

## THE ABSORPTION-LINE SPECTRUM OF 4C 05.34

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### ABSTRACT

The absorption lines in the spectrum of the large-redshift QSO 4C 05.34 are reported, and a preliminary analysis is presented. Evidence is found for five separate absorption-line redshifts, all of which are less than the emission-line value. The distribution of absorption lines is striking in that essentially all unidentified lines are located on the short-wavelength side of the  $L\alpha$  emission line. A probable explanation of this effect is discussed.

In addition to having the largest redshift ( $z = 2.877$ ) thus far reported (Lynds and Wills 1970), the QSO 4C 05.34 is also important because of the character of its absorption-line spectrum. This report is based on six spectrograms obtained in the spring of 1970 with an image-tube spectrograph on the 84-inch telescope of the Kitt Peak National Observatory. Five of the spectrograms cover the spectral region from 3200 to 7500 Å with a spectral resolution of 10 Å; but the absorption spectrum is shown to best advantage of one spectrogram of about 5 Å resolution covering the region from approximately 3500 to 6000 Å. Most of the information on the absorption lines is based on the higher-dispersion spectrogram, reproduced in Figure 1 (Plate 3).

Although this paper is primarily concerned with the absorption-line spectrum of 4C 05.34, a remark concerning the emission lines is in order. The high-dispersion spectrogram in Figure 1 and the several low-dispersion spectrograms show no evidence for emission lines shortward of  $L\alpha$ , other than the two lines marked in the illustration. The wavelengths of these two lines agree well with the values expected for the components of the O VI resonance doublet  $\lambda\lambda 1031.9, 1037.6$ . These identifications indicate a very high level of ionization for the emitting material. It is also worth remarking on the apparent absence of detectable  $L\beta$  emission inasmuch as  $L\beta$  was reported in the spectrum of this object by Oke (1970). As  $L\beta$  should be located only about 35 Å shortward of the O VI lines, it seems possible that the large 80 Å bandpass used by Oke in his scanner observations, together with the confusion contributed by the absorption lines, might have made it difficult for him to distinguish which identification,  $L\beta$  or O VI, was correct. In any case, the O VI emission must contribute to the scanner observations, and until this contribution has been determined, the value of  $L\beta$  emission reported by Oke should be regarded with reserve.

It is seen in Figure 1 that there are many prominent absorption lines and that their most distinguishing characteristic is that they are almost exclusively located on the short-wavelength side of the strong  $L\alpha$  emission line in the center of the spectrogram. The measured wavelengths of the absorption lines are given in Table 1, together with estimated line strengths (in parentheses). The census of lines of strength 0 is probably very incomplete owing to the interference contributed by the stronger lines; strength 0 lines have been listed only when they have a fair probability of being real. The only lines taken from low-dispersion spectrograms (designated LD in the table) are those that were specifically searched for in the line-identification process. Because of the differing strength and character of the lines and because of the insidious effects of blending of unresolved or partially resolved lines, it is difficult to quote a meaningful estimate of

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## PLATE L3

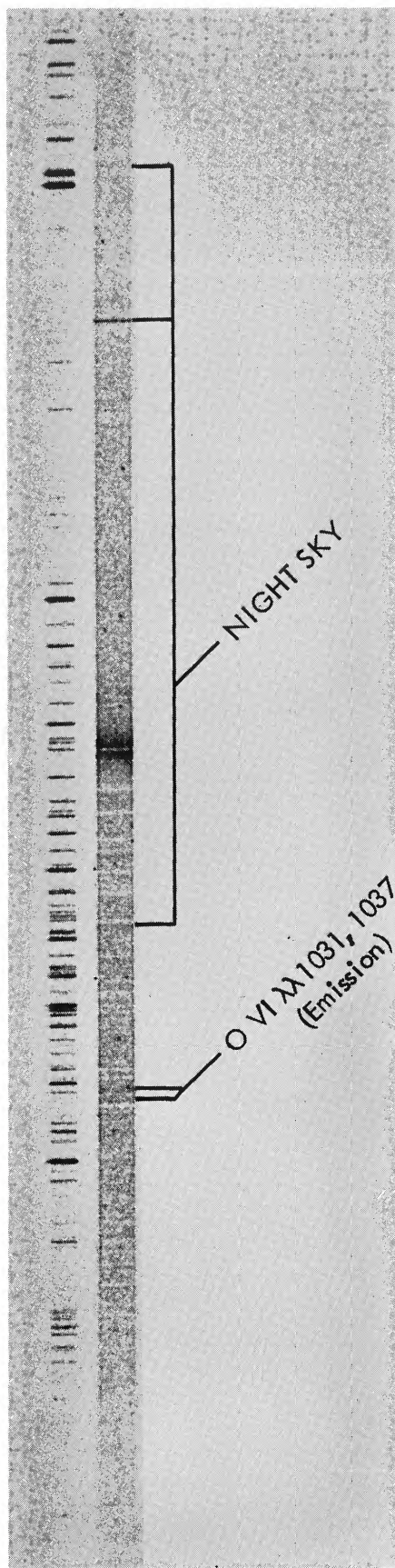


FIG. 1.—A spectrogram illustrating the numerous absorption lines in 4C 05.34. The strong emission line in the center is  $L\alpha$ . The  $O\text{ VI}$  emission lines and several airglow features are also indicated. The comparison spectrum is  $\text{He} + \text{Ar} + \text{Ne}$ .

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TABLE 1

WAVELENGTHS OF ABSORPTION LINES IN 4C 05.34\*

|               |               |               |              |                |
|---------------|---------------|---------------|--------------|----------------|
| 3497.85 (2)   | 3874.82 (0)   | 4185.46 (2,d) | 4502.44 (1)} | 4816.94 (2)    |
| 3514.81 (2)   | 3882.94 (1)   | 4197.38 (2)   | 4507.97 (3)} | 4842.29 (1)    |
| 3535.98 (2)   | 3894.82 (2)   | 4215.43 (2)   | 4519.12 (1)  | 4972.03 (1)    |
| 3565.61 (3,d) | 3908.29 (1,d) | 4223.59 (4)   | 4529.91 (5)  | 5008.10 (1)    |
| 3582.46 (3)   | 3965.40 (1)   | 4233.72 (0)   | 4549.09 (2)  | 5032.97 (0)    |
| 3592.18 (0)   | 3974.34 (1)   | 4246.98 (3)   | 4557.29 (1)  | 5045.89 (1)    |
| 3603.32 (3)   | 3985.83 (2)   | 4256.62 (2)   | 4582.94 (5)  | 5189.21 (0)}   |
| 3630.26 (0)   | 3997.07 (5)   | 4296.49 (3)   | 4624.25 (1)  | 5196.77 (0)}   |
| 3641.86 (3)   | 4010.48 (1)   | 4304.62 (1)   | 4631.03 (4)  | 5377.37 (3)    |
| 3668.39 (2)   | 4019.67 (3)   | 4317.20 (0,d) | 4639.10 (1)  | 5386.67 (3)    |
| 3683.54 (3)   | 4042.23 (1)   | 4329.81 (0,d) | 4653.94 (2)  | 5402.04 (0)    |
| 3706.10 (3,d) | 4053.04 (3)   | 4366.50 (5,b) | 4665.62 (1)  | 5444.95 (1)    |
| 3727.17 (4,b) | 4061.50 (1)   | 4380.43 (2)   | 4676.18 (1)  | 5455.57 (1)    |
| 3744.74 (1)   | 4069.19 (3)   | 4391.09 (1,d) | 4688.01 (2)  | 5478.41 (0)    |
| 3766.27 (3)   | 4084.42 (1,d) | 4422.83 (4,b) | 4710.81 (4)  | 5839.0: (0,LD) |
| 3779.43 (2)   | 4142.34 (0)   | 4436.74 (3)   | 4728.07 (1)} | 5903.8: (1,LD) |
| 3816.09 (2,d) | 4154.96 (0)   | 4451.95 (0)   | 4734.45 (1)} | 6005.6: (1,LD) |
| 3843.96 (1)   | 4163.15 (1)}  | 4465.08 (4,d) | 4759.55 (1)  |                |
| 3867.06 (3,d) | 4171.36 (1)}  | 4479.62 (2)   | 4800.96 (2)  |                |

\* The last decimal place is entirely without significance and is given only for the sake of numerical consistency with Tables 2 and 3. Given in parentheses are estimates of line strength and comments having the following meanings: d, diffuse; b, broad; and LD, low-dispersion spectrograms. A single brace encloses lines that are blended.

accuracy for the wavelengths. The rms error should be in the vicinity of 0.5 Å, but it may be nearer to 1.0 Å because of the aforementioned uncertainties. The errors are likely to be larger for the four lines measured on the low-dispersion spectrograms.

As a consequence of the uncertainties in the wavelengths of the observed lines and their interpretation, the identification process must rely heavily on physical reasonableness and on similarities to solutions that have been shown to be well founded in other objects (see Lynds 1970 for a general discussion of this point of view). Thus, the transitions searched for are those that have been found or those that are similar to the ones that have been found in previously studied objects. Extremely large redshifts, blueshifts, and unusual species or transitions have not been searched for in any comprehensive manner. The identification procedure has been roughly that employed by Burbidge and Lynds (1968). A more formal procedure such as that of Bahcall (1968) would probably yield similar results, with any differences involving primarily matters of detail stemming from differences in the application of criteria.

The search for substantiated line identifications and redshifts has yielded five different systems. The adopted redshifts and identifications in the five redshift systems are given in Table 2. The residuals  $\Delta\lambda$  are equal to the observed wavelength minus the expected wavelength calculated from the adopted redshift. The identifications appearing in boldface type provide most of the evidence in support of the reality of the redshift systems. The values of the adopted redshifts are also based largely on these "primary" identifications. The remaining identifications have a secondary status for a variety of reasons which include poor wavelength agreement, broad or diffuse appearance, and incompatible intensity, any of which may indicate a blending problem or simply an incorrect interpretation. It is interesting that the residuals for the primary identifications tend to support an rms wavelength error of about 0.5 Å, whereas the residuals for all identifications indicate a larger value near 1.0 Å. However, the manner of arriving at the adopted redshifts tends slightly to produce such an effect.

The identification of strong pairs of lines with the O VI resonance doublet in redshift systems I and V (see Table 2) leads to rather large residuals which have about the

TABLE 2  
ABSORPTION-LINE IDENTIFICATIONS\*

| Wavelength<br>(Å)                                | Identification         | Redshift      | O-C<br>(Å)   | Comments                                                     |
|--------------------------------------------------|------------------------|---------------|--------------|--------------------------------------------------------------|
| System I: Adopted Redshift = 2.8754 (Certain)    |                        |               |              |                                                              |
| 3565.61 (3,d).....                               | Ar II λ919.78          | 2.8766        | +1.09        | Contributor.                                                 |
| <b>3974.34</b> (1).....                          | <b>Lβ λ1025.72</b>     | <b>2.8747</b> | <b>-0.74</b> |                                                              |
| 3997.07 (5).....                                 | O VI λ1031.91          | ...           | -2.00        |                                                              |
| 4019.67 (3).....                                 | O VI λ1037.61          | 2.8740        | -1.50        |                                                              |
| <b>4676.18</b> (1).....                          | <b>Si III λ1206.51</b> | <b>2.8758</b> | <b>+0.47</b> |                                                              |
| <b>4710.81</b> (4).....                          | <b>La λ1215.67</b>     | <b>2.8751</b> | <b>-0.40</b> |                                                              |
| <b>4800.96</b> (2).....                          | <b>N V λ1238.80</b>    | <b>2.8755</b> | <b>+0.11</b> |                                                              |
| <b>4816.94</b> (2).....                          | <b>N V λ1242.78</b>    | <b>2.8759</b> | <b>+0.68</b> |                                                              |
| 5045.89 (1).....                                 | O I λ1302.17           | 2.8750        | -0.56        |                                                              |
| 5402.04 (0).....                                 | Si IV λ1393.76         | 2.8759        | +0.68        |                                                              |
| 6005.6: (1,LD)...                                | C IV λ1549.1:          | 2.8768        | +2.23        |                                                              |
| System II: Adopted Redshift = 2.8098 (Probable)  |                        |               |              |                                                              |
| 3706.10 (3,d).....                               | Lγ λ 972.54            | ...           | +0.93        | Questionable weak contributor.                               |
| <b>3908.29</b> (1,d).....                        | <b>Lβ λ1025.72</b>     | <b>2.8102</b> | <b>+0.49</b> | Metastable ground state.                                     |
| 4479.62 (2).....                                 | C III λ1175.6:         | 2.8105        | +0.82        |                                                              |
| <b>4631.03</b> (4).....                          | <b>La λ1215.67</b>     | <b>2.8094</b> | <b>-0.43</b> | λ1238.8 lost in Lα emission?<br>Confused by airglow D-lines. |
| <b>4734.45</b> (1).....                          | <b>N V λ1242.78</b>    | <b>2.8096</b> | <b>-0.29</b> |                                                              |
| 5903.8: (1,LD)...                                | C IV λ1549.1:          | ...           | +2.04        |                                                              |
| System III: Adopted Redshift = 2.7701 (Probable) |                        |               |              |                                                              |
| 3535.98 (2).....                                 | Lε λ937.80             | 2.7705        | +0.37        | Line seems too strong.                                       |
| 3582.46 (3)†.....                                | Lδ λ949.74             | ...           | +1.83        | Contributor only.                                            |
| 3668.39 (2).....                                 | Lγ λ972.54             | 2.7719        | +1.83        | Contributor to the longward edge.                            |
| <b>3683.54</b> (3).....                          | <b>C III λ977.03</b>   | <b>2.7702</b> | <b>+0.05</b> |                                                              |
| 3727.17 (4,b).....                               | N III λ989.79          | ...           | -4.44        |                                                              |
| 3867.06 (3,d).....                               | Lβ λ1025.72            | 2.7701        | -0.01        | Poor agreement. Contributor?                                 |
| 4084.42 (1,d)†....                               | N II λ1083.98          | ...           | -2.28        |                                                              |
| <b>4549.09</b> (2).....                          | <b>Si III λ1206.51</b> | <b>2.7705</b> | <b>+0.43</b> |                                                              |
| <b>4582.94</b> (5).....                          | <b>La λ1215.67</b>     | <b>2.7699</b> | <b>-0.26</b> |                                                              |
| 5032.97 (0).....                                 | C II λ1334.52          | 2.7714        | +1.71        |                                                              |
| <b>5839.0: (0, LD)...</b>                        | <b>C IV λ1549.1:</b>   | <b>2.7693</b> | <b>-1.26</b> |                                                              |
| System IV: Adopted Redshift = 2.7262 (Possible)  |                        |               |              |                                                              |
| <b>3641.86</b> (3).....                          | <b>C III λ 977.03</b>  | <b>2.7275</b> | <b>+1.26</b> | Metastable lower level.                                      |
| 3843.96 (1).....                                 | O VI λ1031.91          | 2.7250        | -1.15        |                                                              |
| 4380.43 (2).....                                 | C III λ1175.6:         | 2.7261        | -0.09        |                                                              |
| <b>4529.91</b> (5).....                          | <b>La λ1215.67</b>     | <b>2.7263</b> | <b>+0.08</b> |                                                              |
| 4759.55 (1).....                                 | C I λ1277.27           | 2.7263        | +0.17        |                                                              |
| 4972.03 (1).....                                 | C II λ1334.52          | 2.7257        | -0.64        |                                                              |
| System V: Adopted Redshift = 2.4739 (Certain)    |                        |               |              |                                                              |
| 3582.46 (3)†.....                                | O VI λ1031.91          | 2.4716        | -2.30        | Poor agreement.                                              |
| 3603.32 (3).....                                 | O VI λ1037.61          | 2.4727        | -1.24        | Metastable lower level.                                      |
| 3766.27 (3).....                                 | N II λ1083.98          | 2.4745        | +0.64        |                                                              |
| 4084.42 (1,d)†....                               | C III λ1175.6:         | 2.4743        | +0.50        |                                                              |
| <b>4223.59</b> (4).....                          | <b>La λ1215.67</b>     | <b>2.4743</b> | <b>+0.47</b> |                                                              |
| 4304.62 (1).....                                 | N V λ1238.80           | 2.4748        | +1.15        |                                                              |
| 4317.20 (0,d).....                               | N V λ1242.78           | 2.4738        | -0.09        |                                                              |
| 4842.29 (1).....                                 | Si IV λ1393.76         | 2.4743        | +0.52        |                                                              |
| <b>5377.37</b> (3).....                          | <b>C IV λ1548.20</b>   | <b>2.4733</b> | <b>-0.94</b> |                                                              |
| <b>5386.67</b> (3).....                          | <b>C IV λ1550.77</b>   | <b>2.4735</b> | <b>-0.54</b> |                                                              |

\* The identifications set in boldface type comprise most of the basis for the adopted redshifts and for the credibility of the redshift systems.

† The line appears in both system III and system V.

same magnitude and sign. It has not yet been determined whether or not the adopted rest wavelengths of the lines can be in error by an amount (several tenths of an angstrom) necessary to explain the discrepancy. Ground-state transitions of neutral species (other than hydrogen) appear to occur in redshift systems I (O I  $\lambda$ 1302.17) and IV (C I  $\lambda$ 1277.27). Identified transitions having, within the same multiplet, resolvable companions arising from excited fine-structure levels occur in system I (O I  $\lambda$ 1302.17 and Ar II  $\lambda$ 919.78), system III (N III  $\lambda$ 989.79, N II  $\lambda$ 1083.98, and C II  $\lambda$ 1334.52), system IV (C II  $\lambda$ 1334.52), and system V (N II  $\lambda$ 1083.98). In these cases the transitions from excited fine-structure levels are not detected.

Almost all of the identifications involve transitions from the ground state. The one exception is C III  $\lambda$ 1175.6 (the wavelength is an average of the transitions from the unexcited fine-structure levels) which arises from the lowest triplet term (metastable). This feature appears to be present in redshift systems II, IV, and V. The possible presence of this transition has been the subject of dispute in at least one previously studied absorption-line QSO (Stockton and Lynds 1966; Bahcall, Sargent, and Schmidt 1967), and its occurrence among the present identifications brings to the fore the difficult question of whether or not the presence of this important transition has really been established—even if one believes in the reality of the suggested redshift systems. A possibly significant statistical answer to the question may eventually be forthcoming, but about all that can be said at present is that a line occurs at the expected position in several instances. Whenever one is clearly dealing with the possibility of multiple absorption redshifts, a similar problem exists for other transitions occurring in spectral regions densely populated with absorption lines. A statistical test similar to that devised by Bahcall (1968) appears to offer reasonable prospects for a *statistical* solution. It must be remembered, however, that the validity of such a solution will still depend critically on the validity of the identification criteria employed.

A statistical test may also be made to render a verdict on the credibility of particular redshift systems, but in this case also the result depends on the adopted identification criteria. No such test has been used in the present case; instead, I have simply given in Table 2 a qualitative statement of my impression of the relative certainty of the adopted redshifts.

There appears to be a significant tendency for large-redshift QSOs to show an abundance of absorption lines in their spectra (Lynds 1970). It also appears to be conclusively established that most of the QSOs having the largest redshifts exhibit more than one absorption-line redshift and that these redshifts often differ greatly from, and are nearly always smaller than, the emission-line value. In many of these QSOs the most thorough and reasonable efforts to identify the lines fail to identify a considerable fraction of them (of the order of one-half). It is also true in those cases which are well studied that nearly all prominent unidentified lines are located on the short-wavelength side of the  $L\alpha$  emission line. The QSO 4C 05.34 exhibits all of these characteristics, especially the tendency for most unidentified lines—indeed, even the identified lines—to be located shortward of the  $L\alpha$  emission. This characteristic must be considered to represent a significant regularity in the distribution of the absorption lines. Although there are undoubtedly many different suggestions that might be advanced to explain the effect, only one will be considered here.

It does not seem likely that the distribution of absorption lines in the spectrum of 4C 05.34 represents primarily the distribution of preferred transitions of preferred species at one or a few redshifts. It does, however, seem reasonable that the distribution reflects to a considerable extent the distribution of redshift systems. This interpretation suggests that one important transition,  $L\alpha$ , dominates in the absorption spectrum. Furthermore, there is evidence in many absorption-line QSOs that  $L\alpha$  usually (but not always) appears much stronger in absorption than do other transitions (Lynds 1970). Thus, on this interpretation, it may be expected that a significant fraction of the promi-

nent unidentified absorption lines shortward of the  $L\alpha$  emission line in 4C 05.34—as well as in the several similar objects that are known—will be due to  $L\alpha$  (see Lynds 1970 for a more complete discussion). In connection with this hypothesis it should be pointed out that the majority of transitions that have been observed in absorption in QSOs either are doublets or should, on any reasonable scheme of ionization or relative abundance, be accompanied by other detectable transitions which are not likely to go unnoticed in the identification process.

The characteristics of the spectrum of 4C 05.34 appear to be compatible with the foregoing interpretation. The C IV resonance doublet appears to be strong in only one of the redshift systems, system IV. The presence of C IV is certain in systems I and II but cannot be regarded as established in systems III and IV—even though  $L\alpha$  is strong in both of these latter systems. It might reasonably be suggested that systems I, II, III, and IV show a relative underabundance of the highly ionized species. The strongest discordance with such a suggestion would seem to be the apparent great strength of the O VI resonance doublet in system I. However, this identification is not certain by any means; the wavelength agreement is not especially convincing, and the strength of the shortward component of the observed doublet is sufficiently great in comparison with the other component as to require a contribution from another superposed line. In short, it is not possible to rule out conclusively the possibility of differences in levels of ionization between redshift systems. Of course, it may well be true that the tentative identifications of lines with the neutral and low ionization species (other than hydrogen)

TABLE 3  
EVIDENCE BEARING ON THE POSSIBLE IDENTIFICATION OF LYMAN ALPHA WITH  
PROMINENT ABSORPTION LINES NOT IDENTIFIED IN SYSTEMS I–V

| Wavelength<br>(Å)       | Identification              | Redshift | Comments                                                                                                                                                                                                                            |
|-------------------------|-----------------------------|----------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 3727.17 (4,b) . . . . . | $L\alpha$ $\lambda$ 1215.67 | 2.0659   | $L\beta$ not within well-observed spectral region.<br>Identified as C III $\lambda$ 977 in system III.                                                                                                                              |
| 3683.54 (3) . . . . .   | $L\beta$ $\lambda$ 1025.72  | 2.5912   |                                                                                                                                                                                                                                     |
| 3706.10 (3,d) . . . . . | O VI $\lambda$ 1031.91      | 2.5915   | The observed line is too strong compared<br>with the preceding line, and it has also<br>been identified with N III $\lambda$ 989 in system<br>III.                                                                                  |
| 3727.17 (4,b) . . . . . | O VI $\lambda$ 1037.61      | 2.5921   |                                                                                                                                                                                                                                     |
| 4366.50 (5,b) . . . . . | $L\alpha$ $\lambda$ 1215.67 | 2.5918   | Identified with Si III $\lambda$ 1206 in system I.<br>There is also evidence for weak absorption<br>near the expected position of C IV $\lambda$ 1549<br>on the high-dispersion and two of the<br>low-dispersion spectrograms.      |
| 4676.18 (1) . . . . .   | O I $\lambda$ 1302.17       | 2.5911   |                                                                                                                                                                                                                                     |
| 4422.83 (4,b) . . . . . | $L\alpha$ $\lambda$ 1215.67 | 2.6382   | $L\beta$ would be positioned in the longward<br>wing of the broad feature at 3727.17 Å.<br>There is also evidence on the high-dispersion<br>spectrogram for diffuse absorption at<br>5631 Å that may be due to C IV $\lambda$ 1549. |
| 4391.09 (1,d) . . . . . | Si III $\lambda$ 1206.51    | 2.6394   |                                                                                                                                                                                                                                     |
| 4465.08 (4,d) . . . . . | $L\alpha$ $\lambda$ 1215.67 | 2.6729   | The position of $L\beta$ is blocked by a line of<br>strength “3” already identified in sys-<br>tem V.                                                                                                                               |
| 3565.61 (3,d) . . . . . | C III $\lambda$ 977.03      | 2.6495   | Identified with Ar II $\lambda$ 919.78 in system I.<br>C IV $\lambda$ 1549 may contribute to an ill-defined<br>feature at 5652 Å.                                                                                                   |
| 3744.74 (1) . . . . .   | $L\beta$ $\lambda$ 1025.72  | 2.6508   |                                                                                                                                                                                                                                     |
| 4436.74 (3) . . . . .   | $L\alpha$ $\lambda$ 1215.67 | 2.6496   |                                                                                                                                                                                                                                     |

in systems I–IV are in some cases erroneous. As a consequence, it is also not possible to rule out a relative underabundance of elements heavier than hydrogen.

In any case, it is clear that in 4C 05.34, as in several other objects, there are substantial differences in the relative prominence of  $L\alpha$  absorption and the absorption lines of ionized heavier elements. If the hypothesis that  $L\alpha$  accounts for a significant fraction of the unidentified lines is correct, then the best hope of verification—within the scope of the present observational material—may be the identification of both  $L\beta$  and  $L\alpha$  at the same redshifts. As  $L\beta$  can be expected to have about one-fifth the strength of  $L\alpha$ , it will be detectable only when  $L\alpha$  is strong. It is seen in Table 2 that  $L\beta$  is tentatively identified in systems I, II, and III. There is also an indication of a weak feature near the expected position of  $L\beta$  in system IV. The lowest intensity estimate for  $L\alpha$  in any of these systems is 4. A search has been made for the possible presence of lines near the expected positions of  $L\beta$ , as well as other possible transitions, under the assumption that each of the unidentified lines of strength 4 or 5 is due to  $L\alpha$ . The results are summarized in Table 3. It might be expected that if  $L\alpha$  appeared as a line of strength 3, it would rarely be accompanied by any supporting identifications. This appears to be the case, as there is supporting evidence in only one instance, also given in Table 3. It is seen in the table that the evidence tends slightly to favor and certainly does not rule out the reality of the suggested  $L\alpha$  identifications.

On the basis of the absorption-line characteristics of 4C 05.34 and those of many other large-redshift QSOs, both published and unpublished, it seems probable that in the future most, if not all, QSOs of redshift greater than about 2.3 will be found to have multiple absorption-redshift systems and that there will be a prevalence of systems showing primarily the Lyman lines. Higher-dispersion observations of 4C 05.34 and several other large-redshift QSOs are being continued, and they should shed more light on the assertions that have been made in this paper.

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