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SPECTROPHOTOMETRY OF THE X-RAY QSO MR 2251−178*

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ABSTRACT

Spectrophotometry of MR 2251−178 performed at the McGraw-Hill Observatory shows a rather typical spectrum for a low-redshift QSO with broad Balmer lines and lines due to He I, He II, [Ne II], [O I], [O II], [O III], [Ne III], and [Ne V]. The redshift is 0.0638 ± 0.0015. The Balmer decrement is moderately steep, but in general the permitted- and forbidden-line strengths are similar to those of other low-redshift QSOs studied by Baldwin. The fact that the spectrum is normal indicates either that all QSOs are powerful X-ray emitters or that the presence of a prodigious X-ray flux in a QSO does not have a characteristic optical signature. The former possibility is consistent with present X-ray observations.

Subject headings: galaxies: redshifts — quasars — X-rays: sources

I. INTRODUCTION

For many years 3C 273 has been the only quasi-stellar object known to emit X-rays (Bowyer *et al.* 1970; see review by Gursky and Schwartz 1977). Generalizations about the X-ray characteristics of other QSOs have been hampered by this uniqueness and also by the fact that 3C 273 is an atypical QSO due to its high luminosity and unusual spectrum (Baldwin 1975*a*, *b*; Boksenberg *et al.* 1975). Recently Ricker *et al.* (1978) discovered that the X-ray source 2A 2251−178 (Cooke *et al.* 1978) is a QSO (MR 2251−178), and shortly thereafter Apparao *et al.* (1978) discovered another (0241+622). Studies of these new objects could yield information on the X-ray properties of QSOs in general. (Here we bypass the question of the perhaps artificial distinction between an extreme Seyfert 1 and a QSO; cf. Weedman 1976*a*.)

In this *Letter* we present the results of a spectrophotometric study of MR 2251−178 performed at the McGraw-Hill Observatory[1] in 1977 November. We find that the optical spectrum of MR 2251−178 is similar to those of other low-redshift QSOs. This indicates either that all QSOs are powerful X-ray emitters easily detectable by the new generation of more sensitive X-ray satellite experiments, or that the presence of a prodigious X-ray flux in a QSO does not have a characteristic optical signature.

II. OBSERVATIONS

All the observations reported here were performed with the McGraw-Hill Observatory 1.3 m telescope and with either the Mark I or Mark II photon-counting spectrometer. These two instruments, which were designed and built at the University of Michigan, are conceptually similar in that they both employ a linear Reticon diode array as the detecting element preceded by six stages of image intensification (see Shectman and Hiltner 1976 for a description of the Mark I instrument and the basic technique). The Mark I has about 500 channels and a rather simple grating spectrograph. The Mark II has about 2000 channels, a considerably more elaborate spectrograph, a television acquisition and guiding system, and a more sophisticated on-line control and data-handling system.

Observations were performed at a variety of dispersions, resolutions, and spectral ranges as listed in Table 1. The aperture was 3″ square for the Mark I and 3″ × 6″ oriented NS for the Mark II (at declination −17° the atmospheric refraction is predominantly NS). The observations were made between new and first-quarter Moon in conditions of good to fair seeing through 1.5–2 air masses. Integrations on MR 2251−178 were interspersed with integrations on the sky and were preceded and followed by measurements of line and continuum calibration sources. Several of Oke's (1974) white-dwarf standards (primarily HZ 4 and LB 1240) were observed on each night after the QSO had set.

The data-reduction technique is similar to that described by Smith (1975) for the Lick Observatory IDS. Scans are corrected for detector dead time, the sky spectra are subtracted, and the result is corrected for

TABLE 1

SPECTRA OF MR 2251−178

No.	Instrument	Dispersion (Å per channel)	Resolution* (Å)	Range for $Z = 0.064$ (Å)	Integration Time (min.)
1..	Mark I	7.2	21	3600–6650	100
2..	Mark I	7.2	21	3600–6650	100
3..	Mark I	3.8	12	6050–6800	50
4..	Mark II	1.1	3.5	3200–5050	70

* Includes the effects of image motion during integration.

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[1] The McGraw-Hill Observatory is operated by the University of Michigan, Dartmouth College, and the Massachusetts Institute of Technology.

atmospheric extinction by using the mean Kitt Peak extinction values of Strom and Barnes (1977). Fixed channel-to-channel variations in sensitivity are removed by dividing each spectrum by the smoothed spectrum of a tungsten lamp. The efficiency at each channel is calculated from the standard white-dwarf spectra and used to convert all spectra to absolute flux units. There is reasonable consistency among our various measures of the same objects, although the effects of light loss at the slit, differential light loss due to refraction, and residual detector nonuniformities probably amount to 10% to 30%.

III. RESULTS

A spectrum of MR 2251−178 (no. 1 of Table 1) taken with the Mark I spectrometer is shown in Figure 1*a*, and Figure 1*b* shows a spectrum taken with Mark II (no. 4). There is reasonable agreement between the two when allowance is made for the different resolutions (see Table 1) and the systematic effects discussed above. The spectra appear similar to many of the spectra of low-*z* QSOs presented by Baldwin (1975*b*), and all the features labeled in the figures are also present in his spectra. Line strengths are listed in Table 2, together with uncertainties based on estimates of systematic difficulties in the determination of line extents and continuum levels. Measurements based on Mark I and Mark II spectra were found to be consistent for those lines which are evident on both. The line strengths are corrected for an assumed extinction of $A_v = 0.31$ due to material in the Galaxy (Allen 1973).

a) *Redshift*

We obtain a mean redshift for the prominent lines of Figure 1 of $z = 0.0638 \pm 0.0015$. Within our accuracy, the permitted and forbidden lines have the same redshift. Our value of *z* compares reasonably well with the redshift 0.065±0.003 determined by Ricker *et al.* (1978) from an objective-prism spectrogram.

b) *Permitted Lines*

The spectra show prominent, broad lines at Hα and Hβ, a blend of Hγ + [O III] λ4363 and weak Hδ. The full width at zero intensity (FW0I) of the Hβ wings corresponds to $\gtrsim$18,000 km s^{-1}. The full width of Hα observed in Figure 1*a* is ~23,000 km s^{-1}, which may include some instrumental contribution, since the line falls near the extreme end of the spectrum. Unfortunately, a spectrum centered on Hα (no. 3 in Table 1) is not sufficiently well calibrated to allow a measurement of the full extent of the Hα wings. These Balmer wings are comparable in breadth to the broadest in Baldwin's data. The full widths at half-maximum of Hα and the broad Hβ component correspond to veloci-

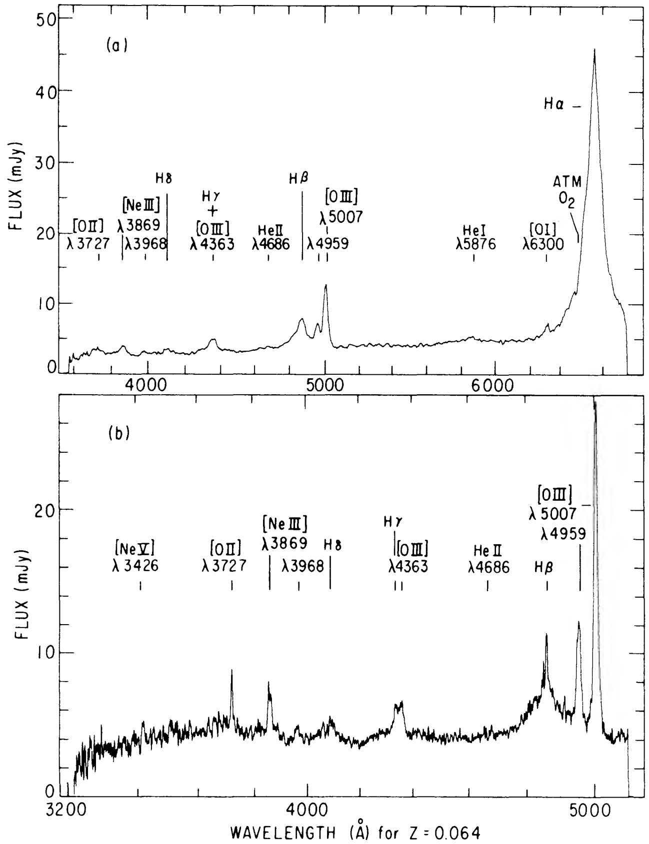

FIG. 1.—Spectra of MR 2251−178 obtained (*a*) with the Mark I spectrometer (500 channels with effective resolution of ~21 Å), and (*b*) with the Mark II spectrometer (2000 channels with effective resolution of ~3.5 Å). The wavelength scale has been shifted to the frame of the QSO. See text for a discussion of systematic uncertainties.

TABLE 2

LINE STRENGTHS OF MR 2251−178

Line	Relative Flux* ($H\beta = 100$)
Hα	480±44
[O I] λ6300	2±1
He I λ5876	24±12
[O III] λ5007	65±7
[O III] λ4959	23±4
Hβ (total)	100±17
Hβ (spike)	4±2
He II λ4686	2±1
[O III] λ4363†	10±5
Hγ†	30±10
Hδ	30±10
[Ne III] λ3968	10±4
[Ne III] λ3869	7±2
[O II] λ3727	14±2
[Ne V] λ3426	4±2

* Errors quoted do not include systematic uncertainties in flux calibrations of up to 30% (see text). Fluxes are corrected for assumed $E_{B-V} = 0.1$ in the Galaxy. The corrected Hβ flux is $9.3 \pm 1.6 \times 10^{-13}$ ergs cm^{-2} s^{-1}.

† Based on assumed [O III] flux; see text.

ties of ~4500–5000 km s^{-1}, which are also at the high end of the range of Baldwin's values.

The Hβ core has a peculiar, multipeaked appearance in Figure 1*b* which could possibly be of instrumental origin (see § II). The prominent spike has a FW0I of ~500 km s^{-1}, which makes it marginally narrower than the forbidden lines. The Hα profile is qualitatively similar in shape to that of PKS 2135−14 (Baldwin 1975*a*, *b*).

The Balmer-line strengths are listed in Table 2. The strength of Hγ was determined by making the ad hoc assumption that (50 ± 25)% of the narrow part of the line is [O III] λ4363 (however, this [O III] strength is plausible; see below). The computed Balmer decrements corrected for galactic extinction are $\alpha/\beta = 4.7 \pm 0.9$, $\gamma/\beta = 0.35 \pm 0.10$, and $\delta/\beta = 0.3 \pm 0.1$, where α/β is the ratio of the strength of Hα to Hβ, etc. These decrements imply a reddening at the source of $E_{B-V} \sim 0.5$ if the intrinsic decrements are due to recombination (see Osterbrock 1974; Baldwin 1975*b*). However, Baldwin (1975*b*) discusses several reasons why collisional excitation is at least partially responsible for the observed decrements, so the true intrinsic reddening is probably significantly smaller than this. The Hβ luminosity is 1.4×10^{43} ergs s^{-1} (for $A_v = 0.31$, and Hubble constant $H_0 = 50$ km s^{-1} Mpc^{-1}; see Weedman 1976*b*).

The only other permitted lines in Figure 1 are He II λ4686 and He I λ5876. Both are weak and probably broad. The poorly determined line strengths relative to Hβ are within the range of those reported by Baldwin (1975*b*). There is no evidence of Fe lines in the spectra of MR 2251−178. Iron emission is present in the spectrum of "nearly every Seyfert type 1 galaxy" (Osterbrock 1977; see also Phillips 1977), but it is only occasionally detected in QSO spectra.

c) *Forbidden Lines*

The spectra of MR 2251−178 show lines of [N II], [O I], [O II], [O III], [Ne III], and [Ne V]. The FW0I of [O III] λ5007 and λ4959 and [Ne III] λ3869 are ~2000 km s^{-1}. The [O III] λ3727 line appears narrower (FW0I ≈ 1000 km s^{-1}), and the others are too weak to measure reliably. All of the forbidden-line fluxes are within the ranges given by Baldwin (1975*b*). The value 0.22 ± 0.04 for the ratio of the flux of [Ne III] λ3869 + λ3968 to that of [O III] λ4959 + λ5007 is at the extreme high end of this range, which could imply electron densities of $\sim 5 \times 10^6$ cm^{-3} in the emitting region if photoionization is assumed (see Baldwin 1975*b* for details of the interpretations of flux ratios). The estimated strength of [O III] λ4363 used to deduce the Hγ strength is ~10% of the [O III] λ4959 + λ5007 strength and falls within Baldwin's (1975*b*) range for this parameter. The lines of [N II] at λ6548 and λ6583 are evident in spectrum no. 3 (Table 1) but are weak.

d) *Continuum*

We have used the data of Figure 1*a* to estimate the spectral index of the continuum and found $\alpha \sim -1.4 \pm 0.6$ (where log [flux] ~ α log [frequency]). This number is subject to several known systematic effects which contribute to the uncertainty, such as possible contamination by unsuspected lines and improper efficiency calibration. The comparable value for the X-ray data of Ricker *et al.* (1978) is $\alpha = -0.5 \pm 0.5$, and a comparison of the optical (Ricker *et al.*, private communication) and X-ray fluxes gives $\alpha \sim -1.0$.

The shape of the continuum on Figure 1*b* around [Ne III] λ3869 and blueward appears to rise and then fall, with even a suggestion of broad emission features. This may be spurious, since the instrumental efficiency of this region is small and rapidly changing and is thus somewhat difficult to calibrate. Integration of the data of Figure 1*a* with the standard response curves (Allen 1973) gives $m_v = 14.5$, $m_B = 15.3$ (subject to the systematic uncertainties described above). These can be compared with the values $m_v = 14.1$, $m_B = 14.6$ determined photoelectrically 2 weeks later at McGraw-Hill. Examination of plates in the Harvard collection shows historical variability on such time scales, so the comparison is only approximate. The photoelectric value implies $M_v = -24.2$ for H_0 and A_v as quoted above. (Photometric details will be published separately, but note that the object is significantly brighter than was estimated by Ricker *et al.* 1978 from 25-year-old POSS plates.)

IV. CONCLUSION

We find that the spectrum of MR 2251−178 is in general similar to that of other low-redshift QSOs. Margon and Kwitter (1978) draw a similar conclusion from their spectrum of the third X-ray QSO, 0241+622. By contrast, the spectrum of 3C 273 is unusual in that the forbidden lines and He II λ4686 are weak or absent (Baldwin 1975*a*; Boksenberg *et al.* 1975). Since the ratio of the X-ray to optical luminosity of MR 2251−178 is several times that of 3C 273 (see Ricker *et al.* 1978, and private communication), the peculiarities in the spectrum of 3C 273 cannot be ascribed to the X-ray emission (see Margon 1977).

The normality of the spectra of MR 2251−178 and 0241+622 (Margon and Kwitter 1978) implies that either all QSOs are X-ray emitters or the spectral properties of QSOs are unaffected by the presence or absence of a cutoff in the continuum at some frequency below the X-ray band. The former possibility (also suggested by Ward *et al.* 1978) is consistent with the observations, since the three X-ray–emitting QSOs are just above the threshold of current detectors and have the highest apparent magnitudes of such objects (Apparao *et al.* 1978). On the other hand, the photoionization models of QSO emission lines (see Davidson 1972, 1973; MacAlpine 1972) do show sensitivity to continuum shape but are probably flexible enough to accommodate continua with and without a cutoff.

Margon and Kwitter (1978) quote a rather narrow Hα width of ~10,300 km s^{-1} for MR 2251−178 (from a Lick scan obtained by H. E. Smith) compared with the ~18,000 km s^{-1} width reported here for Hβ and the apparently even larger but more uncertain Hα width. Another scan acquired by M. Ward (private communication) at the AAT shows a width of ~18,000 km s^{-1} for the Hα wings and ~19,000 km s^{-1} for Hβ. Preliminary analysis of a spectrum obtained by two of us (C.R.C. and J.E.M.) at the CTIO 4 m telescope gives comparable values. Some of this apparent discrepancy may result from instrumental differences and differing estimates of the true extent of the line wing. But if there is a correlation between X-ray luminosity and line widths, as suggested by Elvis *et al.* (1978) for Seyferts, then the known X-ray variability of MR 2251−178 (Ricker *et al.* 1978) would give a corresponding variability in line widths.

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Note added in proof.—The narrow Hα width quoted by Margon and Kwitter (1978) refers to the well-defined sharp portion of the line (Margon, private communication). Their spectrum shows a full width of the wings of ~18,000 km s^{-1}, in good agreement with the other values. This removes any evidence for variability.

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