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RESULTS OF A HOMOGENEOUS SURVEY OF ABSORPTION LINES IN QSOs OF SMALL AND INTERMEDIATE EMISSION REDSHIFT

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ABSTRACT

Results are presented for a spectroscopic survey of an intermediate ($1.20 < z_{em} < 1.95$) and a low ($0.40 < z_{em} < 1.20$) redshift sample, together comprising 66 QSOs. The characteristics and statistics of the incidence of absorption from the C IV and Mg II doublets are discussed. The data indicate that the absorption systems in quasars have three different origins, with each mechanism dominant within a different range of the redshift interval $z_{em} - z_{abs}$. Statistically, absorption systems which are displaced by more than about 20,000 km s^{-1} from the emission redshift are due to intervening material. We find that these systems do not show a significantly nonrandom distribution in redshifts and that the corresponding cross section for intervening galaxies must be of the order of 100 kpc to produce the observed absorption. Absorption systems with $z_{abs} > z_{em}$ have a velocity dispersion very similar to that expected if the absorbing material and the QSO are members of clusters of galaxies, and we interpret systems with $|z_{em} - z_{abs}| \lesssim 3000$ km s^{-1} as predominantly associated with galaxy clusters. The remaining absorption is due to material ejected by the QSO. We suggest that broad-line absorption systems are recently ejected gas which eventually evolves into multiple sharp-line systems, two examples of which are found in our survey. It is suggested that the distribution of C IV and Mg II absorption systems in redshift can be explained by assuming that the absorbing gas in intervening clusters of galaxies is the same as the gas in clusters which contain QSOs, with the exception that the QSO–containing cluster gas has higher ionization.

Subject headings: galaxies: intergalactic medium — line identifications — quasars

I. INTRODUCTION

Three years ago we began a systematic spectroscopic study of QSOs which have intermediate emission-line redshifts. We obtained data which were homogeneous in terms of the equipment used and the observing techniques. The object of the survey was to provide a valid sample for the statistical analysis of absorption lines occurring in a group of QSOs which had not been extensively studied before. We later enlarged the program by initiating a second survey of objects with lower emission-line redshift.

Neither of the surveys is yet complete. However, because the surveys are time consuming and because we believe the main results are now well established despite the fact that the surveys are not finished, we have decided to publish the results as they stand at present, since they have already been alluded to several times in the literature.

Section II describes the samples and the observing technique, § III presents the raw data on the incidence and distribution of the absorption lines, § IV contains some statistical analysis and an interpretation of the results, and § V summarizes our conclusions concerning the origin of QSO absorption-line systems in light of our survey and other existing data.

II. DEFINITION OF THE SAMPLE AND OBSERVING TECHNIQUE

a) *Intermediate Redshift Sample*

The absorption-line systems of QSOs with $z_{em} \gtrsim 1.96$ are often very rich and complex, and they have been the object of numerous individual studies. In spite of this intensive effort, the identification of the lines and the origin of the absorbing gas remain uncertain. By contrast, the study of objects of lower redshift at moderate resolution (2 Å) has been relatively neglected. The reason for this is that the incidence of absorption lines in QSOs drops as Lα becomes inaccessible, and hence a large amount of telescope time yields such a small number of systems that the statistical uncertainties are large. The study of such quasars with relatively simple spectra does have advantages, however, because line identification in lower redshift objects is rarely a problem. In particular, at moderate dispersions the C IV λ1549 and Mg II λ2798 doublets are easily resolved, and the measurement of the appropriate wavelength ratios is enough to make doublet identification virtually certain. Therefore, we decided to investigate the properties of absorption in QSOs by studying those systems in objects of intermediate redshift.

The UV response of the Steward spectrograph and image-tube system is relatively good, and well-exposed plates down to ~3400 Å are not difficult to obtain. We therefore defined the low end of an "intermediate redshift" sample to be $z_{em} = 1.20$, at which redshift the C IV doublet occurs at 3405 and 3410 Å. In order to minimize the line identification problem, the upper end of our emission-line redshift limit was arbitrarily chosen to be 1.95, and several rich-line objects (e.g., PHL 938) having emission redshifts slightly above this value were not included in our study.

For our survey, we defined a magnitude-limited sample by selecting all objects in the catalog of Burbidge, Crowne, and Smith (1977, hereafter BCS) north of $\delta = -20°$, having $1.20 \leq z_{em} \leq 1.95$ and $m_V \leq 18.0$. At the dispersion used in this study exposure times become uncomfortably long ($\gtrsim 2\frac{1}{2}$ hours, at which point the plates generally become of poorer quality) for objects fainter than $m_V = 18$. Unfortunately, the magnitude estimates given in the BCS catalog are not very homogeneous, and we therefore proceeded as follows: (*a*) Finding charts were made for all objects with published identifications which were listed as 18th mag or brighter. (*b*) Highest priority was given to observing those objects listed as being brighter than 18.0 (we refer to these objects as our "primary sample"). Occasionally, after setting on an object and obtaining a count rate from the spectrograph exposure meter, it became clear that the QSO was definitely fainter than 18.0, in which case no attempt was made to observe it. (*c*) Lower priority was given to those objects listed in the BCS catalog as having magnitude $m_V = 18.0$, and we refer to these as the "secondary sample." We attempted to obtain spectra of objects in the secondary sample only when there were gaps in R.A. in the primary program objects, especially when inspection of the objects on the finder chart or TV acquisition system suggested that the QSO was actually brighter than 18.0.

b) Low Redshift Sample

During the course of the survey of intermediate redshift objects, we found a number of Mg II absorption lines. A brief description of several of these systems has been given by Burbidge *et al.* (1977*b*). We decided to observe objects of still lower redshift to see if the incidence of the Mg II lines was dependent upon emission-line redshift. Accordingly, we defined a low redshift sample as follows: all objects in the BCS catalog north of $\delta = -15°$, brighter than $m_V = 17.0$, and having emission-line redshifts in the regime $0.40 < z_{em} < 1.20$.

c) Observing Technique and Homogeneity of the Sample

All spectra were obtained with baked IIa-O emulsion (60° C for 4 hours in dry nitrogen) and developed in MWP-2. The two-stage RCA C33063 image tube was used with the image-tube spectrograph attached to the Cassegrain focus of the Steward Observatory 2.3 m telescope. The plates were driven perpendicular to the dispersion to widen the spectra, and a metal mask with a 150 μm wide slot was placed immediately in front of the spectrograph focal plane to suppress tube noise.

With a few exceptions noted below, all plates were taken using an 832 g mm^{-1} grating in second order, giving a dispersion of 47 Å mm^{-1} and a resolution (FWHM) of about 2.5 Å. No filters were used; therefore, contamination by the first-order continuum usually became noticeable below about 3150 Å.

Each plate covered a wavelength range of about 900 Å with adequate density and good definition. However, the spectral coverage is quite sensitive to the alignment of the mask because of S distortion in the image tube, and there are variations in the coverage for this reason. Since we were interested in examining the spectral region of the C IV emission line for each object in the intermediate redshift sample (and, where feasible, the Mg II emission region in the low redshift sample), the wavelength coverage depended upon the emission-line redshift.

For a few of the objects in the upper end of the low redshift sample we used the spectrograph in a cross-dispersed mode (Carswell *et al.* 1975) in order to increase the coverage, especially to the red, where the 832 line grating efficiency is poor. The resolution in this echellette mode is about 28% higher than the 832 line grating at 3400 Å, about the same at 4600 Å, and about 21% lower at 5800 Å, which is about the useful red limit for the RCA tube. The average resolution and limiting detectable equivalent width for the spectra of these few objects in the low redshift sample is therefore not very different from the 832 line grating data.

As mentioned above, it has been our experience that the quality of the spectra generally becomes noticeably poorer when exposure times exceed about $2\frac{1}{2}$ or 3 hours because of tube noise and mechanical and magnetic flexure. The plates were usually taken with a slit width of 200 μm, corresponding to 2″.0, and widened 0.4 mm. Under poor seeing conditions, we occasionally shortened the trailing to 0.35 mm in order to shorten the exposure. Even under nearly identical situations, we have found that the plates differ noticeably in quality, and this random variation is larger than the systematic difference between 0.4 and 0.35 mm widened spectra. We have attempted to account for the influence of this variation in the quality of the data on our conclusions by visually inspecting each plate and estimating the wavelength interval over which the density of the exposure, quality of the focus, and freedom from magnetic flexure, plate-driven failure, or other flaws are such as to constitute "good quality" data. Similarly, we have judged the wavelength interval over which the data appeared to be of only "fair quality." Microdensitometer tracings of representative material suggests that the limiting detectable equivalent widths for a single plate are about 0.6 Å for the good quality plates and about 1.0 Å for the fair quality plates.

All absorption lines in our spectra which we have judged to be almost certainly real have been noted, and their wavelengths measured on a Grant measuring engine. We have also attempted to classify the absorption-line strengths as "weak," "medium," or "strong." It must be borne in mind that this classification is quite subjective and is based only upon visual inspection. Moreover, the estimate depends upon the quality of the data. For example, a weak line in the good quality data is not generally visible, or is just marginally detectable, in a spectrum of "fair quality."

d) *Completeness and Bias of the Samples*

In the BCS catalog there are 57 objects falling in our primary ($m_V < 18.0$) sample of intermediate redshift QSOs. We have obtained plates of 41, or 72%, of these objects. Two of the objects not observed, OQ 135 and 4C 60.15, were inspected on the TV acquisition system and judged to be definitely fainter than magnitude 18.0 at the time we attempted to observe them. Of the remaining primary objects for which we have no data, most of them are in the R.A. range 15^h–01^h, where generally poor weather conditions the past several years have made their observation difficult. There are an additional 32 objects in our secondary ($m_V = 18.0$) sample of intermediate redshift objects, of which we have observed only 4, or 13%. In the remainder of the discussion we will not distinguish further between the secondary and primary samples of QSOs with intermediate redshift.

There are 37 objects in the BCS catalog satisfying our criteria for the low redshift sample, and we have observed 21, or 57%, of these objects.

Although our study of both the low and intermediate redshift samples is incomplete, this incompleteness is not important as long as there is no serious bias involved in the selection of objects affecting the incidence or distribution of absorption redshifts. In particular, we have avoided preferentially observing objects know to have, or suspected from previous lower resolution investigations to have, absorption lines. Other things being equal, however, we did show a slight preference for observing objects at the higher end of the redshift limit, especially near the faint limit of the sample. As a consequence, the spread in luminosity of the observed set of QSOs is slightly smaller than in the total sample of survey objects.

III. RESULTS OF THE SURVEYS

The list of objects in both surveys for which at least "fair quality" data has been obtained is presented in Table 1. The coordinate designation, other name, emission-line redshift, and apparent visual magnitude are given in columns (1)–(4) of Table 1, as given in the BCS catalog, unless noted in the notes at the end of the table. Columns (5) and (6) list the wavelength coverage for the good quality data for each object, and columns (7) and (8) give the coverage of the fair quality data. Column (9) indicates the presence of one or more C IV or Mg II absorption doublets (labeled "C" or "Mg"), or absorption lines in the neighborhood of, or shortward of, the Lα emission line. An "H" indicates that the line falls in the expected position for Lα in a C IV system, while an "H?" indicates no corresponding C IV lines. An "E" in column (10) indicates that the material is based only on cross-dispersed echellette plates. The numbers in column (10) refer to notes at the end of the table, and a "U" in the last column indicates the presence of unidentified lines longward of Lα emission, whose wavelengths are given in the notes.

Further details concerning the absorption-line systems found in the survey are presented in Tables 2 and 3, which list those objects containing at least one C IV or one Mg II doublet, respectively. Columns (1) and (2) identify the QSO by coordinate designation and give the emission-line redshift. The next column of Table 2 gives the absorption-line redshifts of systems we have identified, followed by a "G" or "F" to indicate the quality of the material. This is followed by an eye estimate of the strength of the C IV absorption (weak, "W"; medium, "M"; or strong, "S") and its width ("b" = broad). For example, "Sb" indicates a strong, broad feature.

We have examined the plates of those quasars in which we have found C IV absorption, looking for possible absorption in the same system from four other lines of interest: N V λλ1238, 1242; Si IV λλ1393, 1402; C II λ1334; and Lα λ1216. The results of this search are summarized in the same manner as that used for the C IV doublet, except that an "N" in the column for the line in question indicates that the wavelength coverage did not extend to the expected wavelength of that line. An "A" in the strength column indicates that the line is absent. Table 3 is similar to Table 2, except that only the Fe II line at λ2600 was searched for in the same systems as detected Mg II doublets.

The occurrence of absorption lines other than C IV may be summarized as follows:

a) We found no system which shows either N V, Si IV, or C II without also showing C IV, although it is possible that a single very weak C II line might have been missed unless Si II λ1260 was also accessible.

b) In six of the 12 C IV systems in which N V is accessible, N V absorption is seen. In three of the cases in which it is not seen, C IV is weak; in only one case is N V not seen in a strong C IV system (in 1756+237).

c) Lα absorption is seen in all 10 of the C IV systems in which the Lα line is accessible.

d) Si IV absorption is observed in 12 out of the 45 C IV absorption systems in which the Si IV is accessible.

e) C II absorption appears in five of the 30 C IV systems in which it might be seen.

Although the survey was not designed to cover the Lα region, we find that out of the 12 objects in which Lα absorption would be observable within ±3000 km s^{-1} of the emission-line redshift, absorption (presumably Lα) is seen in nine of them. The three objects not showing Lα absorption within 3000 km s^{-1} of the emission are 0854+191, 1517+239, and 1634+176. The quality of the spectra of 1517+239 and 1634+176 in the Lα region is only fair, and 1517+239 has a possible Lα absorption feature at −3400 km s^{-1}. We will comment briefly on the possible significance of some of these characteristics in § V.

IV. STATISTICAL PROPERTIES OF THE ABSORPTION-LINE SYSTEMS

a) *Proposed Classification Scheme*

Most discussions of the origins of QSO absorption systems have considered three basic mechanisms for

TABLE 1

CHARACTERISTICS OF SURVEY OBJECTS

Coordinate Designation	Other Name	z_{em}	V^{mag}	λ_{min}(Å) Good	λ_{max}(Å) Good	λ_{min}(Å) Fair	λ_{max}(Å) Fair	Sys-tems	Notes
0024+224	NAB	1.118	16.60	3250	4070	3250	6000	1C	E
0051+291	4C 29.01	1.832	17.80	3500	4600	3500	4600		1
0132+205	NAB	1.782	17.50	3750	4650	3550	4700		
0151+048	PHL 1222	1.903	17.63	3375	4300	3300	4300	4C,1H	2
				4475	5000	4475	5000		
0232-042	4C-04.06	1.436	16.46	3350	4200	3200	4200		
0333+321	4C 32.14	1.258	17.50	--	--	3200	4075		
0349-146	3C 95	0.614	16.22	3700	4650	3550	4650		
0350-073	3C 94	0.962	16.49	3400	6000	3250	6000		E
0414-060	3C 110	0.781	15.00	--	--	3500	4850		E
0454+039	PKS	1.345	16.50	3300	4875	3300	4875	1C	1
0710+118	3CR 175	0.768	16.60	4100	4925	3850	5025		
0742+318	3C 31.30	0.462	16.00	3200	4200	3200	4200		
0835+580	3CR 205	1.532	17.62	--	--	3400	4350	2C	3
0836+195	4C 19.31	1.691	17.60	--	--	3500	4275		
0843+136	4C 13.39	1.875	17.80	3300	4700	3300	4700	Mg,1H?	
0848+164	LB 8775	1.932	16.90	3650	4675	3250	4675	1C,1H	U4
0854+191	LB 8956	1.891	17.60	3475	4675	3475	4675	1C	U5
0856+170	4C 17.46	1.449	17.40	3400	4300	3300	4300	2C	
0856+189	LB 9029	1.286	17.70	3350	4100	3350	4100		
0859-140	PKS	1.327	16.59	--	--	3200	4075		
0952+179	AO	1.472	17.23	3200	4375	3200	4375	1 Mg	
0955+326	3C 232	0.533	15.78	3275	4475	3275	4475		6
0958+550	Mkn 132	1.757	16.00	3300	4300	3300	4300	2C	7
0959+105	M	1.530	17.50	3500	4275	3400	4275		
1011+250	Ton 490	1.631	15.40	--	--	3225	4400	2C	
1038+064	4C 06.41	1.270	16.81	3300	4375	3200	4475	1 Mg	
1055-045		1.430	17.00	3600	4400	3400	4400		
1103-006		0.426	15.40	3190	4275	3190	4275		
1104+167	4C 16.31	0.634	15.70	3650	4675	3500	4675		
1126+101	PKS	1.515	18.00	3200	4250	3200	4250	2C	11
1211+334	B2	1.598	17.00	3500	4400	3400	4475		
1215+113	MC 2	1.396	16.50	3375	4300	3375	4300		
1229-021	PKS	1.038	16.75	3750	4300	3600	4500	1 Mg	1
1246+377	BSO 1	1.241	16.98	3200	4150	3200	4150	1C	
1256+357	B 194	1.882	17.96	3475	4675	3440	4615	4C,2H	3
1257+346	B201	1.375	16.79	3200	4200	3200	4200		
1258+286	WG 1972	1.922	17.75	3480	4700	3480	4700	2C,1H	U8
1301+307	W 33211	1.709	17.56	3700	4475	3400	4475		
1303+308	W 22722	1.770	17.85	3600	4300	3600	4450	8C	
1308+182	4C 18.36	1.689	17.50	3700	4550	3550	4550		
1309+340	BSO 8	1.750	17.43	3700	4475	3500	4475		
1317+277	Ton 153	1.022	15.30	3400	4350	3325	4350		
1318+291	Ton 155	1.703	16.90	3700	4500	3500	4675		
1318+291	Ton 156	0.549	16.40	3700	4650	3500	4750		
1354+195	4C 19.44	0.720	16.02	3825	4950	3825	4950	1Mg	
1416+067	3C 298	1.436	16.79	3200	4275	3200	4275	2C	3
1416+159	MC 3	1.472	17.00	3475	4450	3475	4450	2C	
1421+330	Mkn 679	1.904	16.50	3480	4750	3480	4750	1C	
1511+103	MC 2	1.546	17.00	--	--	3900	4275		
1517+239	LB 9612	1.901	16.40	3750	4600	3500	4675	1H?	
1523+214	LB 9707	1.924	16.90	3500	4650	3450	4650	3H?	
1556+335	GC	1.650	17.00	3175	4400	3175	4400	4C,3H,2H?	
1559+173	4C 17.65	1.944	18.00	3750	4675	3500	4675	1C,1H,1H?	
1634+176	MC 3	1.897	18.00	--	--	3500	4650		
1641+399	3C 345	0.595	15.96	--	--	3500	4700		
1756+237	PKS	1.721	18.00	3250	4550	3200	4850	4C,2H,2H?	9, 11
1828+487	3CR 380	0.692	16.81	3500	4800	3400	5500		E
2044-168	PKS	1.943	16.90	3900	4300	3650	4575	1C	U10
2120+168	3CR 432	1.805	17.96	3850	4550	3500	4700		
2128-123	PKS	0.501	15.98	3500	4425	3450	4425	1Mg	
2145+067	4C 06.69	0.990	16.47	3400	6000	3300	6000		E
2216-038	4C-03.79	0.901	16.38	--	--	3650	5600		E
2251+158	3CR 454.3	0.859	16.10	3500	5500	3300	5500		E
2308+098	4C 09.72	0.432	15.00	3400	3900	3300	4400		
				4200	4400	3300	4400		
2335-181	PKS	1.441	17.50	3400	4225	3200	4225		
2344+092	4C 09.74	0.677	15.97	3200	5500	3200	5900		E

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NOTES TO TABLE 1

1. Description of spectra and emission redshifts from Burbidge *et al.* 1977*b*.
2. Description of spectrum and emission redshift from Williams and Weymann 1976.
3. Description of spectra and emission redshifts from Weymann *et al.* 1977.
4. Weak line at λ3604. Possible additional C IV doublets at λλ3825, 3831 and λλ4436, 4443.
5. Possible additional C IV doublet at λλ4228, 4235; however, on both plates λ4235 appears stronger than λ4228.
6. The Ca II lines in this object discussed by Boksenberg and Sargent 1978 are not visible on our plates.
7. Emission redshift from Adams *et al.* 1978.
8. Possible additional C IV doublet at λλ4032, 4040.
9. Description of spectrum contained in Turnshek *et al.* 1979.
10. Possible additional C IV doublet at λλ3960, 3965.
11. These objects appeared brighter than $m_V = 18.00$ at the time of observation.

TABLE 2

OBJECTS WITH C IV SYSTEMS

			C IV		N V		Si IV		C II		Lα	
OBJECT (1)	z_{em} (2)	z_{abs} (3)	Data (4)	Str (5)	Data (6)	Str (7)	Data (8)	Str (9)	Data (10)	Str (11)	Data (12)	Str (13)
0024+224	1.118	1.109	G	W	N	...	N	...	N	...	N	...
0151+048	1.910	1.934	G	W	G	A	G	A	G	M	G	Sb
		1.618	G	S	N	...	G	A	G	A	N	...
		1.561	G	W	N	...	G	A	G	A	N	...
		1.467	G	M	N	...	G	A	N	...	N	...
0454+039	1.345	1.154	G	M	N	...	N	...	N	...	N	...
0835+580	1.532	1.544	F	S	N	...	F	A	N	...	N	...
		1.536	F	W	N	...	F	A	N	...	N	...
0848+164	1.932	1.917	G	Sb	F	Mb	F	A	F	A	F	Sb
0854+191	1.891	1.354	G	Mb	N	...	G	A	N	...	N	...
0856+170	1.449	1.463	G	W	N	...	G	A	N	...	N	...
		1.383	G	W	N	...	G	A	N	...	N	...
0958+550	1.578	1.732	G	M	N	...	G	A	N	...	N	...
		1.272	G	M	N	...	G	A	N	...	N	...
1011+250	1.631	1.599	F	W	N	...	F	A	F	A	N	...
		1.457	F	W	N	...	F	A	F	A	N	...
1126+101	1.515	1.516	G	S	N	...	G	A	G	A	N	...
		1.438	G	M	N	...	G	A	G	A	N	...
1246+377	1.241	1.243	G	Sb	N	...	N	...	N	...	N	...
1256+357	1.864	1.898	G	Sb	G	Mb	G	A	G	A:	G	Sb
		1.832	G	Mb	G	Blend	G	Wb	G	A	N	...
		1.803	G	S	G	M	G	A	G	A	N	...
		1.281	G	W	N	...	N	...	N	...	N	...
1258+286	1.922	1.893	G	W	G	A	G	A	G	A	G	S
		1.464	G	M	N	...	G	A	N	...	N	...
1303+308	1.770	1.775	G	W	N	...	G	A	G	A	N	...
		1.763	G	M	N	...	G	A	G	A	N	...
		1.746	G	M	N	...	G	M	G	A	N	...
		1.728	G	Sb	N	...	G	Mb	G	W:	N	...
		1.708	G	S	N	...	G	Mb	G	A	N	...
		1.691	G	Sb	N	...	G	Mb	N	...	N	...
		1.671	G	M	N	...	G	W	N	...	N	...
		1.661	G	M	N	...	G	A	N	...	N	...
1416+067	1.436	1.441	G	S	N	...	G	A	G	A	N	...
		1.434	G	S	N	...	G	A	G	A	N	...
1416+159	1.472	1.478	G	S	N	...	G	A	N	...	N	...
		1.473	G	M	N	...	G	A	N	...	N	...
1421+330	1.904	1.462	G	S	N	...	G	A	G	A	N	...
1556+335	1.650	1.652	G	M	G	W	G	W	G	Wb	G	Sb
		1.644	G	Mb	G	Wb	G	A	G	A	G	Sb
		1.610	G	M	G	A	G	W	G	A	G	M
		1.602	G	M	G	A	G	A	G	A	N	...
1559+173	1.944	1.961	G	Sb	F	Mb	G	Wb	G	A	F	Mb
1756+237	1.721	1.723	G	Wb	G	A	G	A	G	A	G	S
		1.673	G	Sb	G	A	G	S	G	S	G	Sb
		1.612	G	M	F	Blend	G	W	G	A	N	...
		1.460	G	S	N	...	G	M	G	W	N	...
2044−166	1.943	1.918	F	Wb	N	...	F	A	F	A	N	...

TABLE 3

OBJECTS WITH Mg II SYSTEMS

			Mg II		Fe II	
OBJECT (1)	z_{em} (2)	z_{abs} (3)	Data (4)	Str (5)	Data (6)	Str (7)
0848+136..........	1.875	0.6069	G	M	G	M
		0.6054	G	W	G	A
0952+179..........	1.472	0.2378	G	M	G	A
1038+064..........	1.270	0.442	G	W	G	A
1229−021..........	1.042	0.395	G	S	F	A
1354+195..........	0.720	0.457	G	M	N	...
2128−123..........	0.501	0.430	G	W	G	A

their formation: (*a*) absorption due to intervening gas from a cosmologically distant system that is not associated in any way with the QSO; (*b*) systems produced by clouds ejected from the QSO; and (*c*) absorption from gas associated with a cluster of galaxies of which the QSO is a member.

Most of the situations which are likely to produce absorption in QSOs can be grouped into one of these categories. In fact, we will argue that the results of this survey can be interpreted in terms of these three types of absorption by demonstrating that the classification scheme is consistent with the statistical and physical properties of the systems we have observed.

We introduce the classification of absorbing systems before discussing the data because it provides a framework for statistical tests which can be applied to the data. With the working hypothesis that the absorbing gas is either intervening, ejected, or associated cluster material, we now consider some of the expected properties of each type of system.

b) *Properties of Intervening Systems*

The fundamental parameter that can be determined from the incidence of absorption by intervening systems is the effective cross section of the galaxies, or halos, etc., required to produce the observed systems, and the corresponding density of the absorbing material. In deriving these quantities from our survey material, we will initially treat all our data as homogeneous and will follow the treatment of Burbidge *et al.* (1977*a*). However, we will briefly indicate the differences in derived values when the effects of inhomogeneities in the quality of the data are allowed for.

When considering those absorption systems which are intervening, we must discriminate against the ejected and associated cluster systems. On the basis of the distribution of absorption redshifts in our data, we will present evidence that the likelihood of absorption being due to cosmologically intervening material becomes highest for systems with $z_{em} - z_{abs}$ corresponding to a velocity difference from the QSO of greater than about 18,000 km s^{-1}. Accordingly, we define a redshift z_{eject} for each QSO which represents an approximate limit to the displacement of ejected systems, such that

$$\frac{1 + z_{eject}}{1 + z_{em}} = \left(\frac{1 - \beta}{1 + \beta}\right)^{1/2} , \quad (1)$$

where $\beta = 0.06$. We will restrict our analysis to those systems with $z_{abs} < z_{eject}$ in order to avoid strong contamination from the other two types of systems.

For each QSO, we have determined the minimum observable redshift at which a line of rest wavelength λ_0 can be seen, $z_{min} = (\lambda_{min}/\lambda_0) - 1$, where λ_{min} is the short wavelength limit of our spectral coverage for the object, as given in Table 1.

We assume that detectable absorption lines are produced whenever the line of sight passes near the center of an object (e.g., a galaxy) having an effective cross section σ. We neglect the possibility that the effective cross section may change systematically with redshift, and we further assume that there is no change in the comoving density of absorbers. That is, we assume that the proper density of absorbers at redshift z, $n(z)$, is equal to $n_0(1 + z)^3$, where n_0 is the present epoch density. Then, the total number N of absorption systems in our sample satisfying $z_{min} < z_{abs} < z_{eject}$ is

$$N = n_0 \sigma c H_0^{-1} \sum l_i , \quad (2)$$

where for the ith QSO, the dimensionless mean free path l_i over which we could detect absorption by a particular line from intervening gas is

$$l_i = \tfrac{1}{2}[(1 + z_{eject})_i^2 - (1 + z_{min})_i^2] \quad \text{for } q_0 = 0 , \quad (3)$$

$$l_i = \tfrac{2}{3}[(1 + z_{eject})_i^{3/2} - (1 + z_{min})_i^{3/2}] \quad \text{for } q_0 = \tfrac{1}{2} . \quad (4)$$

Equations (2), (3), and (4) can then be used to calculate the required value of the mean free path between absorbing clouds $\langle l \rangle = (n_0 \sigma)^{-1}$ at the current epoch needed to produce the observed number of systems in our sample.

In order to obtain some idea of the effect of inhomogeneities in the quality of the data on our derived present epoch mean free path, we have performed separate analyses of the spectral data we considered "good" and those which were only of "fair" quality.

The numbers we have derived which are designated "good" have been obtained by determining the total path length to systems observed in the wavelength regions where the data were considered good (cf. Table 1). Conversely, we have also derived the mean distance between absorbing systems using only those systems which were strong enough to have been detected on data of "fair" quality, but in which the total path length was based upon both the "fair" and "good" quality data.

The results for the mean distance between absorbing systems can be expressed in terms of a mean density of absorbing gas in the form of intervening clouds, $\langle \rho_{\rm cld} \rangle$, by adopting an average column density of C IV and Mg II in the systems, and a metals/hydrogen abundance. Typically, the equivalent widths of these lines were about 1–1.5 Å (observed frame). Assuming that the lines are *unsaturated*, that the abundances are solar, and that C IV and Mg II are the dominant ions of these elements, then the typical hydrogen column densities of the C IV and Mg II systems we have observed are 3×10^{17} cm^{-2} and 4×10^{17} cm^{-2}, respectively. However, the lines typically show some degree of saturation and the actual column densities are probably frequently an order of magnitude higher. We therefore adopt 3×10^{18} cm^{-2} as being representative. We can then express the resulting values of $\langle \rho_{\rm cld} \rangle$ in units of the present epoch mean density of all matter in galaxies, $\langle \rho_{\rm gal} \rangle$, which we have taken to be $\langle \rho_{\rm gal} \rangle = 0.08 \langle \rho_{\rm clos} \rangle$ (Gunn 1979). This mean density for absorbing matter is independent of any assumptions regarding the association of the gas with galaxies or clusters of galaxies.

If the absorption systems are produced by galaxies, an estimate can be made of the required sizes of the galaxies by defining an "effective radius" such that any line of sight passing within the radius produces an observable absorption line (Burbidge *et al.* 1977*a*). We adopt Schechter's (1976) form of the luminosity function for galaxies,

$$\phi(L)dL = \phi^*(L/L^*)^{-5/4} \exp(-L/L^*) d(L/L^*) , \quad (5)$$

where L^* is the luminosity corresponding to $M_B{}^*(0) = -20.6$. The normalization factor ϕ^* is taken as half the value suggested by Felten (1977) as appropriate outside the local supercluster. The factor of $\frac{1}{2}$ is intended to allow for the fact that some objects might not be expected to have such clouds associated with them (e.g., ellipticals). Then, $\phi^* = \frac{1}{2}(2.2 \times 10^{-3}) = 1.08 \times 10^{-3}$ Mpc^{-3}. We assume that the effective galaxy radius scales as $r \sim L^{0.4}$ (Peterson, Strom, and Strom 1979), which is more appropriate for the fainter outer isophotes than is the use of the Holmberg radius–luminosity relation. Integrating over the luminosity function, together with the empirically determined mean free paths, then determines the effective value of R^* required for absorption to be produced by an L^* galaxy. A further increase of $\sqrt{2}$ in the effective radius of the galaxy would be required if we were to assume that the galaxies were flat disks rather than spherical halos, but this factor has not been included.

The results for the mean free paths, mean densities, and effective radii of absorbing systems required to produce the systems we observe are summarized in Table 4.

Several remarks need to be made concerning Table 4. *First*, as in Burbidge *et al.* (1977*a*), the effective radius required to produce absorption, especially for the case of the C IV doublet, is very much larger than that associated with the "Holmberg radius," which is $R_{\rm Holm}{}^* \approx 16$ kpc. Because of this, in searching for galaxies with which such clouds might be associated, we do not generally expect the galaxy center to be seen directly in front of the QSO. *Second*, the assumption made in deriving the effective radius is that any line of sight passing within this distance from the galaxy center *always* intersects a cloud producing observable absorption. The material must almost certainly be somewhat patchy, and the actual mean distance of the clouds to the nearest galaxy nucleus would have to be somewhat larger. *Third*, we must strongly emphasize that the parameters presented in Table 4 apply only to *our* sample at *our* level of detection. The "effective radius" for detecting intervening Lyman lines from neutral hydrogen is much higher, and even a moderate decrease in the limiting equivalent widths in our sample will probably result in additional C IV and Mg II systems, requiring an increase in the effective radius. This is strikingly borne out in a comparison of our data for Markarian 132 with the study by Adams *et al.* (1978), who used the echellette mode (giving about a 28% increase in resolution in the far-UV) and co-added several plates: they detected substantially more lines than we did.

There are a large number of statistical tests which can, in principle, be carried out to check on the intervening hypothesis for this class of absorption system. Unfortunately, our sample is still so small that none of the tests is very powerful, and in the case of the Mg II systems we make only the following observations: it has been suggested (Perry, Burbidge, and Burbidge 1978, hereafter PB^2) that, over the same *absorption* redshift range, highly displaced Mg II doublets occur more frequently in high redshift objects than in our low and intermediate redshift objects, and there is also a suggestion by Miller (cf. PB^2) that they occur more frequently in very *active* radio sources, e.g., two in AO 0235+134 and one in 0735+178, than in *normal* radio or radio-quiet sources. If either of these suggestions was to prove to be true, we would obviously have to reject the intervening hypothesis for highly displaced systems. Our data do not shed any light on the possible association of Mg II with active radio sources except to provide an unbiased and relatively uniform sample from which to compute a mean free path at our limiting equivalent width.

With regard to the suggested correlation of Mg II absorption with high redshift QSOs, if we order our survey objects according to increasing emission-line redshift, we can determine that point in our sample where half of the total path length to the QSOs has been accumulated. In our total sample of objects, this occurs at $z_{\rm em} = 1.45$ (for $q_0 = 0$), and three of the five

TABLE 4

PRESENT EPOCH MEAN FREE PATHS, MEAN DENSITIES, AND EFFECTIVE CROSS SECTIONS

	C IV[a] Data			Mg II[a] Data			
	All	Good	Fair	All	Good	Fair	q_0
Number systems	11	10	9	5[b]	5[b]	4[b]	
Mean free path (Mpc)	1.81 (4)	1.42 (4)	2.21 (4)	4.32 (4)	3.23 (4)	5.40 (4)	0.0
	1.17 (4)	9.23 (3)	1.43 (4)	3.62 (4)	2.71 (4)	4.53 (4)	0.5
$\rho_{\rm cld}/\rho_{\rm gal}$	3.3 (−4)	4.3 (−4)	2.7 (−4)	1.4 (−4)	1.9 (−4)	1.1 (−4)	0.0
	5.2 (−4)	6.6 (−4)	4.2 (−4)	1.7 (−4)	2.2 (−4)	1.3 (−4)	0.5
Radius of L^* galaxy (kpc)	100	113	91	65	75	58	0.0
	125	141	113	71	82	63	0.5

[a] Only systems with $V_{\rm eject} > 18{,}000$ km s^{-1} included.

[b] The two Mg II systems in 0843+136 separated by 200 km s^{-1} have been counted as a single system.

"intervening" Mg II systems occur in QSOs with emission redshifts less than this value. If we consider *all* Mg II systems observed—which is probably appropriate since, as discussed below, we believe that the ejected components tend to be high ionization systems —then for $q_0 = 0$, four of the six systems have been found at the "half total-path" point. Consequently, no evidence for Mg II to occur preferentially in objects of higher $z_{\rm em}$ exists in our data. (The same test carried out for C IV systems results in four of the 11 systems with $V_{\rm eject} > 18{,}000$ km s^{-1} occurring by half the total path length.)

Somewhat more elaborate tests have been carried out to determine the characteristics of the distribution of C IV systems in $z_{\rm abs}$. First, consider the function $Y(z_{\rm abs})$, where Y is the total observed path length between $z_{\rm min}$ and $z_{\rm eject}$ for all objects, normalized to unity, which results by considering all the observed path lengths in our sample as an increasing function of $z_{\rm abs}$. Then, those values of Y which correspond to the 11 displaced C IV doublets can be tested for a uniform distribution in Y, using the Kolmogorov-Smirnov (KS) test. (See Weymann, Boroson, and Scargle 1978 and references therein.)

A statistically significant departure from uniformity detected by this test could arise in two ways: (1) The basic hypothesis concerning the origin of the C IV systems could be correct, i.e., a random distribution in path length of intervening systems, but the specific cosmological model could be wrong (owing, for example, to strong evolutionary effects which might cause a large excess of redshifts at higher redshifts). (2) The basic hypothesis might be wrong, and strong clumping in the redshifts might occur for one reason or another; e.g., the systems are really ejected.

In fact, application of the KS test to the distribution of the observed Y values of the 11 displaced C IV doublets shows no statistically significant departure from a uniform distribution: the observed KS statistic is exceeded by that occurring in a random uniform distribution 36% of the time. This is somewhat surprising because inspection of the actual values of $z_{\rm abs}$ for the 11 displaced ($V > 18{,}000$ km s^{-1}) systems shows them to have a striking clump of five redshifts at $z_{\rm abs} \approx 1.46$. The failure of the KS test to pick this out is apparently due to the occurrence of this clumping in about the midrange in Y, so that the maximum excursion between the observed Y's and the hypothetical uniform distribution never becomes large. As noted in Weymann *et al.* (1978), the KS test applied to the differences $\Delta Y_k = Y_{k+1} - Y_k$ is far more sensitive to clumping than the test applied to the Y's themselves. When this version of the test is applied to these systems, we find that the observed statistic is exceeded only 1% of the time by that occurring in a uniform random distribution. We have no explanation for what selection effects or real physical effects could cause such clumping. The five redshifts are found in five different objects in different parts of the sky having differing $z_{\rm em}$, so that the clumping in $z_{\rm abs}$ is not a clumping in $V_{\rm eject}$.

The number of absorption systems in each of the survey objects should be Poisson distributed, provided proper allowance is made for the large differences in observed path length from object to object. Frankly, we are not sure how best to allow for this latter complication. The raw distribution of multiplicities for the 11 C IV doublets displaced by more than 18,000 km s^{-1} is such that eight quasars have one system each while the remaining three systems occur in 0151+048 (PHL 1222), an object studied previously by two of us in another context (Williams and Weymann 1976). The path length for this object is about 50% larger than the mean path length. There is clearly a risk in devising ad hoc tests for especially interesting occurrences, since the tests can become so specialized that statistical significance is virtually guaranteed, but the following seems reasonable: Consider a very large set of a sample of objects, each sample consisting of the same number of QSOs with precisely the same distribution of path lengths and the same number of absorbing systems. If the 11 systems are distributed randomly over path length, what is the probability that any member of the set will contain one or more objects having three or more absorption systems? The answer for the full data set is that for $q_0 = 0$, the probability is 15%. We consider this result to indicate that there is no serious conflict with these data and the assumption of Poisson statistics for the distribution of C IV systems having $V > 18{,}000$ km s^{-1}.

A different conclusion was reached by Burbidge *et al.* (1977*a*). However, their data set was very inhomogeneous, and they did not attempt to draw a distinction between the ejected systems ($V \lesssim 18{,}000$ km s^{-1}) and the highly displaced systems. Had we not made this distinction in our data, the objects 1556+335 and especially 1303+308 would surely have been incompatible with a Poisson distribution.

c) Properties of the "Associated Cluster" Systems

We now consider the properties of the small-displacement ($V < 18{,}000$ km s^{-1}) absorption systems, which we propose are due to material ejected from the quasar and to clouds bound to a cluster of which the QSO is itself a member. We do this by examining the distribution in velocity of the C IV systems with respect to the emission redshift, where the velocity $\beta = V/c$ is computed from the relation $\beta = (R^2 - 1)/(R^2 + 1)$, and $R = (1 + z_{em})/(1 + z_{abs})$. A histogram of the distribution of the C IV absorption with respect to velocity is plotted in Figure 1. The height of each bar in the histogram is equal to the number of objects in each velocity interval, divided by the bin width and also divided by the number of objects observed over the appropriate wavelength regions which fall in the relevant velocity bin. This figure may be compared with the data of Weymann *et al.* (1977, Fig. 4) and those of Boksenberg (1978, Fig. 5). The prominent peak around $V \approx 0$, extending to about -3000 km s^{-1}, together with a tail to this peak on the positive side, dropping to near zero at about 15,000–18,000 km s^{-1}, both appear to be real features of the distribution. Because of the very small number of objects in each bin, however, any other features of this distribution are very dependent upon the details of how the velocity intervals are chosen. In particular, although Figure 1 gives the impression of a symmetrical distribution about $V = 0$ between -3000 and $+3000$ km s^{-1}, there are in fact 14 systems with $-3000 < V < 0$ and nine with $0 < V < +3000$. As the histogram shows, however, this asymmetry arises entirely from the systems between -1000 and $+1000$ km s^{-1}, and since many emission-line redshifts are themselves uncertain by 500–1000 km s^{-1}, especially when affected by absorption components, we do not regard this asymmetry as significant.

We have argued previously (Weymann *et al.* 1977) that the peak in the distribution is most readily interpreted in terms of clouds bound in a cluster of galaxies of which the QSO is a member. It is therefore of interest to determine the velocity width of the peak and to compare it with the dispersion of known clusters. In computing the dispersion of the peak about zero, it is not clear how one should cut off the sample on the positive-velocity side of the peak because of the asymmetry in the distribution. For this reason we have computed the value of σ about zero velocity for the 14 C IV systems with *negative* velocity, obtaining a value of 1220 km s^{-1}. (One of these systems is associated with 1303+308 and another with 1556+335, which for reasons explained below should perhaps be deleted from this sample. If this were done, we would obtain 1315 km s^{-1}.) A Gaussian distribution (suitably normalized) with a dispersion of 1220 km s^{-1} is shown in Figure 1. Before this value can be compared with that found in clusters, we must divide the above dispersion by $\sqrt{2}$ since, in our interpretation, the peak in Figure 1 measures the *difference* in radial velocity between two objects bound in a cluster. An additional correction ought also to be made for the fact that the error (in terms of km s^{-1}) in the determination of the emission-line redshift of QSOs is certainly much larger than that in a typical determination of a galaxy in a

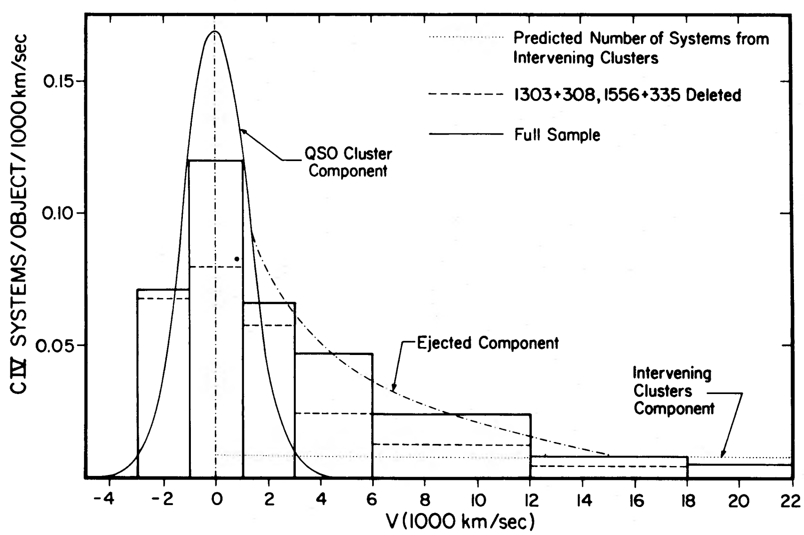

FIG. 1.—A histogram showing the observed distribution of C IV systems in the intermediate redshift sample as a function of the velocity of the absorption system relative to the QSO. Most of the systems occur near the emission redshift, and the distribution has a tail extending from the peak out to velocities of the order of 20,000 km s^{-1}. Smooth curves have been drawn through the three separate components of the distribution which correspond to the different origins of the systems. The calculation of the dotted line marked "intervening clusters component" is explained in the text.

cluster, using H and K absorption and/or (relatively narrow) emission lines, for which we conservatively take $\sigma \approx 150 \text{ km s}^{-1}$ (see, for example, Yahil and Vidal 1977). We estimate the typical uncertainty in the QSO emission-line redshifts to be $\sigma \approx 600 \text{ km s}^{-1}$ on the basis of a comparison of determinations of the emission-line redshift by different observers of the same source. The equivalent velocity dispersion of our sample for a 150 km s^{-1} error in z_{em} would then yield a σ of 1072 km s^{-1}, which when divided by $\sqrt{2}$ yields a value of 758 km s^{-1}, which is to be compared with the value of σ for "typical" clusters. A recent compilation of velocity dispersions for clusters (in which an attempt was made to eliminate nonmembers) has been published by Yahil and Vidal (1977). A total of 48% of the objects in this list have values of σ larger than 758 km s^{-1}. Since no well-defined physical characteristics were used in the selection of clusters which appear in this list, we will not attempt to interpret this any further in terms of the type of cluster which we should associate with the velocity peak. However, the important fact is that there is no apparent incompatibility between the effective dispersion of the velocity peak in our data and the observed velocity dispersions of clusters of galaxies.

Nevertheless, this result implies that QSOs ought to be associated with at least moderately rich clusters, and this is in conflict with the result of Roberts, O'Dell, and Burbidge (1977), who found no association with Abell clusters and low redshift QSOs. Stockton's (1978) investigation of QSO association with galaxies suggests that the QSO–galaxy correlation is stronger than the galaxy–galaxy correlation (Weymann *et al.* 1978), and it is important to settle just how large these groups are and what their velocity dispersions are. Stockton's data also suggest smaller dispersions than that in our $V = 0$ peak.

d) *Ejected Systems*

The large tail on the positive side of the velocity distribution cannot be interpreted entirely in terms of systems of the "associated cluster" type, because these systems should be distributed symmetrically in velocity around $V = 0$ and because the velocities are much too large. Neither can they reasonably be interpreted entirely in terms of intervening systems. In order to demonstrate this, consider the line in Figure 1 marked "intervening clusters component." It was computed as follows: From the discussion in § IV*b*, we know the expected distribution in the number of absorption systems in the interval z_{abs} to $z_{\text{abs}} + dz_{\text{abs}}$ due to intervening material in an object of emission-line redshift z_{em}. For the case $q_0 = 0$, this is

$$dN(z_{\text{abs}}, z_{\text{em}}) = K(1 + z_{\text{abs}})dz_{\text{abs}} \quad \text{for } z_{\text{abs}} < z_{\text{em}}$$
$$= 0 \quad \text{for } z_{\text{abs}} > z_{\text{em}} . \quad (6)$$

We have determined the constant K from those systems with $V > 18{,}000 \text{ km s}^{-1}$, i.e., from the 11 C IV systems discussed in § IV*b*. We now estimate what contribution this component will make to those systems on the histogram of Figure 1 with $V < 18{,}000$ km s^{-1} when the difference $z_{\text{em}} - z_{\text{abs}}$ is interpreted as an ejection velocity. For the range of ejection velocities shown in Figure 1 we can write to good approximation that

$$\beta = V_{\text{eject}}/c \approx (z_{\text{em}} - z_{\text{abs}})/(1 + z_{\text{em}}) .$$

Consequently,

$$P(\beta) = K(1 - \beta)\int (1 + z_{\text{em}})^2 F(z_{\text{em}}) dz_{\text{em}} , \quad (7)$$

where $P(\beta)$ is the probability of observing a system between β and $\beta + d\beta$, and where $F(z_{\text{em}})$ is the distribution of emission-line redshifts in the sample of objects. The value of K determined above, together with the evaluation of the integral in equation (7), then leads to the dotted line in Figure 1. As equation (7) shows and as we expect intuitively, the contribution of intervening systems varies only slightly over the range of velocities shown in Figure 1. More important, Figure 1 shows that after allowance for this contribution and the contribution to the peak around $V = 0$ caused by "associated cluster" systems, there is still a pronounced surplus of systems, which seems to drop to zero at about 12,000–18,000 km s^{-1}. It is this surplus which we believe to be caused by ejected gas, and it was this fact which led us to exclude objects with $V < 18{,}000 \text{ km s}^{-1}$ in discussing the statistics of the intervening systems.

V. DISCUSSION

We first consider whether there are any identifying characteristics of the three types of systems or other arguments which would support the particular classification scheme proposed here. With respect to the ejected systems, there are now a number of QSOs known to have very broad (typically, 5000 km s^{-1}) absorption troughs. PHL 5200 is the prototype (and first discovered) of such objects, and 1246−057 (Boksenberg *et al.* 1978) and MCS 232 and 275 (Green *et al.* 1979) provide other examples. That there are frequently multiple and "detached" (i.e., well-separated from the emission) absorption troughs found in this class of systems makes it extremely likely, in our opinion, that these systems do not represent continuous outflow, but arise in isolated explosive events, perhaps related to the outbursts occurring in the radio and optically active sources. If this interpretation is correct, we would expect the column density in these ejected clouds to gradually decrease as they spread out, perhaps developing and exhibiting more complex velocity structure as the line opacity drops. Eventually, only the strongest isolated features will remain. *We interpret the debris from old PHL 5200–type systems as giving rise to the "ejected" systems in Figure 1.* We would then expect that unless there is very strong deceleration of the material after the broad-line phase, there should be very few PHL 5200–type absorption systems with ejection velocities much in excess of 18,000 km s^{-1}.

There are no systems in our sample which we would put in the PHL 5200 class, but there are two objects in our sample (1303+308 and 1556+335, to be discussed in detail elsewhere) which stand out as having very complex absorption systems and which we regard as intermediate stages in the evolution of PHL 5200–type systems. It is of interest to ask whether the systems in these two objects by themselves can account for the excess in the velocity histogram, which has been attributed to ejected systems. In order to check this, we have removed these two objects from our sample and have redrawn the velocity histogram, which is also shown in Figure 1. There still appears to be a small excess of systems after these two objects are removed from the sample. The remaining systems in the region 3000 km s^{-1} < V < 18,000 km s^{-1} are sharp-line, isolated systems, and it is very difficult to identify any given system in this velocity range as being more likely to be of the intervening, as opposed to the ejected, type. There is, however, one possible distinguishing characteristic of ejected systems. To the best of our knowledge, every PHL 5200–type system (and 1303+308 and 1556+335) shows strong N V absorption; i.e., they are high ionization systems. This is not very surprising for clouds being accelerated in the vicinity of a QSO. It is possible that this high ionization characteristic is retained after the acceleration process has ceased and the clouds have become optically thin. The system at $V \approx 8300$ ($z_{\rm abs} = 1.803$) km s^{-1} in B194 may be an example of such a system. By contrast, the $V = 5350$ ($z_{\rm abs} = 1.673$) km s^{-1} system in 1756+237, which shows strong C IV, but not N V and no C II fine-structure lines, has been interpreted as an intervening system (Turnshek, Weymann, and Williams 1979).

The systems comprising the velocity peak at $V \approx 0$ show a range of ionization, although the ionization tends to be moderately high. In particular, it is striking that although 16 out of 46 of the objects in which C IV absorption could have been seen within ± 3000 km s^{-1} of the emission peak did in fact show such absorption, none of the 18 objects which could have shown similar Mg II absorption in the Mg II emission peak did so. This weakness of Mg II absorption systems with $z_{\rm abs} \approx z_{\rm em}$, relative to C IV, is also borne out by a separate study at lower resolution by Peterson and Strittmatter (1978), and is in a sense even more striking because many of the objects in their list were one in which such absorption had originally been suspected. We attribute this to fairly high ionization of low density material caused by the presence of the QSO in the cluster, in contrast to the intervening material. We also take this fact as an indication that the clouds associated with the peak in the velocity distribution are not associated with the QSO emission-line region, since the ratio of Mg II/C IV emission strengths is usually significantly greater than the corresponding ratio for the strength of Mg II/C IV in the $|V| \lesssim 3000$ km s^{-1} absorption systems.

That there is little absorption which *can* be attributed to the emission-line region we ascribe to the fact that the clouds in the emission-line region are very small and do not completely cover the continuum source (cf. McKee and Tarter 1975 and Blumenthal and Mathews 1975 on this point), except perhaps during PHL 5200–type ejection episodes.

Although we consider the evidence for "associated cluster" and "ejected" absorption systems to be reasonably persuasive, the statistical tests we have discussed for the $V \gtrsim 18,000$ km s^{-1} systems, while consistent with the intervening hypothesis, cannot be considered to be a confirmation of it. There are basically only two arguments, in our view, which are persuasive for the $V > 18,000$ km s^{-1} systems being intervening material: (i) the energetic arguments, based both upon the ionization equilibrium of the gas, derived from limits on n_e due to the absence of C II fine-structure absorption (e.g., Turnshek *et al.*), and upon the absence of Lα halos around some QSOs (e.g., Sargent and Boroson 1979); and (ii) the direct observation of Ca II and H I absorption in 3C 232 at the same redshift as the nearby foreground galaxy NGC 3067 (Haschick and Burke 1975; Boksenberg and Sargent 1978). In particular, we do not regard the argument that it is difficult to accelerate material to 0.7c while still keeping the clouds coherent as a serious difficulty —the coherence could conceivably arise, or the clouds could condense, long after the acceleration process.

If the $V > 18,000$ km s^{-1} systems are in fact intervening, the sizes of the required effective radii suggest that at most a few percent of the absorption systems should arise by the line of sight actually passing through the "optical disk" of a galaxy. Consequently, we do not expect most of the intervening absorption systems to have the same characteristics as those of the interstellar medium. This is borne out by the fact that in our sample the C IV lines are almost always stronger than the C II in the displaced systems, whereas C II is stronger than C IV in nearly all interstellar clouds (E. B. Jenkins 1979, private communication). Possible observational confirmation of C IV in the galactic halo comes from recent observations of stars in the Magellanic Clouds by Savage and de Boer (1979).

On the basis of our data, we cannot decide whether the intervening clouds we observe are in halos of galaxies, clouds embedded in clusters of galaxies but not associated with individual galaxies, or truly intergalactic clouds which have somehow become metal enriched. We now consider the possibility that if the physical properties of the clouds which cause the systems in the QSO–containing cluster are applicable to all clusters, then the expected incidence of the intervening component is sufficient to explain the observed incidence. Empirically, we have seen that the line of sight through the material containing the $V \approx 0$ peak produces observable C IV absorption about 35% of the time. Presumably, this figure should be doubled if the QSO were behind the cluster rather than somewhere inside of it. Thus $\sigma_{\rm eff} \approx 0.7\sigma_{\rm clus}$, where $\sigma_{\rm eff}$ is the effective cross section for production of C IV absorption lines by a cluster and $\sigma_{\rm clus}$ is a typical geometrical cross section for the cluster. Suppose we characterize all clusters by a single size $\sigma_{\rm clus} = \pi R_{\rm clus}^2$. Define a typical density enhancement factor by

$$\mu = \langle n_{\rm gal} \rangle_{\rm clus} / \langle n_{\rm gal} \rangle_{\rm ave} ,$$

where $\langle n_{gal}\rangle_{clus}$ is the number density of galaxies in a cluster and $\langle n_{gal}\rangle_{ave}$ is the number density of galaxies averaged over a large volume of space. Then

$$\mu = \frac{1}{\frac{4}{3}R_{clus}(\sigma_{clus}n_{clus})}, \qquad (8)$$

where n_{clus} is the density of clusters, from which it follows that

$$l = 1/(n_{clus}\sigma_{eff}) = \tfrac{4}{3}R_{clus}\mu/0.70 . \qquad (9)$$

The quantity l is therefore the mean free path between intervening clouds which would result if all clusters had clouds which covered the same fraction of the geometrical cross section of the cluster as they do in clusters containing QSOs. It is very difficult to estimate what appropriate values of R_{clus} and μ to use for "average" clusters. For moderate groups and clusters, $R_{clus} = 2$ Mpc and $\mu = 500$ seem reasonable. Then, $l \approx 2000$ Mpc, which is about 20% of the value of the typical mean free paths found in Table 4 for the C IV systems. *In other words, if about 20% of all clusters have clouds with properties like those in QSO–containing clusters, they will account for the number of intervening* C IV *systems we find*, though this fraction is obviously extremely uncertain.

By way of summary we may make the following six generalizations and predictions *based only on our sample and the interpretation discussed above* and then discuss what difficulties these generalizations face, especially when applied to objects outside our sample:

a) No cases with $z_{abs} > z_{em}$ implying $|V| \gtrsim 5000$ km s^{-1} should exist. This is $\sim 4\,\sigma$ beyond our empirical fit to the $V \approx 0$ peak and would be extremely hard to understand even for very rich clusters.

b) Very few of the PHL 5200–type systems should be found with $V > 0.06c$.

c) Systems of the PHL 5200 type, when observed in the breakup stage and when low ionization systems are present, should show C II and possible Si II fine-structure lines.

d) No statistically significant occurrences of special ratios $R = (1 + z_{em})/(1 + z_{abs})$ should occur for systems having $V > 0.06c$.

e) No correlation of the incidence of Mg II and C IV absorption systems at given z_{abs} (but having $V \gtrsim 0.06c$) with the emission redshift should be found. Nor should the incidence of such systems or their distribution with z_{abs} depend upon any physical property of the QSO. In particular, no correlation between L(QSO) and $z_{em} - z_{abs}$ (Perry and O'Dell 1978) should be confirmed.

f) Systems with $V > 0.06c$ showing C II and Si II fine-structure lines should be infrequent, because we expect that these systems should be produced in regions, e.g., galactic halos, having very low gas density.

With respect our own very limited sample, none of the above statements appear to be violated. One possible conflict involves the comparison between the C IV systems at $z_{abs} \approx z_{em}$ and those for which $V > 0.06c$: we have the impression that the absorption systems in the $V \approx 0$ peak tend to be broader than the $V \gtrsim 0.06c$ systems and to be split into multiple systems ($200 \leq \Delta V \leq 3000$) more often than the $V \gtrsim 0.06c$ systems. In fact, in the present sample we have *no* examples of displaced split C IV systems, though one exists in the Mg II systems. If it were really true that an average of 0.7 C IV systems per *cluster* were produced and if the number of systems per cluster were Poisson distributed, we would have expected the ratio of multiple systems to single systems to be about 0.45. One possible way out of this difficulty is to suppose that the QSOs are found preferentially near the centers of clusters and that the cloud-producing material is concentrated toward the center. The average line of sight through an intervening cluster would then intercept fewer clouds than the 0.7 used above. In this way the multiplicity problem could be avoided. We would then require a larger fraction of the clusters than the 20% estimated above to produce the required number of intervening systems. A disadvantage of this explanation is that if the QSOs are found preferentially at the cluster center, it follows that they do not have the velocity dispersion typical of the cluster. The factor $\sqrt{2}$ by which we divided our empirical velocity dispersion to obtain the value to be compared with a typical cluster is too large, and the resulting velocity dispersion becomes rather large.

In confronting our six generalizations with objects *outside* our data sample, reference should be made to the recent comprehensive compilation and discussion by PB^2.

We are aware of two recent examples of possible violations of generalization (*a*), that is, $z_{abs} > z_{em}$ systems with $|V| \gg 3000$ km s^{-1}. In the one case where the velocity greatly exceeds 3000 km s^{-1}, 0457+024 (Roberts *et al.* 1978), the reality of the system is not well established. In the other case, 0528−250 (Smith, Jura, and Margon 1979), the absorption system and its redshift are well established, but the emission-line redshift is not accurately known: the approximate relative velocity is $V = -3500$ km s^{-1}.

We are aware of about 15 objects which one could reasonably place in the PHL 5200 class. We have examined the velocity distribution of such systems, and it appears that there is *qualitative* agreement with the "ejected component" line of Figure 1 and with the generalization that the broad-line systems with $V > 0.06c$ are rare. (Note that the statement in PB^2 concerning 1246−057 is not correct—the blue edge of the absorption trough has a displacement of $\sim 0.06c$ relative to the emission lines, not $0.1c$.) However, it appears that the distribution drops off more slowly with increasing ejection velocity than our curve in Figure 1, and there appear to be at least one or two systems where velocities of at least $0.1c$ are attained.

The question of the possible occurrence of line locking and the preferential occurrence of low redshift absorption systems in QSOs of high emission redshift (violation of generalizations [*d*] and [*e*]) is still not at all clear and is quite controversial, and we have nothing to add to the discussion in PB^2.

The question of absorption from fine-structure levels in displaced systems is an intriguing one, and such systems *are* apparently found (PB^2; Coleman and Strittmatter 1979), contrary to our generalization (*f*). In all cases, however, they appear to have been found in very rich line systems studied at moderate resolution including some $R = 1.11$ systems. We do not know of any highly displaced systems in relatively uncrowded spectra showing the fine-structure lines. (The systems in 1756+237 [Turnshek *et al.*] and especially 1101−264 [Carswell *et al.* 1979] provide two examples.)

A related question has to do with the enigmatic object PKS 0237−23 (Boroson *et al.* 1978). At face value it seems to us to be an extreme example of an object like 1303+308—i.e., ejected systems of unusually high velocity. It shows troughs of displaced C IV absorption undergoing breakup, but with the ejection velocity of the most prominent troughs being $\sim 0.2c$. The main argument against this interpretation has been an energetic one. The question of the presence or absence of the Si II $\lambda 1533$ fine-structure line in several of the absorption systems is in dispute (Roberts 1979). Recent work by Sarazin, Flannery, and Rybicki (1979) has shown that when the opacity in the ground transition is high, the lower limits on the distance of the absorbing cloud *based upon fluorescence excitation* are substantially less than when the lines are thin. Minimum distances for the absorbing clouds as small as ~100 pc seem possible. The minimum energy and masses inferred from the ionization level and the limits on the electron density deduced from the fine structure scale directly as the electron density, and if the Si II $\lambda 1533$ lines are marginally present, the energies and masses may not be unacceptably large. Moreover, the photoionization argument setting lower limits on the distance of the clouds from the continuum source assumes that the clouds are exposed to the unattenuated UV flux from the QSO continuum source. In objects with extremely complex absorption systems—especially those showing low ionization lines like Si II as PKS 0237−23 does—this is very likely not the case and the corresponding lower limits on the energy and mass would be further reduced.

We conclude with the reminder that our survey and the interpretation of it have been concerned only with systems showing C IV and Mg II absorption, and not with the (possibly) "pure hydrogen" Lα systems.

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REFERENCES

Adams, M. T., Coleman, G. D., Stockman, H. S., Strittmatter, P. A., and Williams, R. E. 1978, *Ap. J.*, **223**, 758.
Blumenthal, G. R., and Mathews, W. G. 1975, *Ap. J.*, **198**, 517.
Boksenberg, A. 1978, *Phys. Scripta*, **17**, 205.
Boksenberg, A., Carswell, R. F., Smith, M. G., and Whelan, J. A. J. 1978, *M.N.R.A.S.*, **184**, 773.
Boksenberg, A., and Sargent, W. L. W. 1978, *Ap. J.*, **220**, 42.
Boroson, T. A., Sargent, W. L. W., Boksenberg, A., and Carswell, R. F. 1978, *Ap. J.*, **220**, 772.
Burbidge, G. R., Crowne, A. H., and Smith, H. E. 1977, *Ap. J. Suppl.*, **33**, 113 (BCS).
Burbidge, G. R., O'Dell, S. L., Roberts, D. H., and Smith, H. E. 1977*a*, *Ap. J.*, **218**, 33.
Burbidge, E. M., Smith, H. E., Weymann, R. J., and Williams, R. E. 1977*b*, *Ap. J.*, **218**, 1.
Carswell, R. F., Hilliard, R. L., Strittmatter, P. A., Taylor, D. J., and Weymann, R. J. 1975, *Ap. J.*, **196**, 351.
Carswell, R. F., Morton, D. C., Smith, M. G., Turnshek, D. A., and Weymann, R. J. 1979, in preparation.
Coleman, G. D., and Strittmatter, P. A. 1979, in preparation.
Felten, J. E. 1977, *A.J.*, **82**, 861.
Green, J., Liebert, J., Strittmatter, P., Turnshek, D., Weymann, R., and Williams, R. 1979, in preparation.
Gunn, J. E. 1979, in *Proc. Conf. Galaxy Formation and Early Evolution*, ed. W. H. McCrae and M. J. Rees (London: Royal Society), in press.
Haschick, A. D., and Burke, B. F. 1975, *Ap. J.* (*Letters*), **200**, L137.
McKee, C. F., and Tarter, C. B. 1975, *Ap. J.*, **202**, 306.
Perry, J. J., Burbidge, E. M., and Burbidge, G. R. 1978, *Pub. A.S.P.*, **90**, 337 (PB^2).
Perry, J. J., and O'Dell, S. L. 1978, *Astr. Ap.*, **62**, 229.
Peterson, B. M., and Strittmatter, P. A. 1978, *Ap. J.*, **226**, 21.
Peterson, B. M., Strom, S. E., and Strom, K. M. 1979, *A.J.*, **84**, in press.
Roberts, D. H. 1979, *Ap. J.*, **228**, 1.
Roberts, D. H., Burbidge, E. M., Burbidge, G. R., Crowne, A. H., Junkkarinen, V. T., and Smith, H. E. 1978, *Ap. J.*, **224**, 344.
Roberts, D. H., O'Dell, S. L., and Burbidge, G. R. 1977, *Ap. J.*, **216**, 227.
Sarazin, C. L., Flannery, B. P., and Rybicki, G. B. 1979, *Ap. J.* (*Letters*), **227**, L113.
Sargent, W. L. W., and Boroson, T. A. 1979, *Ap. J.*, **228**, 712.
Sargent, W. L. W., Young, P. J, Boksenberg, A., Carswell, R. F., and Whelan, J. A. J. 1979, *Ap. J.*, **230**, 49.
Savage, B. D., and de Boer, K. S. 1979, *Ap. J.* (*Letters*), **230**, L77.
Schechter, P. 1976, *Ap. J.*, **203**, 297.
Smith, H. E., Jura, M., and Margon, B. 1979, *Ap. J.*, **228**, 369.
Stockton, A. N. 1978, *Ap. J.*, **223**, 747.
Turnshek, D. A., Weymann, R. J., and Williams, R. E. 1979, *Ap. J.*, **230**, 330.
Weymann, R. J., Boroson, T. A., Peterson, B. M., and Butcher, H. R. 1978, *Ap. J.*, **226**, 603.
Weymann, R. J., Boroson, T. A., and Scargle, J. D. 1978, *Ap. Space Sci.*, **53**, 265.
Weymann, R. J., Williams, R. E., Beaver, E. A., and Miller, J. S. 1977, *Ap. J.*, **213**, 619.
Williams, R. E., and Weymann, R. J. 1976, *Ap. J.* (*Letters*), **207**, L143.
Yahil, A., and Vidal, N. V. 1977, *Ap. J.*, **214**, 347.

Note added in proof.—Recently, Sargent *et al.* (1979) reported that intervening galaxies with halos having radii of only ~35 kpc were required to explain the density of C IV absorption systems found in a high-resolution study of three high-redshift QSOs. In their calculations, they chose to adopt 100 km s^{-1} Mpc^{-1} for H_0 and $4.0 \times 10^{-2}(H_0/100)^3$ Mpc^{-3} for φ^* (the normalization factor for the luminosity function). In our opinion, 50 km s^{-1} Mpc^{-1} and $8.6 \times 10^{-3}(H_0/100)^3$ Mpc^{-3} are more realistic constants. In particular, the value we adopt for φ^* is not enhanced by the local supercluster, and we have further assumed that only one-half of the galaxies have absorbing clouds associated with them (§ IV*b*). Using our adopted constants and the data of Sargent *et al.*, it is found that halos of radius ~130 kpc are required to produce the C IV systems, which is slightly larger than our determination. For the Mg II systems of Sargent *et al.*, it is found that halos of radius ~180 kpc are required, a factor of 2.7 times larger than our determination. We note that the data of Sargent *et al.* have a lower limiting equivalent width than our data.

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