1.1	.32
4	73 12 28.56	C1.5	B	24.84	.22	.03	-.3	.22	7	74 04 01.14	C1.5	U	26.90	1.07	.28	4.8	1.06
4	73 12 28.57	C1.5	G	24.84	.19	.06	-.3	.19	7	74 04 01.16	C1.5	G	26.90	.66	.04	.3	.66
4	73 12 28.58	C1.5	U	24.84	.27	.06	-.2	.27	7	75 04 03.36	S2.3	B	8.76	.76	.01	89.6	-.76
4	73 12 30.51	C1.5	G	24.84	.21	.04	1.2	.21	7	75 04 03.40	S2.3	G	8.75	.73	.02	90.8	-.73
4	73 12 30.51	C1.5	B	24.84	.24	.04	-.3	.24	7	75 06 14.18	C1.5	U	17.01	.36	.		

TABLE I (continued)

Ast. No.	Date (UT)	Tel.	Filt.	Phase	PZ	ϵ_p	θ_r	P_r	Ast. No.	Date (UT)	Tel.	Filt.	Phase	PZ	ϵ_p	θ_r	P_r
8	74 09 08.31	S2.3	G	8.92	.66	.01	88.3	-.66	16	74 07 25.29	C1.5	B	3.71	.78	.03	91.1	-.78
8	74 09 08.31	S2.3	B	8.93	.67	.02	88.6	-.67	16	74 08 24.25	S2.3	G	9.09	.99	.02	90.1	-.99
8	74 10 02.17	C1.5	B	20.60	.18	.02	6.8	.17	16	74 08 24.27	S2.3	B	9.10	.94	.01	90.5	-.94
8	74 10 02.19	C1.5	G	20.61	.09	.02	-1.2	.09	16	74 09 08.28	S2.3	B	14.39	.67	.02	90.0	-.67
9	73 04 13.33	S2.3	B	8.91	.74	.05	89.8	-.74	16	74 09 08.30	S2.3	G	14.40	.74	.03	89.3	-.74
9	73 04 22.27	C1.5	G	12.44	.73	.11	87.4	-.73	16	74 10 26.18	S2.3	B	22.23	.05	.14	108.7	-.04
9	73 05 02.33	C1.5	G	15.89	.54	.14	87.8	-.53	16	74 10 26.19	S2.3	G	22.23	.04	.22	126.3	-.01
9	73 05 02.33	C1.5	B	15.89	.49	.14	91.8	-.49	17	73 04 13.45	S2.3	B	27.27	.83	.14	1.0	.83
9	73 05 08.25	S2.3	G	17.61	.47	.05	88.8	-.47	17	73 04 22.40	C1.5	B	26.39	.88	.19	-5.4	.86
9	73 05 08.25	S2.3	B	17.61	.40	.06	89.1	-.40	17	73 05 02.44	C1.5	B	24.80	.57	.19	1.7	.57
9	73 05 11.18	S2.3	B	18.37	.22	.08	94.3	-.21	17	73 05 08.42	S2.3	B	23.53	.41	.07	-1.7	.41
9	73 05 11.19	S2.3	G	18.37	.39	.06	91.8	-.39	17	73 05 13.40	C1.5	B	22.27	.18	.15	-1.5	.17
9	73 05 13.21	C1.5	G	18.86	.34	.14	91.0	-.34	17	73 05 14.38	C1.5	B	22.00	.27	.18	-10.3	.25
9	73 05 13.23	C1.5	B	18.86	.24	.11	89.5	-.24	17	73 07 23.28	P1.5	B	11.64	.66	.14	91.7	-.66
9	73 05 15.25	C1.5	G	19.32	.30	.12	80.0	-.28	17	73 07 23.30	P1.5	G	11.64	.59	.07	88.7	-.59
9	73 06 14.29	C1.5	B	23.10	.23	.20	.5	.23	17	74 11 24.39	C1.5	B	9.45	.67	.05	89.1	-.67
9	73 06 27.16	C1.5	G	23.30	.23	.12	5.5	.22	17	74 11 24.42	C1.5	G	9.46	.75	.03	92.5	-.75
9	73 06 27.18	C1.5	B	23.30	.23	.15	17.8	-.20	18	74 05 14.43	C1.5	G	27.41	.65	.05	2.5	.65
9	74 07 01.29	C1.5	B	9.56	.62	.06	88.6	-.62	18	74 05 14.46	C1.5	B	27.41	.60	.05	2.2	.60
9	74 07 01.31	C1.5	G	9.55	.64	.04	86.3	-.63	18	74 06 02.36	S2.3	B	26.61	.63	.02	.3	.63
9	74 09 08.17	S2.3	B	20.59	.10	.03	76.8	-.09	18	74 06 02.38	S2.3	G	26.61	.58	.03	-6.6	.58
9	74 09 08.17	S2.3	G	20.60	.11	.03	70.9	-.09	18	74 07 01.36	C1.5	B	21.03	.02	.03	44.5	0.00
9	74 09 29.12	C1.5	B	22.98	.21	.08	-6.8	-.20	18	74 07 01.37	C1.5	G	21.02	.09	.03	82.7	-.09
9	74 09 30.13	C1.5	G	23.04	.07	.06	-9.2	.07	18	74 07 11.42	S2.3	B	17.48	.38	.01	87.4	-.38
10	74 09 24.36	C1.5	B	10.12	1.52	.04	87.3	-1.52	18	74 07 11.43	S2.3	G	17.47	.44	.01	91.4	-.44
10	74 09 24.37	C1.5	G	10.11	1.51	.04	90.7	-1.51	18	74 07 24.31	C1.5	B	11.61	.77	.02	90.2	-.77
10	74 09 29.40	C1.5	B	8.74	1.53	.04	89.1	-1.53	18	74 07 24.32	C1.5	G	11.60	.80	.02	91.8	-.80
10	74 09 29.42	C1.5	G	8.73	1.34	.04	90.1	-1.34	18	74 08 09.32	C1.5	B	3.04	.56	.02	89.5	-.56
10	74 11 13.25	C1.5	G	6.27	1.42	.05	90.4	-1.42	18	74 08 09.33	C1.5	G	3.04	.57	.02	89.1	-.57
10	74 11 13.27	C1.5	B	6.27	1.53	.02	89.0	-1.53	18	74 08 26.33	S2.3	B	8.70	.77	.01	90.9	-.77
11	73 05 08.33	S2.3	B	9.66	.71	.06	91.3	-.71	18	74 08 26.33	S2.3	G	8.70	.79	.01	89.8	-.79
11	73 05 13.34	C1.5	B	7.52	.73	.11	87.5	-.73	18	74 08 26.34	S2.3	U	8.71	.85	.03	90.6	-.85
11	73 05 13.35	C1.5	G	7.51	.69	.09	87.5	-.69	18	74 09 08.27	S2.3	G	16.09	.44	.01	87.8	-.44
11	73 05 14.33	C1.5	B	7.39	.76	.08	87.5	-.76	18	74 09 08.27	S2.3	B	16.09	.44	.01	90.9	-.44
11	73 07 22.25	P1.5	B	22.93	.49	.11	-2.0	.49	18	74 11 13.12	C1.5	G	32.97	1.43	.02	.2	1.43
11	73 07 31.20	S2.3	B	24.19	.71	.06	-4.7	.70	18	74 11 13.12	C1.5	G	32.97	1.34	.03	1.4	1.34
11	73 08 08.21	S2.3	B	25.25	.88	.11	-1.4	.87	19	73 05 08.27	S2.3	B	7.36	1.72	.10	90.9	-1.72
11	73 08 08.21	S2.3	G	25.25	.81	.08	.5	.81	19	73 05 08.28	S2.3	G	7.36	1.66	.07	88.5	-1.66
11	73 08 23.20	C1.5	B	26.31	.99	.20	2.2	.99	19	73 05 11.22	S2.3	B	8.51	1.61	.15	91.2	-1.61
11	74 08 11.48	C1.5	G	25.95	.85	.06	1.4	.85	19	73 05 11.22	S2.3	G	8.51	1.70	.16	89.8	-1.70
11	74 09 08.42	S2.3	B	22.99	.58	.01	.3	.58	19	73 06 04.34	C1.5	B	16.13	1.64	.36	91.5	-1.64
11	74 09 08.43	S2.3	G	22.99	.54	.03	3.1	.53	19	73 06 04.35	C1.5	G	16.13	1.54	.42	86.4	-1.53
11	74 09 30.38	C1.5	G	17.23	.27	.05	94.9	-.26	19	73 06 27.25	C1.5	B	20.07	.49	.25	82.8	-.48
11	74 09 30.39	C1.5	B	17.23	.14	.02	97.0	-.14	19	74 06 02.42	S2.3	B	22.82	.33	.04	-1.6	.32
11	74 10 02.42	C1.5	G	16.51	.25	.02	90.0	-.25	19	74 06 02.42	S2.3	G	22.82	.38	.33	5.9	.37
11	74 10 02.45	C1.5	B	16.50	.22	.04	92.6	-.22	19	74 06 03.40	S2.3	G	22.70	.31	.05	3.3	.31
12	74 04 01.34	C1.5	B	5.72	.60	.04	89.6	-.60	19	74 06 03.42	S2.3	B	22.70	.50	.04	-2.6	.50
12	74 04 01.35	C1.5	G	5.72	.64	.05	94.3	-.63	19	74 06 07.40	S2.3	G	22.16	.20	.05	8.6	.19
12	74 04 10.41	S2.3	B	9.20	.69	.20	84.5	-.68	19	74 07 01.39	C1.5	G	16.58	1.22	.06	88.5	-1.21
12	74 04 26.29	C1.5	B	15.56	.50	.12	100.1	-.47	19	74 07 01.40	C1.5	B	16.57	1.29	.01	90.3	-1.29
12	74 05 14.20	C1.5	B	21.11	.02	.03	80.6	-.02	19	74 07 23.37	C1.5	B	7.78	1.67	.02	89.2	-1.67
12	74 05 28.17	C1.5	B	23.98	.37	.05	-1.6	.37	19	74 07 23.38	C1.5	B	7.77	1.69	.05	90.7	-1.69
12	74 06 01.19	S2.3	B	24.58	.48	.02	-8.8	.48	19	74 07 24.37	C1.5	B	7.29	1.59	.03	89.4	-1.59
12	74 06 03.25	S2.3	B	24.85	.60	.02	0.0	.60	19	74 07 24.38	C1.5	G	7.29	1.61	.03	89.4	-1.61
12	74 06 12.20	S2.3	B	25.75	.72	.03	2.0	.72	19	74 07 25.33	C1.5	B	6.85	1.59	.03	90.0	-1.59
12	74 06 23.20	C1.5	B	26.30	.71	.09	.2	.71	19	74 07 25.34	C1.5	G	6.85	1.54	.03	90.9	-1.54
12	75 07 15.43	S2.3	B	31.11	1.61	.03	1.2	1.61	19	74 08 09.30	C1.5	B	1.54	.47	.03	92.5	-.47
12	75 07 15.43	S2.3	G	31.11	1.33	.02	2.0	1.33	19	74 08 09.31	C1.5	G	1.54	.49	.03	89.5	-.49
13	74 08 11.42	C1.5	B	21.63	.11	.06	82.5	-.07	19	74 09 07.22	S2.3	B	15.17	1.43	.02	91.3	-1.43
13	74 08 11.43	C1.5	G	21.63	.15	.06	107.5	-.13	19	74 09 07.24	S2.3	G	15.17	1.41	.02	90.4	-1.41
13	74 08 27.44	S2.3	B	19.50	.73	.02	91.9	-.73	19	74 10 20.18	C1.5	B	26.18	1.57	.03	-7.7	1.57
13	74 08 27.45	S2.3	V	19.50	.53	.03	86.0	-.52	19	74 10 20.21	C1.5	G	26.19	1.62	.07	-1.1	1.62
13	74 09 07.42	S2.3	G	17.12	1.24	.02	90.5	-1.24	20	74 02 22.41	C1.5	G	23.17	.30	.06	.6	.30
13	74 09 07.42	S2.3	B	17.12	1.16	.02	88.6	-1.16	20	74 02 22.43	C1.5	B	23.17	.40	.04	-5.7	.39
13	74 09 30.41	C1.5	B	9.61	2.18	.04	89.4	-2.18	20	74 03 26.35	C1.5	G	16.82	.28	.12	93.3	-.28
13	74 09 30.44	C1.5	G	9.60	2.07	.04	91.1	-2.07	20	74 03 26.37	C1.5	B	16.82	.19	.12	95.3	-.18
13	74 10 02.35	C1.5	B	8.86	2.09	.04	90.5	-2.09	20	74 04 01.42	C1.5	B	14.56	.39	.04	88.0	-.39
13	75 01 23.12	S2.3	B	22.95	.24	.03	5.4	.23	20	74 04 12.40	C1.5	B	10.61	.65	.07	88.0	-.65
13	75 01 23.15	S2.3	G	22.95	.41	.03	2.1	.41	20	74 04 22.36	C1.5	G	6.21	.65	.10	88.2	-.65
14	74 10 01.46	C1.5	B	22.22	.21	.03	1.8	.21	20	74 04 22.38	C1.5	B	6.20	.74	.10	88.2	-.74
14	74 10 01.47	C1.5	G	22.22	.14	.05	-5.5	.14	20	74 07 12.23	S2.3	G	21.36	.15	.06	3.3	.15
14	74 10 02.49	C1.5	B	22.24	.28	.05	3.5	.28	20	74 07 24.19	C1.5	B	22.21	.29	.07	3.2	.29
14	74 11 12.52	C1.5	B	17.70	.27	.02	94.1	-.26	20	75 06 14.41	C1.5	G	19.95	.01	.05	4.1	.01
14	74 11 13.46	C1.5	G	17.47	.28	.04	93.4	-.28	20	75 06 14.42	C1.5	B	19.95	.11	.05	4.9	.11
14	75 01 12.36	C1.5	B	8.09	.77	.02	89.2	-.77	21	73 05 02.45	C1.5	B	24.69	.07	.14	5.5	.07
14	75 01 12.38	C1.5	G	8.10	.82	.02	90.1	-.82	21	73 05 08.44	S2.3	B	23.81	.16	.11	85.1	-.16
14	75 02 06.15	S2.3	B	17.98	.												

POLARIMETRY OF ASTEROIDS

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TABLE I (continued)

Ast. No.	Date (UT)	Tel.	Filt.	Phase	P _L	ϵ_p°	θ_r	P _r	Ast. No.	Date (UT)	Tel.	Filt.	Phase	P _L	ϵ_p°	θ_r	P _r
23	73 05 11.26	S2.3	G	16.82	.35	.09	87.2	-.35	42	74 07 11.22	S2.3	G	25.93	.95	.04	.8	.95
23	73 05 13.27	C1.5	B	17.40	.24	.13	89.5	-.24	43	75 05 05.45	C1.5	B	24.11	.36	.02	.6	.36
23	73 06 04.17	C1.5	G	22.04	.21	.15	4.7	.20	43	75 05 05.47	C1.5	B	24.10	.35	.03	0.0	.35
23	73 06 04.19	C1.5	B	22.04	.27	.16	2.6	.27	43	75 07 15.35	S2.3	B	14.99	.22	.03	103.4	-.20
23	73 06 27.21	C1.5	B	23.84	.39	.19	0.0	.39	43	75 07 15.36	S2.3	G	15.00	.13	.03	108.1	-.10
24	75 01 24.46	S2.3	B	8.47	1.62	.02	89.3	-1.62	44	74 03 26.44	C1.5	G	21.06	.19	.29	.4	.19
27	73 04 13.30	S2.3	B	27.53	.78	.19	.8	.78	44	74 03 26.46	C1.5	B	21.06	.14	.24	-3.3	.14
27	73 04 22.22	C1.5	B	27.95	.81	.14	-1.4	.81	44	74 04 10.49	S2.3	G	18.09	.04	.20	43.3	0.00
27	73 05 08.16	S2.3	B	27.93	.76	.06	.4	.76	44	74 05 14.25	C1.5	G	6.08	.31	.05	95.9	-.30
27	74 05 28.29	C1.5	B	5.72	.49	.03	90.7	-.49	44	74 05 14.28	C1.5	B	6.07	.31	.01	90.5	-.31
27	74 07 01.26	C1.5	B	9.25	.66	.05	90.8	-.66	44	74 06 02.26	S2.3	G	3.69	.29	.03	92.0	-.29
27	74 07 24.25	C1.5	B	16.59	.36	.06	97.6	-.35	44	74 06 07.20	S2.3	G	5.63	.32	.03	91.1	-.32
27	74 08 11.22	C1.5	B	19.89	.09	.06	-30.7	.04	44	74 06 07.22	S2.3	B	5.63	.29	.03	91.1	-.29
28	75 06 14.30	C1.5	B	9.10	.72	.05	93.3	-.72	44	74 06 23.30	C1.5	B	11.85	.27	.09	88.1	-.27
29	74 07 24.47	C1.5	B	22.99	.37	.04	-7.3	.36	44	74 07 12.24	S2.3	B	17.36	.13	.06	60.0	-.07
29	74 08 10.33	C1.5	B	20.31	.10	.02	95.0	-.10	44	74 07 24.21	C1.5	B	19.64	.10	.02	-16.1	.09
29	74 08 10.34	C1.5	G	20.31	.15	.02	94.7	-.15	44	74 07 24.23	C1.5	G	19.64	.07	.05	3.2	.07
29	74 08 24.31	S2.3	G	16.68	.53	.02	87.6	-.52	44	74 08 10.14	C1.5	B	21.40	.09	.06	-33.6	.04
29	74 08 24.33	S2.3	B	16.67	.45	.01	88.6	-.45	44	74 08 11.19	C1.5	B	21.46	.19	.06	-1.9	.18
29	74 08 26.43	S2.3	G	15.96	.60	.02	89.1	-.60	44	74 08 11.20	C1.5	G	21.46	.10	.09	26.3	.06
29	74 08 27.50	S2.3	B	15.62	.53	.01	89.6	-.53	44	74 08 26.15	S2.3	B	21.76	.20	.03	-7.0	.19
29	74 10 20.42	C1.5	B	9.13	.91	.02	89.8	-.91	44	74 08 26.17	S2.3	G	21.75	.18	.06	-7.2	.17
29	74 10 20.43	C1.5	G	9.13	.87	.02	90.2	-.87	44	74 08 27.15	S2.3	G	21.74	.21	.04	.8	.21
29	75 01 12.15	C1.5	G	24.03	.20	.05	-7.0	.19	44	75 06 14.45	C1.5	B	21.53	.23	.06	5.2	.22
29	75 01 12.19	C1.5	B	24.03	.36	.04	7.9	.35	44	75 06 15.46	C1.5	B	21.49	.12	.03	8.2	.12
30	74 07 11.37	S2.3	B	6.70	.75	.04	90.9	-.75	46	74 11 13.36	C1.5	B	5.31	1.42	.04	89.8	-1.42
30	74 07 11.38	S2.3	B	6.70	.78	.04	90.0	-.78	51	73 12 29.29	C1.5	G	8.13	1.94	.12	88.7	-1.93
30	74 08 09.27	C1.5	G	8.10	.77	.04	92.3	-.77	51	73 12 29.36	C1.5	U	8.11	1.78	.05	89.8	-1.78
30	74 08 09.28	C1.5	B	8.11	.78	.04	89.5	-.78	51	73 12 31.25	C1.5	B	8.16	1.94	.03	88.6	-1.93
30	74 08 22.21	S2.3	B	14.04	.53	.02	91.9	-.52	51	73 12 31.25	C1.5	G	7.66	1.90	.13	88.9	-1.89
30	74 08 22.22	S2.3	G	14.05	.56	.01	89.2	-.56	51	74 01 16.43	C1.5	G	8.48	2.00	.07	90.0	-2.00
30	74 08 26.23	S2.3	B	15.69	.46	.03	89.5	-.46	51	75 04 03.49	S2.3	B	24.83	1.32	.03	-1.3	1.32
30	74 08 26.31	S2.3	G	15.72	.46	.03	87.5	-.46	51	75 05 05.42	C1.5	B	18.54	.53	.04	88.2	-.52
30	74 09 29.17	C1.5	B	24.81	.61	.07	-2.4	.61	54	74 07 23.42	C1.5	G	8.59	2.01	.08	90.1	-2.01
30	74 09 29.21	C1.5	G	24.81	.63	.07	1.5	.63	54	74 07 23.43	C1.5	B	8.58	1.91	.06	90.1	-1.91
30	74 10 02.13	C1.5	G	25.23	.72	.08	-6.2	.70	54	74 07 25.37	C1.5	B	7.56	1.82	.03	90.5	-1.82
30	74 10 20.10	C1.5	G	26.62	.68	.07	-4.2	.67	54	74 07 25.38	C1.5	B	7.56	1.93	.03	90.0	-1.93
30	74 10 20.14	C1.5	B	26.62	.79	.05	2.2	.79	54	74 08 27.35	S2.3	B	9.95	1.91	.03	90.7	-1.90
31	74 04 10.44	S2.3	B	9.41	1.32	.25	88.8	-1.32	54	74 08 27.38	S2.3	V	9.96	1.96	.02	90.1	-1.96
31	74 04 10.46	S2.3	G	9.41	1.28	.26	90.2	-1.28	54	74 09 07.30	S2.3	B	14.80	1.60	.02	91.2	-1.59
39	73 06 14.42	C1.5	G	22.63	.15	.20	8.4	.15	54	74 09 07.32	S2.3	G	14.81	1.53	.02	90.4	-1.53
39	73 06 14.44	C1.5	B	22.63	.27	.14	-7.5	.26	54	74 10 01.19	C1.5	B	22.07	.01	.15	-1.9	.01
39	73 06 26.44	C1.5	B	21.29	.03	.13	-6.5	.03	54	74 10 01.26	C1.5	G	22.09	.15	.16	55.1	-.05
39	73 06 26.44	C1.5	G	21.29	.06	.18	-43.5	0.00	54	74 10 14.16	C1.5	B	24.21	.75	.05	2.3	.75
39	73 07 23.43	P1.5	B	14.93	.48	.05	87.3	-.48	54	74 10 14.20	C1.5	G	24.22	.82	.05	3.5	.82
39	73 07 23.44	P1.5	G	14.93	.48	.08	90.6	-.48	54	74 10 20.25	C1.5	G	24.86	1.07	.05	.4	1.07
39	73 08 08.32	S2.3	G	8.88	.78	.06	89.4	-.78	54	74 11 12.11	C1.5	B	25.50	1.17	.06	2.5	1.17
39	73 08 08.33	S2.3	B	8.87	.76	.05	90.3	-.76	56	74 05 14.36	C1.5	B	25.98	2.05	.04	-.9	2.05
39	73 08 26.29	C1.5	B	.69	.30	.05	83.7	-.29	56	74 05 14.40	C1.5	G	25.98	2.32	.07	.8	2.32
39	73 08 26.33	C1.5	G	.68	.28	.07	88.8	-.28	56	74 05 28.33	C1.5	B	23.01	.94	.15	-1.8	.94
39	73 09 12.25	C1.5	B	7.48	.59	.08	88.3	-.59	56	74 06 02.34	S2.3	G	21.62	.62	.04	.7	.62
39	73 09 12.26	C1.5	G	7.49	.70	.06	88.5	-.70	56	74 06 03.30	S2.3	G	21.34	.46	.05	1.9	.46
39	73 10 24.15	C1.5	G	20.96	.04	.11	51.4	-.01	56	74 06 03.35	S2.3	B	21.33	.47	.03	-2	.47
39	73 10 24.14	C1.5	B	20.96	.06	.09	9.6	.06	56	74 06 30.28	C1.5	B	11.61	1.42	.06	89.7	-1.42
39	73 10 25.15	C1.5	B	21.17	.10	.08	3.9	.10	56	74 07 11.33	S2.3	B	8.48	1.47	.02	90.5	-1.47
39	73 10 25.17	C1.5	G	21.17	.08	.09	34.8	.03	56	74 07 11.34	S2.3	G	8.48	1.45	.03	89.2	-1.45
39	73 11 16.11	C1.5	G	23.47	.25	.09	-5.7	.24	56	74 08 09.23	C1.5	B	15.25	1.02	.03	96.8	-.99
39	73 11 16.13	C1.5	B	23.47	.31	.08	-3	.31	56	74 08 09.24	C1.5	G	15.26	.96	.04	89.7	-.96
39	74 11 12.41	C1.5	G	17.90	.25	.04	90.2	-.25	56	74 08 11.24	C1.5	B	16.03	.92	.04	91.6	-.92
39	74 11 12.43	C1.5	B	17.89	.24	.05	94.5	-.23	56	74 08 11.25	C1.5	G	16.04	.75	.04	89.3	-.75
39	74 11 24.52	C1.5	B	14.84	.41	.03	90.5	-.41	56	74 08 24.19	S2.3	G	20.66	.37	.02	23.3	.37
39	74 12 21.41	C1.5	G	6.29	.70	.03	89.0	-.70	56	74 08 24.22	S2.3	B	20.67	.21	.02	-1	.21
39	74 12 21.43	C1.5	B	6.29	.64	.04	90.6	-.64	56	74 08 24.22	S2.3	G	20.67	.21	.05	1.3	1.75
39	75 01 24.33	S2.3	G	11.09	.69	.02	91.8	-.69	56	74 09 08.25	S2.3	B	24.71	1.66	.06	1.3	1.66
39	75 01 24.35	S2.3	B	11.10	.70	.02	90.8	-.70	57	75 06 15.35	C1.5	B	8.34	.70	.05	87.5	-.70
40	73 06 14.46	C1.5	B	26.36	.75	.26	-11.0	.70	58	75 01 24.49	S2.3	B	6.98	1.49	.05	89.3	-1.49
40	73 06 14.47	C1.5	G	26.36	.62	.34	-17.0	.51	58	75 01 24.52	S2.3	G	6.97	1.45	.05	92.2	-1.45
40	73 06 26.47	C1.5	G	24.76	.52	.23	-1.9	.51	58	75 03 05.34	C1.5	B	10.98	1.79	.10	86.0	-1.77
40	73 06 27.43	C1.5	B	24.59	.43	.11	2.5	.43	63	73 04 22.49	C1.5	B	28.23	1.12	.10	-1.4	1.12
40	73 06 27.44	C1.5	G	24.59	.40	.19	1.0	.40	63	73 05 08.47	S2.3	B	26.71	.91	.09	.1	.91
40	73 07 23.47	P1.5	B	17.43	.33	.09	89.0	-.33	63	73 06 04.45	C1.5	B	20.35	.16	.10	-8.2	.15
40	73 07 23.48	P1.5	G	17.42	.34	.08	92.3	-.34	63	73 07 31.31	S2.3	G	9.38	.74	.09	90.1	-.74
40	73 07 31.36	S2.3	B	14.22	.57	.07	90.2	-.57	63	73 07 31.33	S2.3	B	9.39	.63	.09	88.3	-.63
40	73 07 31.38	S2.3	G	14.22	.61	.07	86.9	-.60	63	73 08 22.26	S2.3	G	18.66	.10	.11	89.3	-.10
40	73 08 08.37	S2.3	B	10.58	.76	.06	91.1	-.76	63	73 08 22.28	S2.3	B	18.66	.07	.10	97.8	-.07
40	73 08 08.35	S2.3	G	10.59	.76	.07	89.5	-.76	63	73 08 23.27	C1.5	B	19.01	.05	.15	89.3	-.05
40	73 08 22.30	S2.3	B	4.13													

TABLE I (continued)

Ast. No.	Date (UT)	Tel.	Filt.	Phase	PZ	ϵ_p°	θ_r	$P_r\%$	Ast. No.	Date (UT)	Tel.	Filt.	Phase	PZ	ϵ_p°	θ_r	$P_r\%$
64	75 04 03.22	S2.3	G	18.43	.08	.02	118.9	-.04	192	74 11 12.39	C1.5	G	6.85	.69	.02	89.5	-.69
64	75 05 05.17	C1.5	B	24.01	.29	.04	-3.6	.29	192	74 11 24.10	C1.5	G	9.47	.59	.03	89.6	-.59
64	75 05 05.21	C1.5	G	24.01	.21	.05	-7.8	.20	192	74 11 24.11	C1.5	B	9.47	.60	.02	89.2	-.60
65	75 04 03.33	S2.3	B	8.09	1.28	.05	89.9	-1.28	192	74 12 18.25	C1.5	B	19.57	.03	.04	77.5	-.03
68	74 12 18.27	C1.5	B	9.17	.62	.05	92.0	-.62	192	74 12 18.26	C1.5	G	19.57	.08	.04	53.9	-.03
68	74 12 21.36	C1.5	G	10.36	.69	.05	88.5	-.69	192	74 12 21.23	C1.5	B	20.59	.14	.11	31.9	.06
70	75 04 03.39	S2.3	G	6.11	1.68	.03	89.9	-1.68	192	75 01 24.28	S2.3	B	27.37	.84	.05	-8	.84
70	75 05 05.29	C1.5	B	9.78	1.83	.05	90.9	-1.83	192	75 01 24.31	S2.3	G	27.37	.73	.03	-4	.73
71	75 07 15.39	S2.3	B	7.04	.59	.03	92.7	-.59	230	74 06 12.42	S2.3	B	26.30	.91	.04	-1.3	.91
71	75 07 15.40	S2.3	G	7.03	.60	.04	93.7	-.59	230	74 07 25.42	C1.5	G	22.55	.22	.04	-6.6	.21
80	75 04 03.31	S2.3	B	6.58	.76	.03	90.4	-.76	230	74 07 25.44	C1.5	B	22.55	.45	.04	-6.5	.44
80	75 05 05.26	C1.5	B	8.11	.67	.03	90.7	-.67	230	74 08 09.34	C1.5	G	18.75	.26	.05	95.7	-.25
83	75 05 05.36	C1.5	B	7.85	1.45	.05	90.4	-1.45	230	74 08 09.36	C1.5	B	18.75	.22	.05	82.9	-.21
84	74 08 11.39	C1.5	B	17.95	.66	.06	88.4	-.66	230	74 08 11.28	C1.5	G	18.15	.29	.04	94.4	-.28
84	74 08 11.40	C1.5	B	17.95	.75	.06	97.0	-.73	230	74 08 11.29	C1.5	B	18.15	.27	.04	66.6	-.18
84	74 08 26.36	S2.3	B	9.83	1.54	.02	89.8	-1.54	230	74 09 07.38	S2.3	B	8.56	.92	.03	89.6	-.92
84	74 08 26.37	S2.3	G	9.82	1.52	.01	89.3	-1.52	230	74 09 07.39	S2.3	G	8.50	.95	.02	90.5	-.95
84	74 09 08.32	S2.3	B	3.93	.99	.02	90.6	-.99	230	74 09 24.34	C1.5	G	7.81	.84	.05	85.8	-.84
84	74 09 08.36	S2.3	G	3.93	1.00	.02	91.5	-1.00	230	74 09 24.35	C1.5	B	7.81	.96	.03	84.8	-.94
84	74 09 24.28	C1.5	G	10.36	1.53	.07	83.7	-1.50	230	74 09 29.27	C1.5	B	9.25	.91	.05	91.4	-.91
84	74 09 24.30	C1.5	B	10.37	1.41	.06	87.5	-1.41	230	74 09 29.32	C1.5	G	9.27	.96	.05	89.1	-.96
84	74 11 12.25	C1.5	B	28.50	2.49	.07	.5	2.49	230	74 11 12.29	C1.5	B	23.10	.35	.06	-9.4	.33
84	74 11 13.15	C1.5	G	28.65	2.54	.06	.4	2.54	230	74 11 13.17	C1.5	G	23.27	.47	.04	1.9	.47
85	73 08 26.42	C1.5	B	16.94	.42	.10	87.9	-.42	306	75 06 15.40	C1.5	B	8.02	.65	.03	92.7	-.65
85	73 09 19.38	C1.5	B	6.00	1.25	.06	90.6	-1.25	324	73 04 06.50	C1.5	G	20.24	.15	.03	-8.0	.15
88	75 01 24.38	S2.3	B	7.12	1.48	.03	89.7	-1.48	324	73 04 06.51	C1.5	B	20.24	.10	.17	1.0	.10
89	73 12 31.29	C1.5	G	7.32	.87	.16	89.6	-.87	324	73 04 22.45	C1.5	B	19.08	.42	.35	103.1	-.38
89	73 12 31.45	C1.5	B	7.25	.90	.14	88.5	-.89	324	73 08 08.18	S2.3	B	20.53	.02	.15	80.4	-.02
89	74 01 16.44	C1.5	G	2.89	.54	.09	90.2	-.54	324	73 08 08.20	S2.3	G	20.53	.05	.10	38.9	.01
93	75 01 25.48	C1.5	B	7.88	1.18	.09	89.2	-1.18	324	73 08 22.16	S2.3	B	23.75	1.23	.14	.2	1.23
93	75 03 05.39	C1.5	B	8.22	1.19	.11	90.6	-1.19	324	73 08 22.18	S2.3	G	23.75	1.15	.15	2.1	1.15
95	74 10 02.25	C1.5	G	8.07	1.79	.06	89.6	-1.79	324	73 08 26.19	C1.5	B	24.46	1.58	.23	-1.4	1.57
95	74 10 02.25	C1.5	B	8.07	1.74	.07	90.1	-1.74	324	73 08 27.19	C1.5	B	24.62	1.51	.27	-1.0	1.51
95	74 10 20.35	C1.5	G	13.02	1.62	.07	90.6	-1.62	324	74 10 20.51	S2.3	G	25.87	2.03	.06	.4	2.03
114	75 04 03.45	S2.3	G	10.17	1.18	.04	90.0	-1.18	324	74 10 26.51	S2.3	B	25.61	1.75	.06	6.5	1.71
114	75 04 03.47	S2.3	B	10.17	1.16	.03	89.0	-1.16	324	74 12 21.46	C1.5	B	13.17	1.33	.03	89.4	-1.33
115	74 08 27.30	S2.3	B	12.15	.56	.02	89.5	-.56	324	74 12 21.49	C1.5	G	13.16	1.35	.06	89.9	-1.35
115	74 08 27.32	S2.3	V	12.14	.63	.01	88.5	-.63	324	75 03 05.30	C1.5	G	16.98	.81	.06	95.1	-.80
115	74 09 07.36	S2.3	G	8.34	.74	.02	88.9	-.74	324	75 03 20.18	S2.3	G	19.22	.15	.05	95.1	-.15
115	74 09 07.37	S2.3	B	8.33	.72	.01	89.3	-.72	324	75 03 20.21	S2.3	B	19.22	.16	.04	103.6	-.15
115	74 09 24.32	C1.5	B	9.59	.63	.05	86.4	-.62	324	75 04 03.18	S2.3	B	20.14	.06	.02	20.9	.05
129	75 01 16.39	C1.5	B	4.76	.71	.20	84.1	-.70	338	75 06 15.29	C1.5	B	10.67	.92	.12	87.2	-.91
135	74 11 13.32	C1.5	B	5.90	.96	.04	91.3	-.96	345	75 01 24.39	S2.3	B	7.93	1.43	.03	90.4	-1.43
139	74 04 05.32	C1.5	G	3.77	.83	.05	95.7	-.82	345	75 02 06.19	S2.3	B	11.62	1.54	.04	90.6	-1.54
139	74 04 05.35	C1.5	B	3.78	.84	.07	90.2	-.84	349	74 03 26.30	C1.5	G	9.56	.38	.18	93.8	-.38
139	74 04 10.25	S2.3	B	6.23	1.14	.10	90.2	-1.14	349	74 03 26.31	C1.5	B	9.56	.33	.13	91.6	-.33
139	74 04 22.26	C1.5	B	11.83	1.30	.14	88.1	-.14	349	74 04 01.27	C1.5	B	11.33	.41	.04	93.3	-.41
139	74 04 22.28	C1.5	G	11.84	1.22	.14	90.3	-1.22	349	74 04 01.29	C1.5	G	11.33	.39	.06	95.3	-.38
139	74 05 14.22	C1.5	B	19.49	.28	.03	87.1	-.28	349	74 06 03.26	S2.3	B	18.67	.04	.04	-6.0	.04
139	74 05 28.23	C1.5	B	22.50	.52	.07	.8	.51	349	75 06 14.25	C1.5	B	10.83	.40	.05	93.3	-.40
141	73 08 23.34	C1.5	B	15.75	1.42	.09	92.5	-1.42	349	75 06 15.25	C1.5	G	11.12	.33	.03	91.1	-.33
141	73 08 26.39	C1.5	B	14.58	1.56	.16	89.9	-1.56	354	74 06 28.32	C1.5	B	6.71	.53	.03	89.1	-.53
141	73 09 12.30	C1.5	B	8.17	1.71	.12	88.4	-1.71	354	74 06 28.35	C1.5	G	6.71	.47	.05	89.5	-.47
141	73 09 19.28	C1.5	B	6.84	1.47	.09	89.5	-1.47	356	74 11 13.30	C1.5	B	7.61	1.49	.05	89.7	-1.49
141	73 10 08.23	S2.3	B	11.56	1.83	.10	89.8	-1.83	367	75 02 06.22	S2.3	B	10.87	.66	.05	89.8	-.66
141	73 10 08.25	S2.3	G	11.57	1.77	.10	89.0	-1.77	389	75 06 14.38	C1.5	B	4.63	.71	.04	89.5	-.71
141	73 10 08.27	S2.3	U	11.57	1.48	.32	90.0	-1.48	410	74 06 12.30	S2.3	G	5.69	1.67	.02	89.7	-1.67
141	73 10 08.31	S2.3	R	11.59	1.81	.38	86.3	-1.80	410	74 06 12.31	S2.3	B	5.68	1.66	.02	89.5	-1.66
141	73 10 24.19	C1.5	G	17.82	.92	.20	85.4	-.91	410	74 07 11.30	S2.3	B	10.61	1.87	.03	90.6	-1.87
141	73 10 24.19	C1.5	B	17.82	.97	.12	90.9	-.97	410	74 07 11.31	S2.3	G	10.62	1.86	.03	90.0	-1.86
141	73 10 25.09	C1.5	B	18.22	.84	.09	87.4	-.84	410	74 07 24.28	C1.5	B	16.54	1.05	.02	94.5	-1.04
141	73 10 26.21	C1.5	G	18.30	.75	.17	87.9	-.75	410	74 08 26.21	S2.3	B	25.65	1.78	.05	-2	1.78
141	73 11 04.31	S2.3	B	21.41	.07	.10	-29.9	.04	410	74 09 08.14	S2.3	B	27.10	2.29	.05	-4	2.29
141	73 11 16.18	C1.5	B	24.28	.98	.16	-1.9	.98	415	75 02 06.28	S2.3	B	9.68	1.26	.02	89.0	-1.26
141	73 12 07.18	S2.3	B	27.11	2.20	.16	1.9	2.20	416	75 03 10.51	C1.5	B	11.12	.65	.05	86.8	-.64
141	73 12 07.21	S2.3	G	27.12	2.21	.21	1.9	2.21	416	75 03 20.33	S2.3	B	8.21	.77	.03	90.0	-.77
141	73 12 29.12	C1.5	B	27.64	2.21	.32	.4	2.21	451	74 11 13.49	C1.5	B	7.76	1.63	.04	91.7	-1.62
141	73 12 29.16	C1.5	G	27.64	2.30	.27	-1.5	2.29	451	74 11 24.43	C1.5	B	3.89	1.16	.03	87.2	-1.16
145	75 04 03.41	S2.3	B	10.35	1.87	.04	90.6	-1.87	471	74 06 02.17	S2.3	B	8.94	.66	.04	88.7	-.66
145	75 05 05.39	C1.5	B	7.65	1.74	.06	90.3	-1.74	471	74 06 03.26	S2.3	G	9.45	.58	.06	92.8	-.57
172	74 09 30.26	C1.5	B	7.44	.71	.16	86.6	-.71	471	75 06 15.42	C1.5	B	8.91	.59	.04	89.6	-.59
172	74 09 30.34	C1.5	G	7.41	1.08	.06	89.6	-1.08	511	73 07 31.44	S2.3	B	19.33	.11	.08	95.4	-.11
182	74 09 30.47	C1.5	B	9.51	.65	.06	85.4	-.64	511	73 07 31.45	S2.3	G	19.33	.10	.17	31.8	.05
182	74 10 02.31	C1.5	B	8.51	.63	.20	87.9	-.63	511	73 08 06.42	S2.3	B	18.96	.13	.08	91.0	-.13
192	73 04 13.38	S2.3	B	11.17	.55	.20	87.0	-.55	511	73 08 06.45	S2.3	G	18.95				

TABLE I (continued)

Ast. No.	Date (UT)	Tel.	Filt.	Phase	P%	ϵ_p %	θ_r	P_r %
511	74 12 21.52	C1.5	G	16.15	.90	.05	90.8	-.90
511	74 12 21.54	C1.5	B	16.15	.84	.02	92.5	-.84
511	75 01 12.44	C1.5	B	9.23	1.70	.02	89.8	-1.70
511	75 01 12.46	C1.5	G	9.22	1.68	.04	91.2	-1.68
511	75 01 25.37	C1.5	B	4.84	1.33	.02	88.6	-1.33
511	75 01 25.39	C1.5	G	4.84	1.30	.03	90.7	-1.30
532	73 04 13.32	S2.3	B	19.89	.02	.03	97.8	-.02
532	73 04 22.33	C1.5	B	21.98	.19	.08	4.3	.18
532	73 05 08.22	S2.3	B	24.63	.49	.05	-.5	.49
532	73 05 11.15	S2.3	B	24.97	.61	.09	-2.2	.61
532	73 05 13.17	C1.5	B	25.19	.66	.09	-.3	.66
532	73 06 03.15	C1.5	B	26.33	.72	.10	.8	.72
532	74 07 01.33	C1.5	G	7.47	.82	.03	89.0	-.82
532	74 07 01.34	C1.5	B	7.47	.76	.04	89.0	-.76
532	74 08 10.22	C1.5	B	8.63	.72	.04	88.4	-.72
532	74 08 10.23	C1.5	G	8.63	.77	.02	90.6	-.77
554	75 03 05.46	C1.5	B	10.65	1.38	.07	-21.6	1.01
554	75 03 10.44	C1.5	B	8.49	1.61	.15	-23.2	1.11
563	74 08 27.41	S2.3	B	23.91	.56	.03	.7	.56
563	74 09 08.39	S2.3	B	21.52	.27	.03	1.5	.27
563	74 10 20.45	C1.5	B	7.75	.69	.06	92.9	-.69
563	74 11 24.19	C1.5	B	16.27	.28	.07	84.9	-.27
584	74 08 10.29	C1.5	B	32.49	1.74	.07	1.7	1.74
584	74 08 11.32	C1.5	B	32.39	1.73	.06	.9	1.73
584	74 08 11.34	C1.5	G	32.39	1.40	.08	-1.5	1.40
584	74 08 24.36	S2.3	G	30.56	1.32	.04	.6	1.32
584	74 08 24.38	S2.3	B	30.55	1.51	.02	1.1	1.51
584	74 09 07.44	S2.3	G	27.42	.88	.02	2.3	.87
584	74 09 07.46	S2.3	B	27.41	1.06	.04	2.2	1.06
584	74 09 29.36	C1.5	B	19.98	.28	.04	3.1	.28
584	74 09 29.38	C1.5	G	19.98	.04	.03	20.6	.03
584	74 11 12.31	C1.5	B	13.78	.31	.03	91.7	-.31
584	74 11 12.34	C1.5	G	13.79	.52	.03	88.9	-.51
584	74 11 24.15	C1.5	G	17.96	.07	.03	92.3	-.07
584	74 11 24.17	C1.5	B	17.97	.10	.04	6.8	.10
602	74 09 30.18	C1.5	B	9.69	1.83	.10	89.9	-1.83
602	74 09 30.22	C1.5	G	9.71	1.62	.14	88.7	-1.62
654	73 12 31.15	C1.5	G	16.51	.97	.06	88.4	-.97
654	73 12 31.16	C1.5	B	16.52	1.36	.12	90.0	-1.36
654	74 01 15.34	C1.5	G	23.56	.94	.08	0.0	.94
654	74 01 15.35	C1.5	B	23.57	.85	.14	1.5	.85
654	74 01 30.27	C1.5	B	28.93	2.81	.11	.6	2.81
654	74 01 30.27	C1.5	G	28.93	2.89	.22	-.7	2.89
654	75 06 14.33	C1.5	B	5.52	1.18	.06	89.7	-1.18
674	75 03 20.31	S2.3	B	9.53	.80	.03	88.8	-.80
704	74 08 11.37	C1.5	B	15.83	.03	.04	85.5	-.03
704	74 08 11.38	C1.5	G	15.83	.09	.03	-15.4	.08
704	74 09 07.27	S2.3	G	10.31	1.27	.02	91.0	-1.27
704	74 09 07.28	S2.3	B	10.31	1.27	.02	90.6	-1.27
704	74 09 24.20	C1.5	G	10.50	1.14	.05	86.8	-1.14
704	74 09 24.22	C1.5	B	10.51	1.08	.05	83.9	-1.08
704	74 10 20.29	C1.5	G	16.03	.08	.02	-1.1	.08
704	74 10 20.31	C1.5	B	16.04	.12	.02	8.4	.12
704	74 11 12.16	C1.5	B	20.25	1.50	.03	.2	1.50
704	74 11 12.19	C1.5	G	20.25	1.40	.02	-0.0	1.40
737	74 08 22.26	S2.3	B	7.83	.87	.02	90.0	-.87
737	74 08 27.47	S2.3	B	6.63	.90	.01	90.2	-.90
737	74 08 27.48	S2.3	V	6.63	.83	.03	91.0	-.83
737	74 09 07.34	S2.3	G	8.24	.79	.02	92.2	-.79
747	75 03 05.42	C1.5	B	7.75	1.29	.08	88.7	-1.29
747	75 03 20.29	S2.3	B	12.23	1.15	.05	91.8	-1.15
887	73 11 16.33	C1.5	G	27.52	1.19	.50	-2.7	1.19
887	73 12 28.45	C1.5	B	15.76	.29	.18	86.4	-.29
887	73 12 28.47	C1.5	G	15.74	.32	.12	85.0	-.31
887	73 12 30.30	C1.5	G	13.68	.44	.12	91.8	-.44
877	73 12 31.37	C1.5	G	12.41	.56	.20	88.7	-.56
887	74 01 16.30	C1.5	G	5.75	.70	.13	87.8	-.70
887	74 01 16.30	C1.5	B	5.75	.67	.10	90.7	-.67
887	74 01 16.49	C1.5	G	5.92	.72	.10	89.5	-.72
887	74 01 16.49	C1.5	B	5.92	.67	.08	87.2	-.67
887	74 01 19.46	C1.5	G	8.47	.77	.03	92.5	-.77
1058	74 08 25.30	S2.3	V	4.46	.60	.08	89.4	-.60

* The method of computing the formal error ϵ_p in the observed polarization underwent changes in February and March 1974. Observations since that time have systematically smaller but probably more realistic estimates of the error.

normal to the Sun-asteroid-Earth plane. All observations with $P_{\text{obs}} \gg \epsilon_p$ show θ_r near 0° or 90° , i.e., the polarization is unambiguously "positive" or "negative." Observations of asteroid 554 Peraga on two nights in March 1975 provide a single notable exception. Misidentification is unlikely since motion of the asteroid with respect to field stars was noted on both nights. We cannot account for the curious results, and 554 will not be considered further in this paper.

The observed polarization-phase curves for selected asteroids are plotted in Figs. 1, 2, 3, and 4. While hardly any two well-observed asteroids are polarimetrically indistinguishable, the systematic differences between the various types are apparent. Generally within a few minutes of locating a new asteroid at the telescope, we know whether we have an *S*, a *C*, or something different.

With few exceptions the asteroid polarizations are found to be repeatable from hour to hour, night to night, and apparition to apparition at the same solar phase angle within the observational accuracy of roughly $\pm 0.05\%$. For 433 Eros, Zellner and Gradie (1976) found the polarization to be constant over rotation and aspect to one part in 40. McCord and Chapman (1975a) have suggested that 19 Fortuna shows marked color variation. Simultaneous photometry and polarimetry of Fortuna over roughly half a rotation period, at a time when the lightcurve amplitude was the largest yet observed (Taylor 1971),

is illustrated in Fig. 5. While our rotational and aspect coverage is not complete, we see no evidence for variability in Fig. 5, or in Fig. 1 for the polarization-phase curve observed over two apparitions. The *UBV* colors of Fortuna found by Zellner *et al.* (1975), the radiometric albedos by Morrison (1974) and Hansen (1976), and the 1973 spectrophotometric data of McCord and Chapman are appropriate for a *C* asteroid, and we suggest that their anomalous spectrum in 1972 was the result of misidentification.

For asteroid 39 Laetitia, which is known to show modest color variations (Wamsteker and Sather 1974), scatter in our data between 6° and 12° phase suggests variegation. The 1974 results for 63 Ausonia near 22° phase are discordant with respect to 1973 data, and only the results from 1973 are used below. Misidentification seems likely for the single night's observation of very weak polarization for 43 Ariadne at 15° phase. Even for a few of the brighter asteroids the phase coverage is still incomplete. For example, 2 Pallas has not been observable at phases below 12° during recent apparitions, due to its high orbital inclination.

Numerical parameters describing the polarization-phase curves are given in Tables II and III. The maximum depth of the negative branch, denoted by P_{min} , is estimated from data between 5° and 11° phase. Least-squares fits to data points at phase angles near 15° and larger give the slope h of the

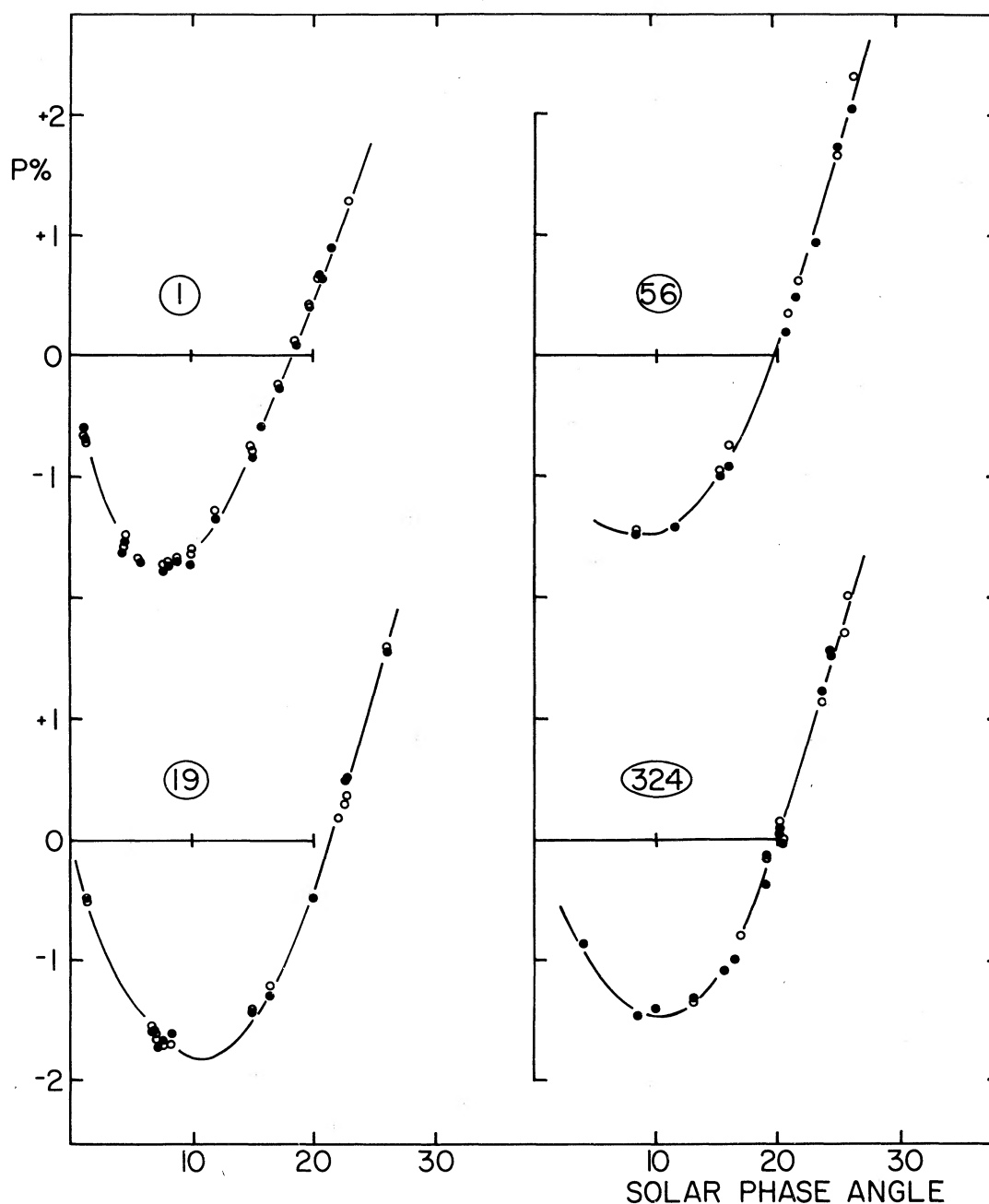


FIG. 1. Polarization-phase curves of the typical C asteroids 1 Ceres, 19 Fortuna, 56 Melete, and 324 Bamberga. Open circles indicate data taken in green light, and filled circles in the blue.

ascending polarization branch and the inversion angle α_0 where the polarization changes sign. Fragmentary data or poor phase coverage are indicated by question marks (?), and noisy or discordant data by colons (:).

For the determinations of h and α_0 either a linear or a parabolic fit is made, as seems appropriate for the data, and the slope is taken at the derived inversion angle in the latter case. The curvature of the ascending branch between 15° and 30° phase is found to be small ($<1\%$) but positive for all well-observed

objects. In a few cases such as for 410 Chloris, where we are constrained to use linear fits because of the paucity of data, it is possible that we underestimate slightly both the inversion angle and the slope.

II. ALBEDOS AND DIAMETERS

The seventh column of Table III gives geometric albedos at the listed wavelengths derived from the slope-albedo law as formulated by Zellner *et al.* (1974; see also Veverka and Noland 1973; Bowell *et al.* 1973;

Bowell and Zellner 1974), namely

$$\log p = -\log h - 1.78.$$

The last column gives albedos reduced to the visual wavelength from the values in blue and green light. In some cases (e.g., 12 Victoria) the asteroid color is poorly known or only guessed, and the transformation to the visual wavelength introduces additional uncertainty.

The limitations of the slope-albedo law for application to the asteroids have been described by Zellner *et al.* (1974) and by Chapman *et al.* (1975). It is essentially an empirical result, well-calibrated only for lunar materials, which is useful in the absence of more direct measures of asteroid albedos and diameters. One limitation can be seen in our asteroid data itself. In Table III the visual geometric albedos

derived from the slopes in blue and green light agree very well for some asteroids (3, 5, 7, 21, 29, 63, 192, and 230) but disagree by as much as 15% for others (8, 9, 11, 18, and 20) even when the slopes are well-defined at both wavelengths. This curious effect is examined in Fig. 6, where we plot the ratio of blue to green slopes, in magnitude units, versus the $B-V$ color. Surfaces for which the same slope-albedo law applies at both wavelengths should lie along the dashed line. For the anomalous asteroids the polarimetric slope does not increase toward shorter wavelengths in proportion to the decrease in albedo; in fact it holds constant in some cases. If the albedos derived from observations in green light were assumed to be correct, then use of the same slope-albedo law for the blue (and for many objects we have blue-light

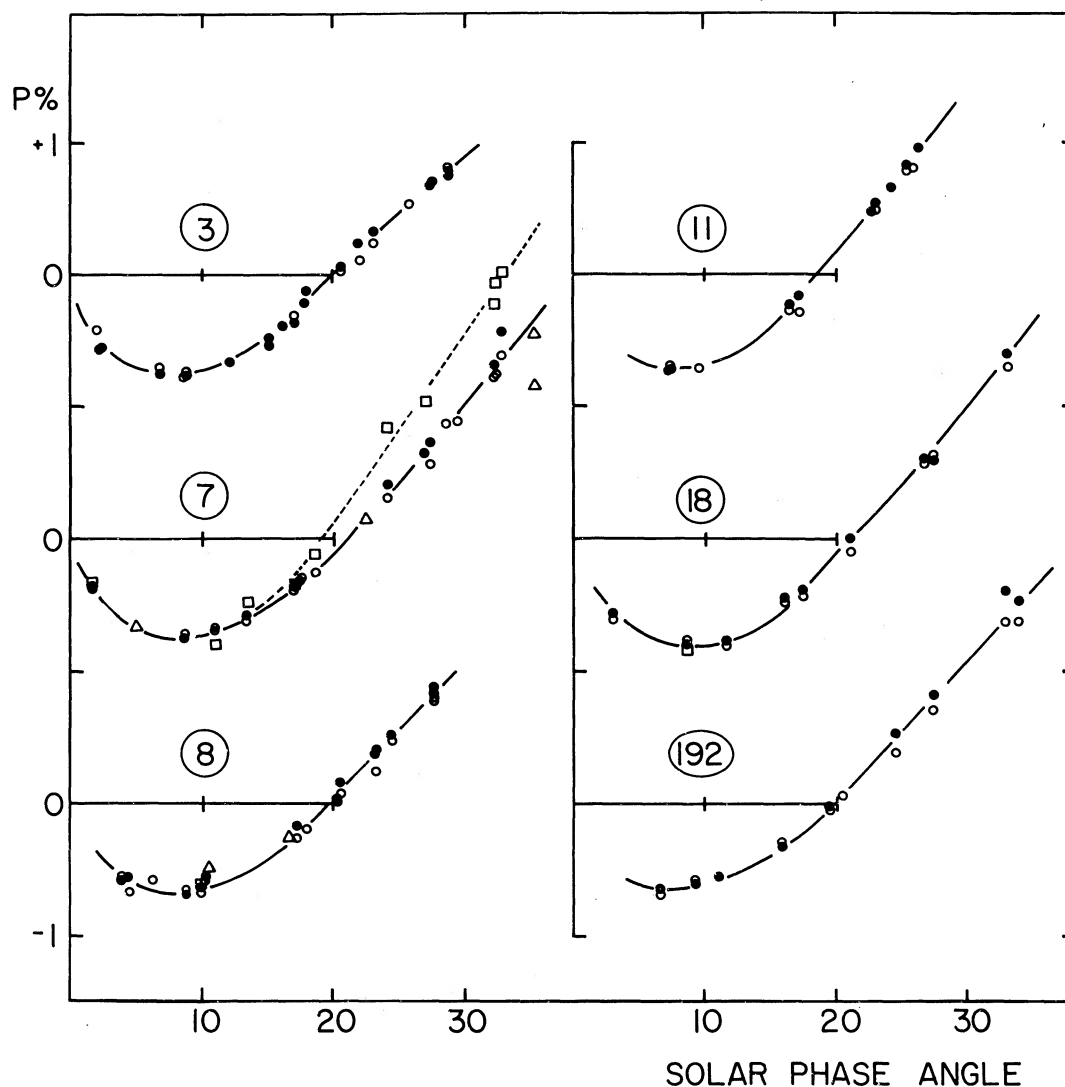


FIG. 2. Polarization-phase curves of the typical S asteroids 3 Juno, 7 Iris, 8 Flora, 11 Parthenope, 18 Melpomene, and 192 Nausikaa. Symbols are as in Fig. 1, except that open squares for 7 Iris represent results in the ultraviolet filter.

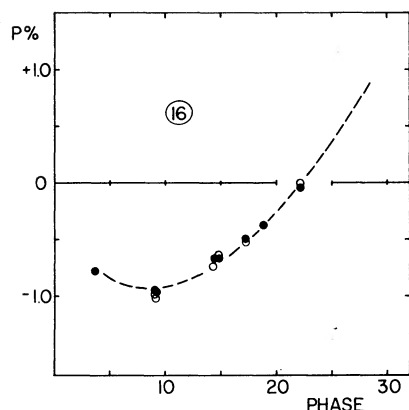


FIG. 3. Points represent polarimetric observations of asteroid 16 Psyche, with symbols as in Fig. 1. The dashed curve is the average of blue- and green-light laboratory results for fine iron filings, with size $< 50 \mu\text{m}$, from unpublished work by Dollfus and Zellner. The filings are slightly oxidized but still strongly magnetic, and have albedo 0.12 at the visual wavelength relative to MgO at 5° phase.

data only) would lead to an overestimate of the visual albedo.

Thus, we have, for some objects, a wavelength-

dependent failure of the slope-albedo law. Analogous effects have not been clearly demonstrated in laboratory data, and do not exist for lunar materials (Bowell *et al.* 1973). This "Q-effect" does not seem to correlate with any other spectral, polarimetric, or orbital parameters. If present for the C asteroids it is masked by their weak colors, but it does represent an optical property, of unknown nature, in which the S asteroids differ from one another.

The slope-albedo law is poorly documented for very dark materials, and the absence of derived polarimetric albedos below 0.05 may reflect only a saturation of the law. Also, a note of caution is appropriate for the high albedo listed for 64 Angelina. While few if any lunar powders and meteorites studied in the laboratory have albedos as high as 0.5, there is no reason to doubt the slope-albedo law itself in this domain (Bowell and Zellner 1974). However the law refers essentially to *normal* albedos measured at small incidence angles, whereas actual astronomical bodies covered with bright, low-opacity material may show substantial limb darkening. Thus, the global *geometric* albedo may be lower than the derived value.

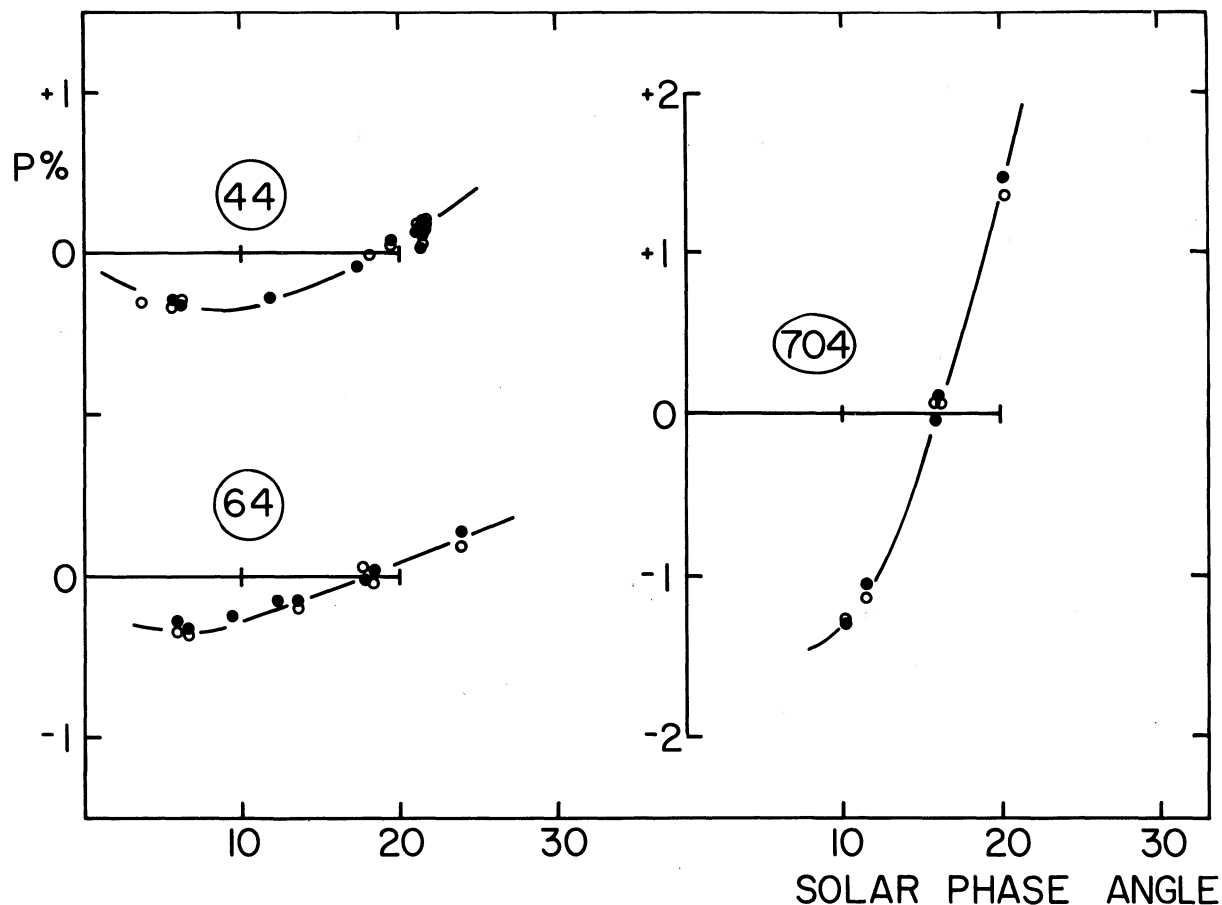


FIG. 4. Polarization-phase curves of the high-albedo asteroids 44 Nysa and 64 Angelina (left), and the unusual dark object 704 Interamnia (right).

In Table IV we give geometric albedos at the visual wavelength derived from weighted averages of results in Table III without regard for the difficulties discussed above. For asteroids clearly identifiable as belonging to the *S* type (Sec. IV), the average geometric albedo is 0.18 with rms scatter ± 0.02 ; for the *C* objects it is 0.060 ± 0.005 . Diameters are then computed from the adopted absolute magnitudes in the second column. Three significant digits are usually given for computational purposes, without any implication that albedos are known to the nearest thousandth or that diameters may be computed to the nearest kilometer. The polarimetric diameters are systematically about 15% smaller than radiometric results by Morrison (1974) and substantially more discrepant with reference to the radiometric diameters listed by Hansen (1976). However, we all agree as to which asteroids are dark and which ones are lighter. More detailed comparisons between the polarimetric and radiometric asteroid albedo scales will be made in subsequent papers.

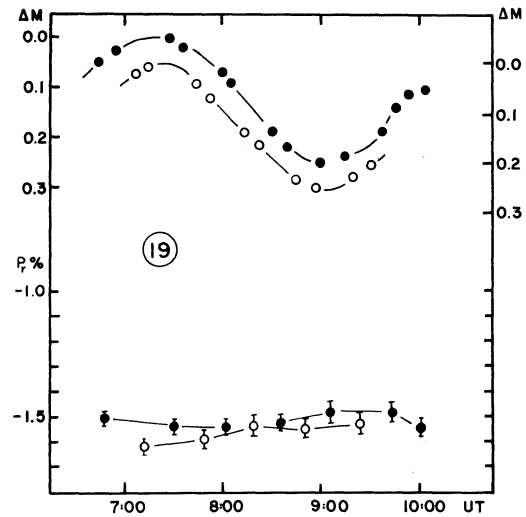


FIG. 5. Lightcurve (top) with respect to a comparison star and polarization (bottom) for asteroid 19 Fortuna on 24 July UT 1974, at phase 7.3 (Table I). Open circles indicate data in green light, and filled circles in the blue. The polarization points are averages from 5 min of integration time.

TABLE II. Depth $P_{\min}$ of the negative polarization branch, various spectrophotometric parameters, and optical type for asteroids.

Asteroid	$P_{\min}\%$	$B-V^a$	$U-B^a$	Bend ^b	Depth ^b	Type
1 Ceres	1.72	0.71	0.44	0.11	1.00	<i>C</i>
2 Pallas	1.38	0.65	0.26	0.09	1.00	<i>C</i> pec
3 Juno	0.76	0.81	0.39	0.13	0.90	<i>S</i>
4 Vesta	0.55?	0.77	0.46	0.14	0.74	<i>U</i>
5 Astraea	0.70	0.83	0.36	0.10	0.84	<i>S</i>
6 Hebe	0.80	0.83	0.41	0.14	0.89	<i>S</i>
7 Iris	0.75	0.81	0.45	0.17	1.00	<i>S</i>
8 Flora	0.68	0.87	0.45	0.22	0.81	<i>S</i>
9 Metis	0.74	0.85	0.50	0.15	1.00	<i>S</i>
10 Hygeia	1.50	0.70	0.40	0.12	...	<i>C</i>
11 Parthenope	0.73	0.84	0.38	0.16	1.00	<i>S</i>
12 Victoria	0.68	...	...	0.24	1.00	<i>S</i>
13 Egeria	2.10	0.75	0.43	0.24	1.00	<i>C</i>
14 Irene	0.80?	0.82	0.36	0.13	0.83	<i>S</i>
15 Eunomia	0.72?	0.81	0.42	0.14	0.93	<i>S</i>
16 Psyche	1.00	0.74	0.25	0.04	1.00	<i>M</i>
17 Thetis	0.74	0.83	0.42	0.17	0.92	<i>S</i>
18 Melpomene	0.80	0.82	0.35	0.16	0.93	<i>S</i>
19 Fortuna	1.72	0.76	0.39	0.21	1.00	<i>C</i>
20 Massalia	0.71	0.81	0.43	...	...	<i>S</i>
21 Lutetia	1.30?	0.71	0.19	0.09	1.00	<i>M</i>
22 Kalliope	0.98	0.72	0.28	0.07	0.91	<i>M</i>
23 Thalia	0.74	0.87	...	0.13	...	<i>S</i>
24 Themis	1.63?	0.70	0.35	0.18	1.00	<i>C</i>
27 Euterpe	0.66	...	...	0.16	0.88	<i>S</i>
28 Bellona	0.73?	...	...	0.18	0.88	<i>S</i>
29 Amphitrite	0.88?	0.83	0.45	0.06	0.93	<i>S</i> pec
30 Urania	0.78	0.88	0.45	0.15	1.00	<i>S</i>
31 Euphrosyne	1.32?	...	...	...	...	<i>C?</i>
39 Laetitia	0.77:	0.88	0.49	0.16	0.93	<i>S</i>
40 Harmonia	0.78	0.84	0.41	0.16	0.93	<i>S</i>
41 Daphne	1.88?	...	...	...	...	<i>C</i>
42 Isis	0.64	...	...	...	...	<i>S</i>
44 Nysa	0.31	0.67	0.22	...	...	<i>E</i>
46 Hestia	1.54?	0.68	0.24	...	...	<i>C</i> pec

TABLE II (*continued*)

Asteroid	$P_{\min}\%$	$B-V^a$	$U-B^a$	Bend ^b	Depth ^b	Type
51 Nemausa	1.96	0.80	...	0.30	1.00	C pec
54 Alexandra	1.95	0.76	0.42	...	...	C
56 Melete	1.47	0.67	0.36	...	...	C
57 Mnemosyne	0.71?	...	...	...	...	S
58 Concordia	1.70?	...	...	0.16	1.00	C
63 Ausonia	0.70	0.91	0.46	0.18	0.89	S
64 Angelina	0.32	0.77	0.27	...	...	E
65 Cybelle	1.29?	...	...	...	...	C
68 Leto	0.68	0.86	0.47	0.10	1.00	S
70 Panopaea	1.83	...	...	...	...	C
71 Niobe	0.61?	...	...	...	...	S
80 Sappho	0.75:	...	...	0.27	1.00	S pec
83 Beatrix	1.47?	...	...	...	...	C
84 Klio	1.49	0.74	0.44	0.21	...	C
85 Io	1.36?	...	...	0.15	0.90	U
88 Thisbe	1.50?	...	...	0.14	1.00	C
89 Julia	0.90	0.83	0.43	0.15	0.83	S pec
93 Minerva	1.22	...	...	0.14	...	C pec?
95 Arethusa	1.78	0.72	0.36	...	...	C
114 Cassandra	1.24?	...	...	...	...	C?
115 Thyra	0.71	0.83	0.45	0.13	0.90	S
129 Antigone	0.80?	0.71	...	...	...	?
135 Hertha	1.06?	0.71	0.27	...	...	M?
139 Juewa	1.31	...	...	0.15	1.00	C
141 Lumen	1.78	...	...	0.17	1.00	C
145 Adeona	1.86	...	...	0.20	1.00	C
182 Elsa	0.64	0.86	0.45	...	...	S
192 Nausikaa	0.75	0.92	0.49	0.17	0.93	S
230 Athamantis	0.94	0.87	0.49	0.07	0.97	S pec
306 Unitas	0.66?	...	...	...	...	S
324 Bambergia	1.46	0.69	0.29	0.16	...	C
338 Budrosa	0.98?	...	...	...	...	M?
345 Tercidina	1.55	...	...	...	...	C
349 Dembowska	0.39	0.96	0.55	0.26	0.75	U
354 Eleonora	0.52?	0.93	0.54	0.19	1.00	S pec
356 Liguria	1.50?	0.72	0.37	0.20	...	C
367 Amicita	0.71?	...	...	...	...	S
389 Industria	0.80?	...	...	...	...	S
410 Chloris	1.94	...	...	...	...	C
415 Palatia	1.28?	0.72	0.26	...	...	C pec?
416 Vaticana	0.77	0.90	0.46	...	...	S
433 Eros	0.70	0.88	0.50	0.15	0.90	S
451 Patienta	1.62	0.67	0.31	...	...	C
471 Papagena	0.63	...	...	...	...	S
511 Davida	1.69	0.71	0.35	0.17	1.00	C
532 Herculina	0.78	0.84	0.44	0.19	0.93	S
563 Sulieka	0.70	0.89	0.50	0.16	...	S
584 Semiramis	...	0.91	0.53	0.24	...	S
602 Marianna	1.76?	...	...	...	...	C
654 Zelinda	1.46?	...	...	0.29	1.00	C pec
674 Rachelle	0.81?	...	...	0.17	1.00	S
704 Interamnia	1.45?	0.66	0.27	0.06	1.00	U
737 Arequipa	0.84	...	...	...	...	S
747 Winchester	1.30	0.71	0.32	...	...	C
887 Alinda	0.76	0.89	...	0.27	0.95	S
1058 Grubba	0.69?	...	...	...	...	S
1566 Icarus	...	0.80	0.54	...	...	S?
1620 Geographos	...	0.87	0.50	...	...	S
1685 Toro	...	0.88	0.47	0.26	0.84	S

^a From Zellner *et al.* (1975). From Millis *et al.* (1976) for 433 Eros.^b From Chapman *et al.* (1975). From Pieters *et al.* (1976) for 433 Eros.

POLARIMETRY OF ASTEROIDS

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TABLE III. Polarimetric slopes, inversion angles, and geometric albedos for asteroids.

Asteroid	Filt. ^b	Ascending branch ^a					
		<i>N</i>	$\epsilon\%$	α_0	slope <i>h</i>	<i>p</i>	<i>p_v</i>
1	<i>B</i>	8	0.04	18.2	0.253	0.066	0.071
	<i>G</i>	6	0.01	18.1	0.257	0.064	0.066
2	<i>B</i>	7	0.05	18.7	0.190	0.087	0.089
	<i>G</i>	5	0.02	18.1	0.230	0.072	0.073
3	<i>B</i>	12	0.04	19.6	0.107	0.155	0.183
	<i>G</i>	6	0.02	20.2	0.098	0.170	0.179
4	<i>B</i>	14	0.02	21.3	0.067	0.248	0.282
	<i>G</i>	14	0.03	21.9	0.066	0.250	0.260
5	<i>B</i>	7	0.04	18.9	0.110	0.151	0.182
	<i>G</i>	6	0.03	19.1	0.096	0.173	0.183
6	<i>B</i>	5	0.03	20.5	0.086?	0.194?	0.233
	<i>G</i>	4	0.02	20.8	0.091?	0.182?	0.193
7	<i>B</i>	4	0.01	20.4	0.108	0.153	0.181
	<i>G</i>	8	0.05	21.2	0.097	0.171	0.179
8	<i>B</i>	8	0.04	19.3	0.103	0.161	0.200
	<i>G</i>	8	0.04	20.0	0.104	0.160	0.171
9	<i>B</i>	8	0.04	21.1	0.099	0.168	0.205
	<i>G</i>	8	0.05	21.8	0.102	0.163	0.173
11	<i>B</i>	7	0.02	18.4	0.123	0.134	0.163
	<i>G</i>	5	0.04	18.9	0.124	0.134	0.142
12	<i>B</i>	8	0.04	21.1	0.137	0.122	0.149
13	<i>B</i>	4	0.04	22.0	0.258	0.064	0.072
	<i>G</i>	4 ^c	0.08	21.7	0.257	0.065	0.067
14	<i>B</i>	6	0.03	20.2	0.116	0.143	0.171
	<i>G</i>	5	0.03	20.5	0.105	0.158	0.167
15	<i>X</i>	8	0.10	20.8	0.120	0.138	0.145
16	<i>B</i>	5	0.03	23.1	0.080?	0.207?	0.229
	<i>G</i>	4	0.03	22.5	0.090?	0.184?	0.189
17	<i>B</i>	6	0.05	20.5	0.131	0.126	0.152
18	<i>B</i>	6	0.05	21.3	0.098	0.170	0.202
	<i>G</i>	6	0.04	21.6	0.101	0.164	0.173
19	<i>B</i>	7	0.13	21.4	0.302	0.055	0.062
	<i>G</i>	7	0.08	21.7	0.305	0.054	0.056
20	<i>B</i>	5	0.01	18.8	0.090	0.185	0.218
	<i>G</i>	4	0.01	19.8	0.092	0.180	0.190
21	<i>B</i>	7	0.05	24.5	0.176	0.094	0.102
	<i>G</i>	5	0.05	24.2	0.169	0.098	0.100
23	<i>B</i>	5	0.02	19.6	0.097	0.171	0.213
27	<i>B</i>	5	0.03	19.9	0.099	0.168	0.205
29	<i>B</i>	5	0.06	20.6	0.112	0.148	0.177
	<i>G</i>	4	0.01	22.0	0.098	0.170	0.179
30	<i>B</i>	4	0.04	19.3	0.109	0.153	0.192
	<i>G</i>	5	0.08	19.8	0.104	0.160	0.172
39	<i>B</i>	8	0.03	20.5	0.098	0.169	0.213
	<i>G</i>	7	0.01	21.0	0.090	0.184	0.197
40	<i>B</i>	5	0.02	20.7	0.106	0.156	0.190
	<i>G</i>	6	0.05	20.8	0.100	0.166	0.176
42	<i>B</i>	6	0.01	17.3	0.133	9.125	0.153
	<i>G</i>	4	0.04	18.4	0.129	0.129	0.137
44	<i>B</i>	8	0.03	18.5	0.052	0.317	0.347
51	<i>B</i>	2	...	20.3?	0.292?	0.057?	0.066
54	<i>B</i>	4	...	22.0	0.300?	0.055?	0.062
	<i>G</i>	4	...	22.2	0.357?	0.046?	0.048
56	<i>B</i>	7	0.07	20.0	0.316	0.053	0.055
	<i>G</i>	7	0.05	19.7	0.318	0.052	0.053
63	<i>B</i>	7 ^d	0.02	19.4	0.124	0.134	0.174
	<i>G</i>	4	0.03	19.8	0.102	0.163	0.176
64	<i>B</i>	5	0.03	17.1	0.0379	0.438	0.498
	<i>G</i>	4	0.05	18.2	0.0365	0.454	0.472
84	<i>B</i>	2	...	20.2?	0.299?	0.056?	0.062
	<i>G</i>	2	...	20.3?	0.306?	0.054?	0.056
89	<i>X</i>	8	0.13	22.1:	0.119:	0.140:	0.148
139	<i>B</i>	2	...	20.6?	0.262?	0.063?	0.067
141	<i>B</i>	7	0.06	21.3	0.306	0.054	0.059
	<i>G</i>	4	0.03	20.6?	0.330?	0.050?	0.052
192	<i>B</i>	6	0.06	19.6	0.102	0.163	0.210
	<i>G</i>	7	0.04	19.8	0.084	0.198	0.213
230	<i>B</i>	5	0.04	19.8	0.140	0.118	0.147
	<i>G</i>	4	0.02	20.6	0.122	0.136	0.145
324	<i>B</i>	9	0.08	20.1	0.308	0.054	0.057
	<i>G</i>	7	0.09	20.0	0.278	0.060	0.061
410	<i>B</i>	3	...	19.9?	0.313?	0.053?	0.058

TABLE III (continued)

Asteroid	Ascending branch ^a						
	Filt. ^b	<i>N</i>	$\epsilon\%$	α_0	slope <i>h</i>	<i>p</i>	<i>p_v</i>
433	V	17	0.05	20.6	0.082	0.203	0.203
	B	10	0.05	19.4	0.100	0.166	0.209
511	B	8	0.03	19.6	0.287	0.058	0.062
	G	8	0.05	19.4	0.277	0.060	0.061
532	B	6	0.04	20.2	0.122	0.136	0.166
563	B	3	...	18.8	0.108	0.154	0.196
584	B	6	0.04	17.4	0.114	0.146	0.188
	G	5	0.06	19.1	0.108	0.153	0.165
654	B	3	...	21.1?	0.328?	0.051?	0.055
	G	3	...	20.5?	0.280?	0.059?	0.061
704	B	3	...	15.8	0.338	0.049	0.050
	G	3	...	15.7	0.305	0.054	0.055
887	B	4	0.08	19.4	0.101?	0.164?	0.210
1566	B	5	0.16	...	0.107?	0.155?	0.181
	G	4	0.13	...	0.082?	0.202?	0.212
1620	B	4	0.10	...	0.108?	0.154?	0.192
	V	4	0.25	...	0.074?	0.224?	0.224
1685	B	8	0.16	...	0.130?	0.128?	0.161

^a Parameters are derived by least-squares fits to *N* points at phases near 15° and larger; ϵ is the rms deviation from the fitted curve.

^b Symbol X indicates measurements by Veverka (1973) with no filter.

^c One measurement at the V wavelength is incorporated.

^d Data from 1973 only; see text.

Widorn (1974) has proposed that asteroid albedos may be computed from the depth of the pyroxene absorption band near 0.95- μ m wavelength. The shortcomings of this approach are obvious in Fig. 7. While

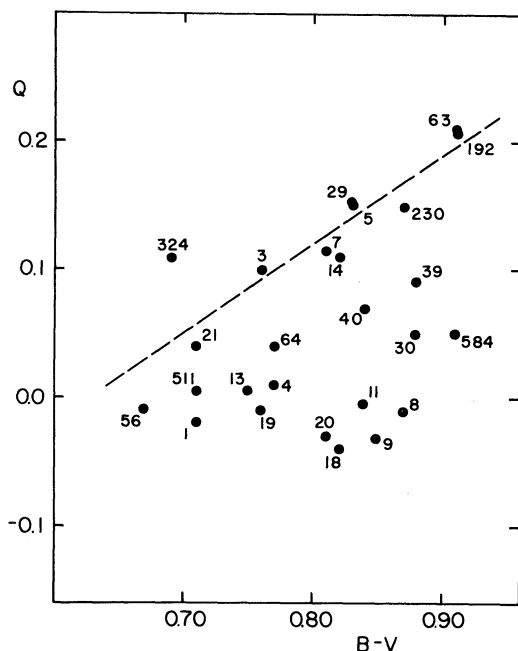


FIG. 6. The quantity $Q = 2.5 \log (h_B/h_G)$ vs $B-V$ color for asteroids with well-determined polarimetric slopes *h* at both wavelengths; *Q* is the ratio, in magnitude units, of the indicated polarimetric albedo in the green to that in the blue. Objects for which the slope-albedo law indicates the same diameter at both wavelengths should fall along the line given by $Q = 0.70 (B-V - 0.63)$, where the factor 0.70 arises from the transformation from $B-V$ to $B-G$ colors (Zellner and Capen 1974) and $B-V = 0.63$ is the color of the Sun.

none of the dark *C* asteroids show such a band, some of the *S* asteroids do and some (containing no pyroxene) do not, with no systematic difference in albedo. Also, no band is expected for the very bright *E* asteroids (Sec. IV). Widorn's conclusions were the result of an unfortunate choice of preliminary data for the albedos of asteroids.

The existence of a color-albedo relationship, admittedly crude but adequate for estimation of albedos and diameters for cases in which only color data are available, was proposed by Chapman *et al.* (1975) but doubted by Hansen (1976). One might also attempt to compute albedos from $P_{\min}$. With reference to the polarimetric albedos of Table IV, the actual situation is seen in Figs. 8 and 9. In both cases the *S* and *C* types make distinct clumps, but there are no well-delineated albedo-color or albedo- $P_{\min}$ relationships within each group. Thus, once an asteroid is securely identified as an *S* or a *C* from its spectrum or $P_{\min}$, then the corresponding mean albedos of 0.18 and 0.06, respectively (or their radiometric equivalents), can be used for diameter calculations. The results should be satisfactory for statistical purposes, certainly better than assuming that all asteroids have the same albedo, and perhaps better than relying on a single noisy albedo determination by the radiometric or polarimetric methods.

The rarer types of asteroids scatter widely in albedo and color; no very dark, very red asteroids appear in our sample, but neutral colors are found among both the lightest and the darkest objects. A relationship between $P_{\min}$ and albedo, namely

$$\log p_V = -1.31 \log P_{\min} - 0.9 \pm 0.1,$$

TABLE IV. Derived geometric albedos and diameters for 52 asteroids.

Asteroid	V(1,0)	Source ^a	p_V	Diameter (km)
1	3.72	3	0.068	914
2	4.53	2	0.082	573
3	5.63	1	0.181	233
4	3.55	2	0.271	496
5	7.17	2	0.178	116
6	5.87	2	0.206	195
7	6.03	2	0.180	194
8	6.67	2	0.186	158
9	6.45	2	0.189	156
11	6.97	1	0.152	137
12	8.0	5	0.149	86
13	7.15	1	0.069	187
14	6.60	1	0.169	154
15	5.48	2	0.145	279
16 ^b	6.4	3	0.213?	150?
17	7.86	2	0.152	91
18	6.97	2	0.187	123
19	7.50	1	0.060	171
20	6.67	2	0.204	136
21	7.90	1	0.101	110
23	7.47	2	0.213	92
27	7.66	5	0.205	86
29	6.38	1	0.178	166
30	7.90	2	0.182	82
39	6.53	4	0.205	145
40	7.56	1	0.184	95
42	8.0	5	0.148	87
44	7.35	2	0.347?	76
51	7.86	2	0.066?	138
54	8.10	1	0.055	135
56	8.91	1	0.055	94
63	7.53	1	0.174	99
64	8.01	1	0.490	47
84	9.60	1	0.059?	66
89	7.0:	2	0.148?	137
139	8.47	5	0.067?	103
141	9.0	5	0.056	88
192	7.71	1	0.212	83
230	7.75	1	0.146	98
324	7.41	1	0.059	180
410	9.0	5	0.058?	88
433	10.78	6	0.201	21
511	6.46	1	0.062	272
532	7.14	2	0.165	122
563	8.76	1	0.196	53
584	9.11	1	0.177	47
654	9.2	5	0.058?	80
704	6.81	1	0.053?	251
887	14.5	2	0.201?	3.6
1566	16.75	2	0.20 ?	1.3
1620	15.80	2	0.22 ?	1.9
1685	13.8	2	0.15 ?	5.9

^a Adopted absolute magnitudes are from the following sources: (1) *UBV* photometry by Zellner *et al.* (1975); (2) compilation of Zellner *et al.* (1974); (3) *UBV* photometry by Gehrels *et al.* (1976); (4) *UBV* photometry by Sather (1976); (5) catalogue values of *B* and estimated or poorly known *B-V*; (6) Zellner (1976), magnitude and mean diameter at photometric maximum.

^b There is reason to believe (Sec. IV) that Psyche is substantially larger and darker than is indicated by the formal results.

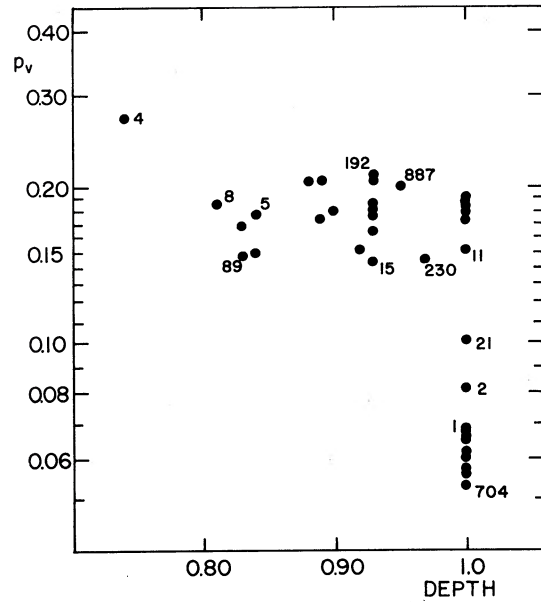


FIG. 7. Asteroid geometric albedos at the visual wavelength, from Table IV, versus the spectrophotometric parameter DEPTH indicating the strength of the Fe^{2+} absorption band near $0.95\text{-}\mu\text{m}$ wavelength (McCord and Chapman 1973a, 1973b); DEPTH = 1.0 means that no band is present.

seems to hold more generally but may fail for very small asteroids if they are unable to hold particulate matter on their surfaces (Sec. III).

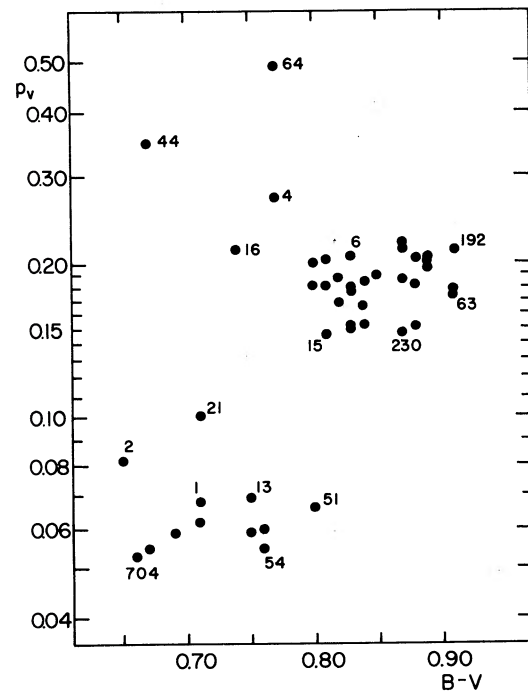


FIG. 8. Polarimetric albedos of asteroids at the visual wavelength versus the *B-V* color.

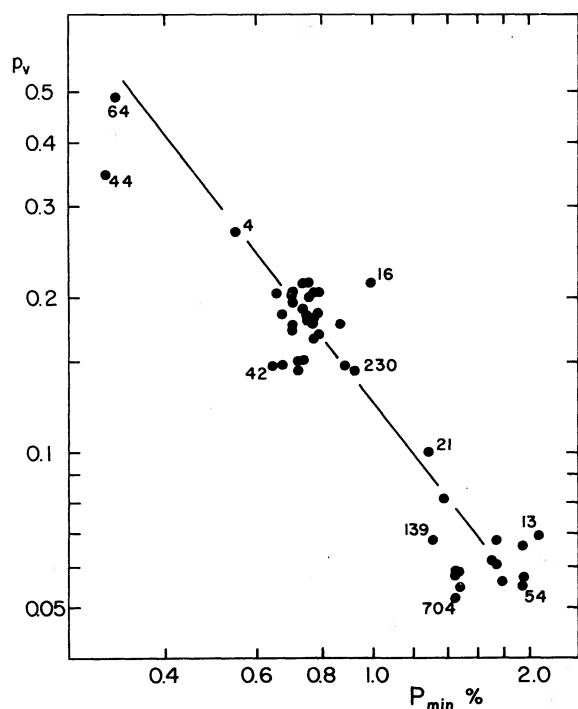


FIG. 9. Polarimetric albedos of asteroids at the visual wavelength versus the depth $P_{\min}$ of the negative polarization branch.

III. SURFACE STRUCTURE

The negative polarization branch, seen for all asteroids, can be produced only in a microscopically rough, porous, or particulate surface in which the scattering elements are opaque enough for mutual shadowing (Bowell and Zellner 1974; Wolff 1975). The dependence of the shape of the polarization-phase curve on surface microstructure is illustrated by Fig. 10 for the Pultusk ordinary chondrite, from unpublished laboratory polarimetry by Dollfus and Zellner. In this work the zero point of the polarization was uncertain by as much as $\pm 0.2\%$, so that numerical values particularly of the inversion angle cannot be trusted. However, the shapes and relative positions of the curves for the powdered sample and the broken interior surface should be correct. Both preparations have the same albedo (fortuitously), and the same polarimetric slope between 15° and 35° phase. The dust-free chip has a weaker negative branch, a smaller inversion angle, and much stronger polarizations at large phases.

Working with the full polarization-phase curve of the Moon, Dollfus (1955) was able to synthesize the microscopic appearance of lunar soils quite accurately more than a decade before the first lunar landings (e.g., Fig. 14 of Dollfus 1971). For the asteroids the highly diagnostic phase range beyond 100° is not accessible, and we must draw our conclusions from the depth $P_{\min}$ of the negative branch and the inversion angle.

With the exception of the peculiar objects 16, 21, and 704, all of the asteroids in Table III have polarimetric inversion angles between 17° and 22° . Bowell and Zellner (1974) concluded that the asteroids characteristically have dusty surfaces on the basis of the proportionality between $P_{\min}$ and albedo seen in Fig. 9, i.e., essentially that the inversion angles all fall near 20° . By comparison with laboratory results for lunar materials, Dollfus and Geake (1975) conclude that the asteroidal values of $P_{\min}$ and α_0 are more characteristic of consolidated surfaces covered with adhesive debris than of a regolithic layer of soil. However, compositional effects are certainly important, and it is not at all clear that inferences based on lunar materials can be extended to the asteroids; for example, rather smooth metallic surfaces show large inversion angles.

Radar observations of asteroid 433 Eros (Jurgens and Goldstein 1976) argue against a well-developed regolith. Arguments for a dust coating can also be made on mechanical grounds (Chapman 1971, 1976) and on the basis of the remarkable photometric uniformity of most asteroids (e.g., Zellner 1976). Thus, the best evidence favors asteroid surfaces which are neither microscopically clean nor soil covered but in some intermediate state. Better understanding awaits improved laboratory measurements, especially for meteoritic materials. We note that within the optically homogeneous C and S classes there are no correlations between asteroid diameter and the measured $P_{\min}$

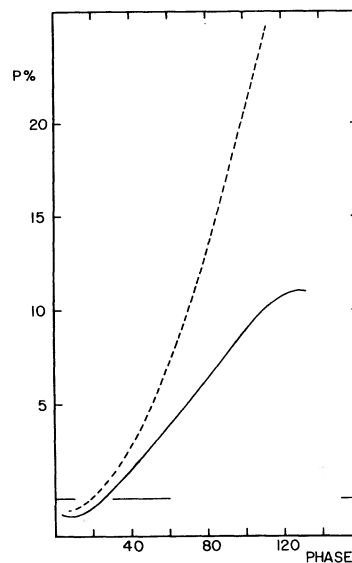
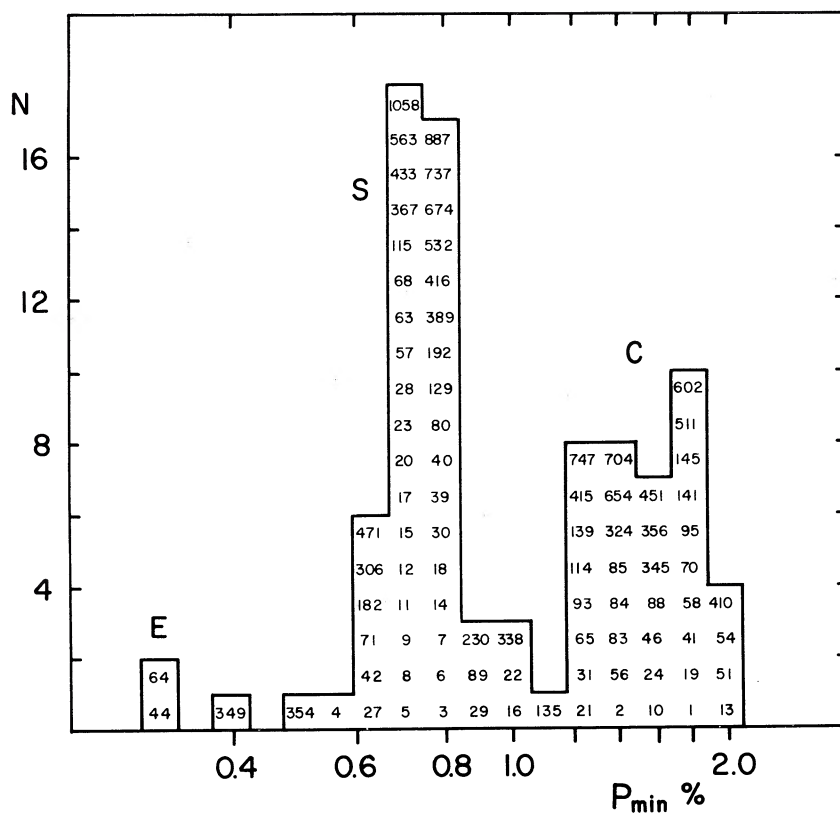


FIG. 10. Polarization versus phase angle for the Pultusk H5 ordinary chondrite, from unpublished laboratory data in blue light by Dollfus and Zellner. The solid line represents a powdered sample with particles smaller than $100 \mu\text{m}$, of albedo 0.173 relative to MgO at 5° phase. The dashed line is for a broken interior surface with a very rough microstructure, blown dust free with a mild air jet but not washed. The broken surface has albedo 0.176 and shows maximum polarization 32% near 140° phase. The polarimetry has a relative precision of $\pm 0.1\%$ with a comparable systematic error in the zero point.

FIG. 11. Distribution of the depth $P_{\min}$ of the negative polarization branch for 90 asteroids. Types are as identified in Sec. IV.



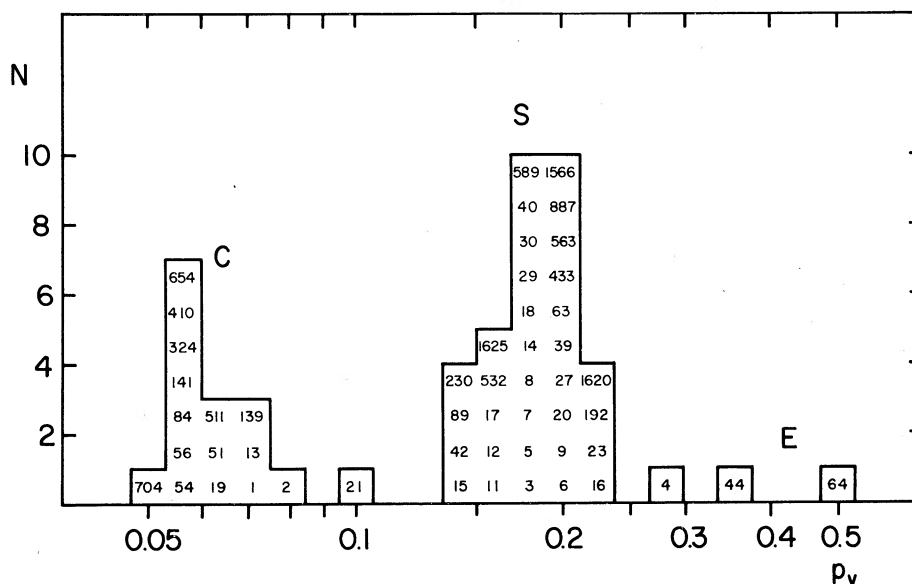
or α_0 . Thus, if dust layers do not form on the surfaces of very small asteroids, the critical dimensions would appear to be less than 5 km.

IV. COMPOSITIONAL TYPES

The prevalence and relative optical homogeneity of the C and S compositional types are reflected in the gross bimodalities of Figs. 11 and 12 for the distribu-

tions of $P_{\min}$ and polarimetric albedo, and similar bimodalities in the broad-band color over the visible spectral range (McCord and Chapman 1975b) and in radiometric albedos (Hansen 1976). [Strictly speaking, the polarimetry is sensitive not directly to composition but to the complex refractive index (Wolff 1975). However, we feel justified in describing the C, S, and other asteroid populations as "compositional types"

FIG. 12. Distribution of the polarimetric albedo at the visual wavelength for 52 asteroids.



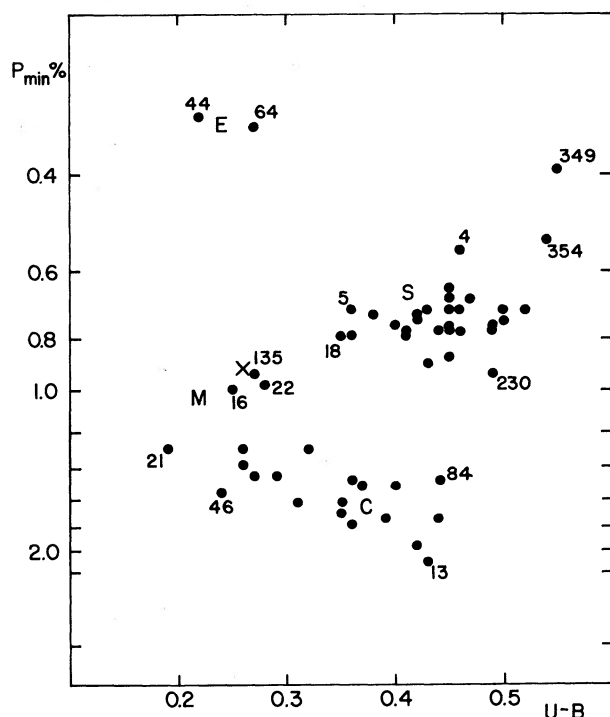


FIG. 13. Depth $P_{\min}$ of the negative polarization branch versus the $U-B$ color for asteroids. The cross represents the presumed domain of pure metallic surfaces, with $P_{\min}$ from Fig. 3 above and $U-B$ from the average of four nickel-iron meteorite spectra measured by Gaffey (1974).

in view of their observational distinctness in various optical properties and the fact that the differences are readily attributable to the content of silicates, carbon, iron, etc.]

Among the outliers, 4 Vesta is spectrally unique and its surface is firmly identified as corresponding to certain basaltic achondrites (McCord *et al.* 1970; Veeder *et al.* 1975; Larson and Fink 1975). The asteroid 349 Dembowska is similarly identified with low-iron ordinary chondrites (McCord and Chapman 1975b). The high-albedo object 44 Nysa has a surface composition of low opacity and totally lacking in ferrous iron, probably identifiable with the aubrites or pure-enstatite achondrites (Zellner 1975). This object and 64 Angelina we provisionally designate as belonging to a class *E*.

Asteroids 16 Psyche, 21 Lutetia, and a few others with gently sloping linear spectra, values of $P_{\min}$ near 1.0%, and inversion angles larger than 23° are suspected of a free-metal or metal-rich enstatite composition such as that of the nickel-iron meteorites or enstatite chondrites (Chapman and Salisbury 1973; Johnson and Fanale 1973; McCord and Gaffey 1974), and we denote this class of asteroids by the symbol *M*. Laboratory polarimetric data for metallic surfaces are scanty, but as shown in Fig. 3 the identification of 16 Psyche with free iron seems plausible enough. In albedo the *M* asteroids generally seem to be inter-

mediate between the typical *C* and *S* values. For 16 Psyche the formal solutions in Table III yield $p_V = 0.21$, but the phase coverage is poor. In Figs. 3 and 9 the data are seen to be reasonably consistent with $p_V = 0.12$, which is much closer to the radiometric albedo by Morrison (1974) and similar to our value for 21 Lutetia. Much-improved thermophysical data were obtained for 16 Psyche in late 1975.

In the last column of Table II we assign surface types *C*, *S*, *M*, and *E* on the basis of the polarimetry and also spectrophotometric and radiometric observations described above. Peculiarities and uncertain classifications are noted. The symbol *U* (unclassified) is now reserved for asteroids not belonging to any of the above four types. For 129 Antigone the single observations of polarization and $B-V$ color are not consistent with any recognized type; in *JHK* colors it resembles the *C* asteroid 511 Davida (Chapman and Morrison 1976).

V. INDICATIONS OF METALLICITY

Relationships between the principal asteroid types may be seen in Figs. 13 and 14, which show a remarkable distribution of $P_{\min}$ (essentially an indicator of albedo) versus the $U-B$ color index and the spectrophotometric parameter BEND defined by McCord and Chapman (1975a). For iron-bearing silicates both parameters may be taken as crude indicators of the *metallicity* or Fe/Fe^{2+} ratio; the curving visible spec-

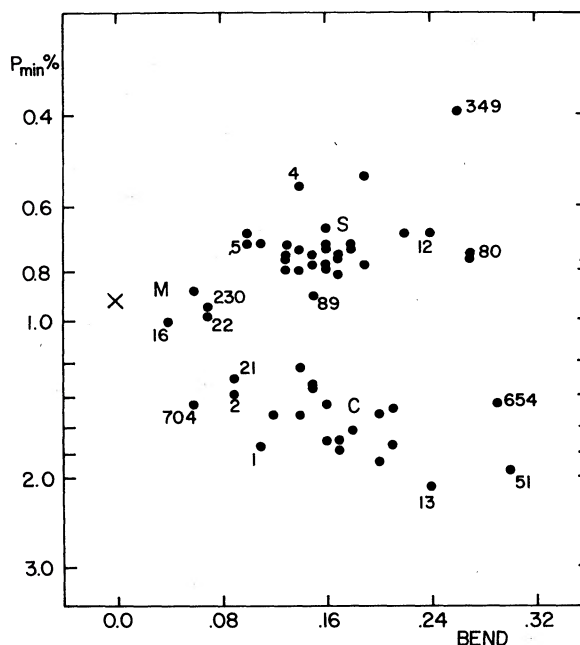


FIG. 14. $P_{\min}$ versus the spectrophotometric parameter BEND for asteroids. BEND is a measure of the curvature of the reflectance spectrum between 0.40- and 0.73- μm wavelength (McCord and Chapman 1975a). The cross represents the presumed domain of pure iron surfaces.

trum and sharp UV dropoff that is characteristic of transition-metal ions in a silicate lattice is flattened and linearized by addition of a free-metal component (Gaffey 1974; Zellner *et al.* 1975). Thus, the metallicity increases to the left in both plots, and we have indicated the (poorly established) parameters representing pure iron. McCord and Chapman (1975b) have noted that among the *S* asteroids large values of BEND (low metallicity) occur preferentially in the inner parts of the belt. The same may be demonstrated for the *C* objects.

Many objects do not fall at exactly analogous positions in Figs. 13 and 14, giving evidence that the interplay of opacity sensitive and metallicity sensitive parameters for various mineral assemblages is complex. However, no asteroid in our sample has large values of BEND or $U-B$ together with intermediate values of $P_{\min}$. That is, we see *no simple mixtures of C and S material*. In both figures we see a continuum of moderate-albedo asteroids ranging from domains representing a low Fe/Fe²⁺ ratio, through the *S* surfaces which are presumably more metal rich, to the Fe-dominated objects 16 and 22. A similar trend of widely varying metal/silicate ratio is seen for the *C* asteroids. It is as if distinct original populations of proto-*C* and proto-*S* material are both seen in various stages of reduction toward the common state of pure iron. For the present we leave it to others to evaluate whether such interrelationships are consistent with meteoritical evidence or cosmological considerations.

VI. CONCLUSIONS AND FUTURE WORK

To summarize, we have useful polarimetry for 94 asteroids and fragmentary data for several others. Over a range of more than a factor of 50 in diameter, or a factor of 10⁵ in mass, the asteroids all seem to have microscopically very rough or particulate surface textures. Albedos derived for 52 objects range from 0.05 to almost 0.5. In terms of their polarimetric properties, we identify 48 asteroids belonging to the broad *S* class, with albedos near 0.18 and compositions corresponding to stony-iron meteorites or possibly iron-rich ordinary chondrites. We find 34 objects of the *C* class, with albedos near 0.06, probably identifiable with carbonaceous chondrites. The *C* asteroids are underrepresented relative to their true abundance because of their low albedos and concentration toward larger heliocentric distances (Chapman *et al.* 1975). We have at least three and possibly five *M* asteroids with surfaces rich in free metal, two with low-opacity surfaces (class *E*) such as pure enstatite, and five objects belonging to other compositional types. We find no examples of transition cases between the *C* and *S* classes, but we suggest that the *M* asteroids may represent extremely reduced examples of either *C* or *S* compositions.

For the larger and nearer minor planets the polarimetric survey is essentially complete. In subsequent papers we will examine the distributions of the various types of asteroids over shape, size, rotation rate, and orbital parameters. During the next apparitions we will continue to fill gaps in the phase coverage for some of the brighter asteroids, but our principal observational thrust will be toward objects in the 10- to 40-km diameter range, which is presently almost *terra incognita* for the main belt.

It should be evident that the asteroid polarimetry has substantially advanced beyond the laboratory and theoretical investigations needed for its interpretation. Plots similar to Figs. 6, 9, 13, and 14 for a representative sample of meteoritic materials, for example, would be invaluable. The polarimetry doubtless holds indications of particle size as well as absolute carbon and metal content, etc., but better understanding of the observations now available awaits improved experimental results.

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