5i. Lunar, Planetary, Solar, Stellar, and Galactic Magnetic Fields

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LUNAR AND PLANETARY MAGNETIC FIELDS

5i-1. Moon.[5,6] According to the measurements made aboard the satellite *Explorer* 35, there appeared to be no magnetic field attributable to the moon at the distance of 800 km from the lunar surface. On the basis of the *Explorer* 35 observations the magnetic moment of the moon, even if the moon is magnetized, must be less than 4×10^{20} cgs units, which is less than 10^{-5} times the earth's magnetic moment. The conductivity of the moon seems to be sufficiently low to allow the interplanetary

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[1] Lunar and planetary fields.
[2] Galactic fields.
[3] Stellar fields.
[4] Solar fields.
[5] N. F. Ness, K. W. Behannon, C. S. Scearce, and S. C. Cantarano, *J. Geophys. Research* **72**, 5769 (1967).
[6] C. P. Sonett, D. S. Colburn, and R. G. Currie, *J. Geophys. Research* **72**, 5503 (1967).

magnetic field to be convected through it without noticeable change; the upper limit to the effective average conductivity has been estimated to be 10^{-5} mho meter^{-1}.

5i-2. Venus.[1] *Mariner V* detected a bow shock around Venus; the bow shock appeared to be similar to, but much smaller in dimension than, that of the earth (Sec. 5h-20). The creation of the bow shock has been attributed to the presence of a dense ionosphere which prevents rapid penetration of the solar wind magnetic field and plasma into the atmosphere. The standoff distance of the bow shock at the time of the *Mariner V* traversal appeared to be about 4,000 km (or about 0.7 Venus radii) from the surface of the plane. No planetary magnetic field was detected at this distance. The upper limit to the magnetic dipole moment of Venus was estimated to be about 10^{-3} times that of the earth. The observation that trapped charged particles (electrons with $E_e > 45$ kev and protons with $E_p > 320$ kev) were absent in the vicinity of Venus is in agreement with the above estimate.

SOLAR FIELD

5i-3. General Magnetic Field of the Sun. Magnetic fields on the solar surface are measured by means of the Zeeman effect in solar spectrum lines. Since 1952 measurements of magnetic fields outside sunspots have been made with the solar magnetograph.[2] Tables 5i-1 and 5i-2 summarize data on magnetic fields in polar regions.

TABLE 5i-1. THE POLAR MAGNETIC FIELDS OF THE SUN: 1912–1954

Investigator	Field intensity at North Pole[a]	Years of measurement	Remarks
Hale, Langer[b]	−4 gauss	1912–1932	Reanalysis in 1935 of early data
Nicholson, Ellerman, and Hickox[c]	+3 ± 1.7	1933–1934	±45° solar latitude
	−2.0 ± 2.8	1948–1949	Visual
von Klüber[d]	<1–2	1949–1950	±45°, photographic
Thiessen[e]	+1.5 ± 3.5	1947–1948	±45°, photoelectric
	+1.5 ± 0.75	1949	
	+2.4 ± 0.5	1951	
Kiepenheuer[f]	<1	1951	Full disk, photoelectric
H. D. and H. W. Babcock[g]	+2–4	1952–1954	±70°, full disk, photoelectric

[a] Polarity definition: magnetic vector toward observer is +.
[b] G. E. Hale, *Nature* **136,** 703 (1935).
[c] *Ann. Rept. Mt. Wilson Observ., C.I.W. Yearbook*, p. 12, 1934; p. 138, 1949.
[d] H. von Klüber, *Monthly Notices Roy. Astron. Soc.* **111,** 2 (1951); **114,** 242 (1954).
[e] G. Thiessen, *Z. Astrophys.* **26,** 16(1949); **30,** 185(1952); *Nature* **169,** 147(1952); *Ann. astrophys.* **9,** 101 (1946).
[f] K. O. Kiepenheuer, *Astrophys. J.* **117,** 447 (1953).
[g] H. W. Babcock, *Astrophys. J.* **118,** 387 (1953); **119,** 687 (1954); H. W. Babcock and H. D. Babcock, *Publ. Astron. Soc. Pacific* **64,** 282 (1952); *Astrophys. J.* **121,** 349 (1955).

Although field strengths of the polar fields are measured to be small, this is strictly an effect of integration over a relatively large area. At least a large fraction of the polar magnetic fields is confined to small regions where the magnetic field is some tens of gauss in strength.[3] The polar fields are somewhat variable,[4] and may be thought of as the result of the poleward drift of following portions of old low-latitude active

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[1] C. W. Snyder et al., Collection of *Mariner V* Papers, *Science* **158,** 1665 (1967).
[2] H. W. Babcock, *Astrophys. J.* **118,** 387 (1953).
[3] R. Howard, "Stellar and Solar Magnetic Fields," R. Lüst, ed., p. 129, North-Holland Publishing Co., Amsterdam, 1965.
[4] H. W. and H. D. Babcock, *Astrophys. J.* **121,** 349 (1955).

regions, rather than as a relatively permanent dipole field.[1] During the maximum of solar cycle 19 (1957), the polar fields of the sun reversed polarity.[2]

5i-4. Sunspot Fields. Sunspots[3] vary greatly in both size and magnetic field strength, although area and field show a positive correlation. Sunspot areas vary from as small as one to as large as 5,500 millionths of a solar hemisphere. Sunspot magnetic fields vary from about 100 to nearly 4,000 gauss. Spots generally consist of an inner dark region called the *umbra*, and a surrounding annular region, brighter than the umbra, called the *penumbra*. The magnetic fields are measured from the Zeeman effect in absorption lines in sunspot spectra. Within a sunspot the magnetic field strength varies with distance r from the center of the spot approximately as Broxon's[4] formula: $H = H_m(1 - r^2/b^2)$, where H_m is the maximum field strength, and b is the outer radius of the penumbra. Sunspots generally occur in groups consisting of an eastward and westward spot or group of spots. These are called the preceding or following spots according to the direction of solar rotation. In most cases the magnetic polarities of the preceding sunspots are all the same and opposite to that of the following spots. In any cycle the preceding spots in the north hemisphere of the sun are nearly all of the same magnetic polarity, and this is opposite to the polarity of the preceding spots in the southern hemisphere.[5] During the next 11-year activity cycle all spot polarities are reversed. Thus the solar activity cycle is actually a 22-cycle. Solar magnetic field data covering a period of many years have been published in the

TABLE 5i-2. THREE-MONTH AVERAGES OF NORTH AND SOUTH POLAR MAGNETIC FIELDS OF THE SUN (GAUSS)*

Year	Jan.–Mar.		Apr.–June		July–Sept.		Oct.–Dec.	
	N	S	N	S	N	S	N	S
1956	+2	−2	+1.5	−1	+1	−1	+1	—1.5
1957	−0.5	−1	0	0	0	+0.5	+1	+2
1958	0	+1	+2	+2	+1	+1	−2	+1.5
1959	−2	+2	.....	.....	−1	+0.5	−1	+1
1960	−1	+0.5	−1	+0.5	−1.5	+1	−1	+1
1961	−1	+1	−1	0	−0.5	0	−0.5	0
1962	−0.5	0	−1	−0.5	−1	+0.5	−0.5	+0.5
1963	.....	.....	−0.5	+0.5	−1	+0.5	−0.5	0
1964	−0.5	+1	−0.5	+0.5	−0.5	+0.5	−0.5	+0.5
1965	+0.5	+1	−0.5	+0.5	−1.5	+0.5	−1	+0.5
1966	−1	+0.5	0	+0.5	−0.5	0	−0.5	−0.5
1967	0	+0.5	−0.5	0	−0.5	+0.5	+1	+0.5
1968	+1	+1.5	−0.5	+0.5	0	0	0	0

* Taken from : H. D. Babcock, *Astrophys. J.* **130,** 364 (1959); R. Howard, "Stellar and Solar Magnetic Fields," p. 129, R. Lüst, ed., North-Holland Publishing Company, Amsterdam, 1965; D. W. Beggs and H. von Klüker, *Monthly Notices Roy. Astron. Soc.* **127,** 134 (1964); R. Howard, *Bull. Am. Astron. Soc.*, **1,** 280 (1969); and unpublished data.

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[1] H. W. Babcock, *Astrophys. J.* **133,** 572 (1961); V. Bumba and R. Howard, *ibid.* **141,** 1502 (1965).

[2] Harold D. Babcock, *Astrophys. J.* **130,** 364 (1959).

[3] R. J. Bray and R. E. Loughhead, "Sunspots," John Wiley & Sons, Inc., New York, 1964.

[4] J. W. Broxon, *Phys. Rev.* **62,** 508 (1942).

[5] G. E. Hale and S. B. Nicholson, *Astrophys. J.* **62,** 270 (1925).

TABLE 5i-3. MAGNETIC STAR DATA (AS OF 1958)

No.	Star or HD	R.A.*	Dec.*	m_v	Sp.	w†	No. of obs.‡	H_ϵ extremes§		Per.‖	Remarks#
1.....	2453	$0^h25^m50^s$	+32°09′	6.7	A2p	0.14	6/15	− 425	− 710	.....	Like HD 188041
2.....	4174	0 41 53	+40 24	7.5	M2e	......	11/41	−1200	+1100	.....	[Ne III], [O III], *H*
3.....	8441	1 21 23	+42 53	6.6	A2p	0.08	13/31	− 750	+ 400	2.96	Sr, Gd; sp. binary
4.....	9996	1 35 30	+45 09	6.3	A0	0.1:	2/6	− 990	+ 135	.....	Sp. binary
5.....	43 Cas	1 38 36	+67 47	5.5	A0p	0.7:	1/2	−1200	+	.....	Si, Sr
6.....	10783	1 43 04	+ 8 18	6.6	A2p	0.3:	18/53	−1200	+2200	4.16	Si, Sr, Cr, (Eu, Gd)
7.....	11187	1 48 10	+54 40	7.1	A0p	0.27	7/10	− 70	+1250	.....	Si, λ 4201
8.....	HR 710	2 23 37	−15 34	5.8	A4p	0.15	39/50	−1080	− 320	.....	Sr, Eu, Cr; sp. binary
9.....	21 Per	2 54 15	+31 44	5.2	A0p	0.6:	13/44	−1270	+1350	1.73	Si, Mn, Sr, Eu, λ 4200; variable profiles
10.....	19445	3 05 28	+26 09	8.0	F6	......	1/3		+ 415	.....	High-velocity subdwarf
11.....	20210	3 12 53	+34 30	6.4	A7	0.4	1/4	− 260	+	.....	Ba; sp. binary
12.....	9 Tau	3 34 01	+23 03	6.7	A2p	0.15	1/7		+ 140	.....	Si
13.....	HR 1105	3 37 48	+63 03	5.3	S	......	2/9	0:	+ 450	.....	Heavy elements
14.....	25354	3 59 52	+37 55	7.9	A0p	0.2*v*	4/8	− 380x	0:	.....	*Eu*, *Cr*, Mn, λ 4201; var. profiles
15.....	41 Tau	4 03 32	+27 28	5.3	A0p	0.43	3/8	− 530	+ 700	.....	Sr, Si, λ 4201; pec. profiles; sp. binary
16.....	68 Tau	4 22 36	+17 49	4.2	A2V	0.2	1/4	− 400		.....	Metallic-line star
17.....	30466	4 46 06	+29 29	7.2	A0p	0.5*v*	2/8	− ?	+2320	.....	Si, λ 4201; var. profiles
18.....	32633	5 02 51	+33 51	6.9	B9p	0.4:	24/24	−3960x	+2220	6.43	Si, Cr; rapid reversal
19.....	16 Ori	5 06 34	+ 9 46	5.4	F2	0.3	2/4	− 420	+ 375	.....	Metallic-line star
20.....	μ Lep	5 10 41	−16 16	3.3	B9p	0.3	5/28	− 170	+ 325	.....	Si, Mn, Y
21.....	WY Gem	6 08 54	+23 14	7.4	M3p	......	1/8	−	+ 540	.....	[Fe II]
22.....	42616	6 10 10	+41 43	6.9	A2p	0.4:	4/12	− 840	0:	.....	Sr; K-profile pec.; varies
23.....	45677	6 25 59	−13 01	7.5	B2e	0.3:	1/7	−1600		.....	*H*, Fe II, [Fe II], [S II] in emission; K pec., varies
24.....	49976	6 48 18	− 7 59	6.2	A0p	0.4*v*	1/14	− 810	+	.....	*Sr*, *Ca;* profiles diverse, vary irregularly
25.....	50169	6 49 25	− 1 35	8.9	A4p	0.12	6/11	+ 670	+2120	.....	Sr, (Eu); resembles HD 188041
26.....	R Gem	7 04 21	+22 47	6+	Se	......	2/2	+ 370	+ 400		
27.....	56495	7 14 33	− 7 26	7.5	A3p	0.4*v*	2/7	− ?	+ 570	.....	Sr, *Cr*, *Mg* I
28.....	53 Cam	7 57 27	+60 28	6.0	A2p	¼–1*v*	20/20	−5120x	+3700	.....	*Ti*, Sr, Cr, Eu, *Mg* II
29.....	15 Cnc	8 10 03	+29 48	5.6	A0p	0.7:	0/9	0:	+ str	.....	Si; profile of K varies
30.....	71866	8 27 52	+40 24	6.7	A0p	0.26	61/65	−1700x	+2000	.....	*Eu*, *Gd*, Sr
31.....	3 Hya	8 33 02	− 7 48	5.6	A2p	0.31	16/22	− 480	+ 740	.....	Sr; velocity varies; sp. binary?
32.....	49 Cnc	8 42 02	+10 16	5.6	A0p	0.26	9/26	− 200	+1450	.....	Si, Sr, (*Eu?*)

33.	*ν* Cnc	8 59 49	+24 39	5.4	B9p	0.5:	2/2	+ 105	+ 470	. . . . .	**Si, Sr, Cr; pec. profiles**
34.	*κ* Cnc	9 05 02	+10 52	5.1	B8p	0.13	8/17	− 640	+ 460	. . . . .	**Mn, Si; sp. binary (6$^{\mathrm{d}}$4)**
35.	30 UMa	10 20 33	+65 49	4.9	A0p	0.08	2/3	− 290	+ 340	. . . . .	Si, Sr, (Mn); sp. binary (11$^{\mathrm{d}}$6)
36.	45 Leo	10 25 01	+10 01	5.9	A2p	0.2*v*	5/14	−	+ 400	. . . . .	Many profiles peculiar and variable; $\underline{x}$
37.	98088	11 14 26	− 6 52	6.0	A2p	0.4:	12/15	−1000	+ 800	5.905	*Sr*, *Ba*, *Ti:* no. $\underline{x}$; sp. binary
38.	17 Com A	12 26 25	+26 11	5.4	A0p	0.4:	9/21	−1150	+ 360	. . . . .	Sr, Cr, (Eu); profiles-vary
39.	17 Com B	12 26 25	+26 11	6.7	A3	. . . . . .	0/2		+mod.	. . . . .	Metallic-line star
40.	110066	12 36 14	+36 14	6.3	A4p	0.1:	5/7	− 55	+ 300	. . . . .	Sr, Cr; λ 4210 wide
41.	*l* Cen	12 37 10	−39 43	4.8	B8p	0.2:	1/1		+ 580	. . . . .	Mn, Si
42.	*ν* Vir	12 39 07	− 1 10	2.9	F0V	. . . . . .	1/3	− 390		. . . . .	Standard F0
43.	111133	12 44 30	− 6 13	6.4	A4p	0.14	1/2	− 990		. . . . .	Sr, Cr
44.	*α*^{2} CVn	12 53 42	+38 35	2.9	A0p	0.3*v*	28/96	−1400$\underline{x}$	+1600	5.469	*Eu*, *Cr*, Sr; profiles vary
45.	115708	13 16 11	+26 38	8.3	A2p	0.2:	1/3		+ 740	. . . . .	Sr, Eu
46.	78 Vir	13 31 35	+ 3 55	4.9	A2p	0.2	50/76	−1680$\underline{x}$	− 140	3.77	Sr, Cr, Eu
47.	BD1913	13 53 50	+45 59	9.7	Ap	0.2:	/1		+ 500:	. . . . .	BD+46°
48.	125248	14 15 52	−18 29	5.7	A0p	0.2*v*	33/40	−1900$\underline{x}$	+2100	9.29	*Eu*, *Cr;* long-period sp. binary
49.	126515	14 23 23	+ 1 13	7.0	A2p	0.1+	1/4	−	+1310	. . . . .	Cr, Si, Sr; ($\underline{x}$); pec. profiles
50.	*π* Boo A	14 38 22	+16 37	4.9	B8p	0.4	2/12	− 75	+ 190	. . . . .	Si, Mn, Y, Sc
51.	*μ* Lib A	14 46 34	−13 56	5.4	A0p	0.3:	7/13	−1300	− 200	. . . . .	Sr, Cr
52.	133029	14 58 56	+47 28	6.2	A0p	0.4	50/74	+1150	+3270	. . . . .	Si, Cr, λ 4201
53.	134793	15 09 05	+ 8 43	8.2	A3p	0.3 + *v*	4/11	− 530	+ 450	. . . . .	*Eu*, *Sr*, Cr; widths vary
54.	135297	15 11 48	+ 0 33	8.0	A0p	0.3:	1/3	−1110	+	. . . . .	Sr, Cr
55.	*β* CrB	15 25 46	+29 17	3.7	F0p	0.15	61/89	− 960	+1020	18.50	Sr, Eu; sp. binary
56.	33 Lib	15 26 45	−17 16	7.2	F0p	0.15	1/2		+1120	. . . . .	Sr, Eu
57.	*ι* CrB	15 59 26	+29 59	4.9	A0p	0.07	6/10	− 340	+ 75	. . . . .	Mn, Si, Sr, Zr, Y
58.	*ω* Oph	16 29 10	−21 21	4.6	A7p	0.6	0/19	−	+	. . . . .	Sr, Cr, pec. profiles
59.	45 Her	16 45 19	+ 5 20	5.3	A0p	0.4 + *v*	0/6	−		. . . . .	*Eu*, Sr, Si; profiles vary
60.	52 Her	16 47 46	+46 04	4.9	A4p	0.4	2/19	+ 840	+1430	. . . . .	Sr, (Eu)
61.	153286	16 54 41	+47 26	6.9	F	. . . . . .	2/3	− 500		. . . . .	Sr; metallic-line star
62.	153882	16 59 16	+15 01	6.2	A4p	0.4:	32/38	−1200$\underline{x}$	+1440	6.01	(*Sr*, Cr, Mn); profiles vary
63.	165474	18 03 25	+12 00	7.4	A7p	0.15	1/3		+ 900	. . . . .	Eu, Sr
64.	171586	18 33 08	+ 4 54	6.7	A2p	0.8:	1/4	− 740		. . . . .	Sr, Cr
65.	173650	18 43 28	+21 55	6.4	A0p	0.2+	20/43	− 540	+ 700	10.1	*Sr*, *Eu*, Si, Mn, Cr, Gd, λ 4201; pec. variable profiles
66.	10 Aql	18 56 29	+13 50	5.9	A4p	0.1:	5/10	− 315	+ 440	. . . . .	Sr, Eu, Mn
67.	21 Aql	19 11 11	+ 2 12	5.2	B8	0.4	4/6	− 590	+ 173	. . . . .	Si
68.	RR Lyr	19 23 52	+42 41	7.8	F	. . . . . .	18/47	−1580	+1170		
69.	51 Sgr	19 33 00	−24 50	5.7	F	. . . . . .	1/3	− 230		. . . . .	Sr, Eu. Metallic-line star; sp. binary
70.	184905	19 33 09	+43 50	6.6	A0p	1:*v*	0/26	−		. . . . .	*Si*, *Eu*, *Ca;* profiles vary

TABLE 5i-3. MAGNETIC STAR DATA (AS OF 1958) (*Continued*)

No.	Star or HD	R.A.*	Dec.*	m_v	Sp.	w†	No. of obs.‡	H_e extremes§		Per.‖	Remarks#
71.	187474	$19^h48^m27^s$	−40°01′	5.4	A0p	0.1+	5/5	−1870	+1700	2350	Eu, Si, Ti, Fe, (Mn, Al)
72.	188041	19 50 42	− 3 15	5.6	A5p	0.11	75/84	− 230	+1470	226	*Gd, Eu, Sr;* secular changes; variable amplitude
73.	190073	20 00 31	+ 5 36	7.9	Aep	0.2+	1/12	+ 120		. . . . .	*Ca*
74.	191742	20 08 04	+42 24	7.8	A7p	0.12	2/5	− 510	− 175	. . . . .	Sr, (Si, Eu)
75.	192678	20 12 18	+53 30	7.1	A4p	0.2:	0/1		+2000:	. . . . .	Cr
76.	192913	20 14 23	+27 37	6.7	A0p	0.2:	4/10	− 670	+ 380	. . . . .	Si, λ 4201
77.	73 Dra	20 32 11	+74 47	5.2	A2p	0.13	9/14	− 700	+ 200:	. . . . .	*Ti, Eu, Sr;* sp. variations periodic?
78.	ν Equ	21 07 55	+ 9 56	4.8	A7p	0.09	21/31	+ 180	+ 880	. . . . .	Eu, Mg, Sr, (Si)
79.	θ¹ Mic	21 17 34	−41 01	4.9	A2p	0.6−	1/3	− 650		. . . . .	*Eu, Sr*, Cr; diverse profiles
80.	AG Peg	21 48 37	+12 23	7.6	B+M	. . . . . .	14/30	−1000	+ 500		
81.	VV Cep	21 55 14	+63 23	5–6	M+B	. . . . . .	5/17	− 360	+ 850	. . . . .	Sp. binary
82.	215038	22 38 18	+75 24	8.0	A0p	0.8:	0/2	−3000:		. . . . .	Si, λ 4201
83.	216533	22 50 36	+58 33	7.9	A2p	0.15	5/6	− 650	0	. . . . .	*Sr*, Cr, Eu, (Si)
84.	κ Psc	23 24 22	+ 5 58	4.9	A2p	0.8*v*	0/17	−	+	. . . . .	*Sr, Ca, Eu*, Cr
85.	β Scl	23 30 18	−38 06	4.5	B9p	0.3:	1/3		+ 660	. . . . .	Mn, Si; Y has neg. polarity
86.	ι Phe	23 32 23	−42 54	4.8	A2p	0.4:	0/2		+	. . . . .	Sr, Cr; pec. profiles
87.	108 Aqr	23 48 46	−19 11	5.3	A0p	0.8:	0/12	−	+	. . . . .	*Sr, Ca, Eu*, Si, λ 4201; pec.
88.	224801	23 58 10	+44 58	6.2	A0p	0.8:	2/22	−	+2300	. . . . .	*Eu*, Si, Sr, λ 4201
89.	4778	0 47 30	+44 44	6.1	A0p	½–1	0/4	−	+	. . . . .	*Eu, Mg*, Sr, Cr

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* Position for 1950.

† Index of line width, w.

‡ Number of plates measured/number of plates taken.

§ H_e = effective field intensity in gauss; crossover effect indicated by x̲.

‖ Period in days, or irregular.

Elements showing abnormal line intensity, italicized if variable.

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STELLAR MAGNETIC FIELDS

5i-5. Spectral Observations. Many stars have strong magnetic fields that can be detected and measured by means of the Zeeman effect. This method requires that the spectrum lines be relatively sharp, i.e., not much broadened by stellar rotation, and that the magnetic field be largely coherent as to polarity over the visible hemisphere of the star. The presence of numerous lines of the metals and of the rare-earth elements, showing predictable Zeeman splitting and polarization in a magnetic field, facilitates measurement. Instrumentation includes a rather large telescope for light-gathering power, a differential optical analyzer for polarization, and spectrographic equipment of high dispersion and high resolution. Most of the results to date have been obtained with the 100-, 120-, and 200-in. telescopes and coudé spectrographs of the Mount Wilson, Lick, and Palomar Observatories, respectively. Results have been limited to stars brighter than 8.5 magnitude (photographic). Brighter stars can be observed at higher dispersion (4.5 Å/mm) and with better precision.

Except in a very few instances (e.g., HD215441), the components of Zeeman patterns are not individually resolved, but the use of a differential analyzer for right-hand and left-hand circular polarization permits measurement of the displacement of the centroid of the blended Zeeman pattern when the two modes of polarization are compared. Results are expressed in terms of the effective field H_e. This is the uniform longitudinal magnetic field in gauss that would produce the measured displacement. It has been shown that a uniformly magnetized spherical star, with limb-darkening, viewed pole-on, would have a field strength at the pole equal to 3.3 H_e. By convention, the polarity is taken to be positive when the field vector points toward the observer.

Stars showing strong magnetic fields are mostly of spectral type late B, A, and early F.[1,2] The most outstanding are the stars previously classified as the peculiar stars and spectrum variables of type A, practically all of which show fields in the range of several hundred to a few thousand gauss. All stellar fields adequately tested are found to be variable; many of the variations are periodic. Among the spectrum variables, the magnetic variations, roughly sinusoidal, are synchronous with periodic variations in the intensity of lines of various groups of elements such as the rare earths, chromium, and strontium. These variations are generally attributed to axial rotation of a star carrying an asymmetric distribution of magnetic areas.

The periods of variation are characteristically a few days, but range up to 226 days for HD188041 and 2,350 days for HD187474. Preston[3] has tabulated the periodic magnetic variables as identified in 1967. Of these, 15 show reversals of magnetic polarity; only 3—HD188041, 78 Virginis, and HD215441—show always the same polarity.

The strongest magnetic field yet measured in nature is that of the AOp star HD215441; for this the field at maximum has been measured at 35,700 gauss.

Table 5i-3 summarizes data for 89 magnetic stars as of 1958,[1] except that recently determined periods have been added for several stars from the work of Preston, Renson, Steinitz, and Wehlau.

Table 5i-4 provides data for 38 additional magnetic stars discovered between 1958 and 1966.

Much of the observational and interpretive work on the subject is reviewed by various authors in the Proceedings of the American Astronomical Society–National

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[1] H. W. Babcock, *Astrophys. J.* **128**, 228 (1958).

[2] H. W. Babcock, *Astrophys. J. Supp.* **3** (30), (1958).

[3] G. W. Preston, *Astrophys. J.* **150**, 547 (1967).

TABLE 5i-4. MAGNETIC STAR DATA (FOR STARS DISCOVERED 1958–1966)

Star or HD	R.A.*	Dec.*	m_v	Sp	w	No. of obs.	H_e extremes	
2837	0h29m59s	+43°29′	9.1	A0		1/1		+700 ± 127
5797	0 58 6	+60 14	8.8	A0p		3/3	0 ± 148	+1420 ± 120
9393	1 30 53	+43 41	8.5	A0p		4/4	−1960 ± 272	+2790 ± 170
12288	2 0 14	+09 23	8.0	A0p		4/5	−1345 ± 95	−195 ± 109
16778	2 40 51	+59 40	7.7	B9p(?)		3/6	+21 ± 153	+1620 ± 141
17775	2 50 48	+61 43	8.8	A0p		1/1		+1290 ± 111
18078	2 53 34	+56 1	8.0	A2p	2	3/3	+700 ± 90	+1075 ± 115
24712	3 53 23	−12 13	5.9	A5, F0		3/4	+575 ± 60	+1000 ± 125
50729	6 52 19	− 4 51	9.1	A5p		1/1	−540 ± 88	
51106	6 53 52	− 1 30	7.7	A3p		1/3		+890 ± 190
E Pup 55719	7 10 56	−40 26	5.4	A2		1/1		+1215 ± 150
59435	7 27 42	− 9 10	7.9	A5p		2/2	−430 ± 88	+848 ± 103
89069	10 17 42	+78 59	8.1	(A0p) A3p		6/6	−440 ± 114	+445 ± 112
94660	10 53 12	−42 2	6.3	A0	≈0.1	7/12	−1960 ± 87	−1020 ± 108
115006	13 10 4	+13 13	8.3	A2	≈0.3	2/4	−810 ± 139	−60 ± 143
133652	15 4 7	−30 46	6.0	A0p	≈0.5	1/4	−2080 ± 320	
141988	15 47 53	+62 28	8.3	A2p		4/5	−810 ± 122	+1235 ± 129
143939	16 2 3	−39 20	7.0	B9p	≈0.5	2/3	+690 ± 236	+730 ± 260
162950	17 50 57	+27 12	7.8	A3		1/1	−565 ± 87	
170973	18 30 7	+ 3 38	6.3	A0p		8/8	−1140 ± 71	+755 ± 52
171782	18 34 31	+ 5 15	7.9	A0p		11/16	−1380 ± 130	+1190 ± 181
177984	19 4 45	+ 7 37	9.1	A2p		1/1	−785 ± 110	
179259	19 8 36	+44 30	8.9	A5p		2/3	−540 ± 77	+40 ± 118
183806	19 30 27	−45 18	5.9	A0p	≈0.5	1/3	−720 ± 271	
186343	19 41 17	+22 12	8.2	A2p		1/1	−430 ± 60	
190145	19 58 48	+67 22	7.4	A2p		1/2	−580 ± 77	
190068	20 0 52	+15 15	8.0	A0p	0.4	4/4	+990 ± 192	+1780 ± 183
189932	20 1 3	−33 54	6.9	F0p		1/4		+525 ± 86
355163	20 10 44	+13 52	8.7	A0p		1/1		+790 ± 228
192687	20 13 47	+13 43	8.6	A2	≈0.3	1/2		+1120 ± 264
+29°4202	20 49 3	+29 39	8.8	A0p		4/4	−1520 ± 90	+1500 ± 134
200311	20 59 47	+43 54	7.9	(A0p) B9p		7/13	−1900 ± 159	+760 ± 139
201174	21 4 56	+45 6	8.5	A0p		27/32	−1825 ± 143	+1765 ± 177
204411	21 25 26	+48 40	5.3	(A3p) F0?		5/6	−515 ± 41	+665 ± 70
212385	22 22 16	−39 20	6.9	A2p		1/2	−1260 ± 319	
215441	22 42 42	+55 22	8.6	A0p		28/37	+4100 ± 370	+35, 700
220147	23 19 3	+62 11	7.6	B9p		4/5	−835 ± 151	+735 ± 138
221568	23 30 55	+57 41	8.0	A0p		6/8	−225 ± 172	+470 ± 69

* Position for 1960.

Aeronautics and Space Administration Symposium held at Greenbelt, Maryland, in 1965.[1] The book is replete with references.

GALACTIC MAGNETIC FIELD

5i-6. Summary. Some of the gross features of the galactic magnetic field have been inferred from information related to cosmic rays (cf. Ginzburg and Syrovatskii, 1964). A comparison of the observed cosmic-ray electron spectrum with the nonthermal radio spectrum arising from galactic synchrotron radiation indicates (Okuda and Tanaka, 1968) that the magnetic field is 10 to 20 microgauss near the galactic center, 5 to 10 microgauss near the solar system, and $\gtrsim 2.5$ microgauss for the halo. Dynamical considerations (Parker, 1968) of the cosmic-ray pressure, due mainly to energetic protons, suggest that the average field of the disk is about 5 microgauss.

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[1] "The Magnetic and Related Stars," Robert C. Cameron, ed., Mono Book Corporation, Baltimore, 1967.

Polarization measurements (cf. van de Hulst, 1967) of galactic nonthermal radio emission indicate that the coherence scale of the magnetic field of the disk is about 10^2 light years. The Faraday rotation measure for the polarization of distant discrete radio sources varies quite smoothly with galactic coordinates (Morris and Berge, 1964; Gardner and Davies, 1966) and corresponds to a field whose lines of force run parallel to the galactic plane in the direction $l^{II} \approx 70°$ for $b^{II} > 0$, while below the plane ($b^{II} < 0$) the direction of the field is opposite. These directions are in general agreement with the studies of the polarization of starlight by magnetically aligned interstellar grains (Smith, 1956; Behr 1959) and with the direction of the local Orion spiral arm (Sharpless, 1965). A search (Verschuur, 1968) for the Zeeman splitting of the 21-cm-absorption line by the atomic hydrogen of this local arm yields a limit to this HI-associated field as 0.6 ± 0.9 microgauss. A relatively strong magnetic field of 20 microgauss in the Perseus spiral arm, in the direction of Cassiopeia A, was clearly detected by the Zeeman effect in the course of the same observations. This measurement of a strong HI-associated magnetic field suggests that the search for detectable Zeeman effects in other absorption or emission spectra throughout the galactic disk should yield much new information.

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