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ON THE SPECTRUM AND RELATIVE INTENSITIES OF INTERSTELLAR OH LINES

The initial detection of the OH lines in the interstellar medium involved the two strongest lines at 1665.402 Mc/s and 1667.357 Mc/s of the four hyperfine lines making up the $^2\Pi_{3/2}$, J = 3/2, Λ-doublet.[1] Subsequent observations resulted in the detection of the two weaker lines at 1612.201 Mc/s and 1720.559 Mc/s.[2] The strong OH absorption in the direction of the galactic centers, noted by the Australian workers,[3] and the unexpected disagreement between the theoretical and observed intensity ratios of the lines,[2] make it important to consider the detection possibilities of other radio lines of OH in the interstellar medium. A discussion of molecular energy levels and the physical mechanism responsible for the Λ-doublet levels of OH has been prepared for publication elsewhere,[4] but in this article we wish to call attention to 14 microwave lines of various energy levels and isotopic species of OH, some of which appear to be capable of detection at the present time. The line frequencies, theoretical relative intensities, and transition probabilities are presented in Table I. The frequencies have been computed by using the theory of Dousmanis, Sanders, and Townes,[5] and the hyperfine coupling constants given by Radford.[6] The dipole moment for all isotopic species has been taken to be $(1.60 \pm 0.12) \times 10^{-18}$ e.s.u., although this was determined only for $O^{16}H^1$.[7]

The lines given in Table I arise from the ground levels of $O^{16}H^2$, $O^{18}H^1$, and the ground and excited states of $O^{16}H^1$. Detection of the $O^{16}H^2$ lines does not appear to be very probable, because of the upper limit of 1/13,000 for the

$H^2/$[redacted] abundance ratio in the direction of Cassiopeia A,[8] therefore only the strong $\Delta F = 0$ lines are presented. The OH/H abundance ratio, however, varies by a factor of ~1000 between the directions of Cassiopeia A and the galactic center,[1,3] hence large spatial variations in the H^2/H^1 abundance ratio might also exist. The lines of $O^{18}H^1$ are particularly interesting. If the terrestrial O^{18}/O^{16} abundance ratio of 1/490 holds throughout the galaxy, then an optical depth of $\sim 2 \times 10^{-3}$ can be expected for the +40 km/s component of OH absorption in the galactic center. This would give an absorption of $\sim 0.5°K$ for the 210-ft radio telescope at Parkes. A further consideration of the $O^{18}H^1$ lines is that their frequencies are sufficiently close to the $O^{16}H^1$ lines that new equipment is not needed. The frequencies of the first two excited states of $O^{16}H^1$ are also given in Table I. Because of radiative decay to the ground state, detection of these lines is less probable but the population of these levels could be drastically influenced either by the infrared radiation field or the method of production of OH in the interstellar medium.

An unexpected result of the astronomical OH observations is that the intensities of the four $^2\Pi_{3/2}$, $J = 3/2$ lines are in the ratios 1:2.2:2.7:1, whereas the theoretical values are 1:5:9:1.[2] A possible explanation is the existence of many small condensations of large optical depth,[2,3] but very special velocity and spatial distributions are needed to explain the entire observed profile. The OH observations have been interpreted by using the radiation theory developed by Milne[9] as modified by Wild[10] for the radio domain, but this theory may be inappropriate when the distance between absorbers is large compared with a wavelength and the radiation field is nonisotropic. Milne, and consequently Wild, considered isotropic radiation in the derivation of the optical depth and no account was taken of the possibility of atomic (or molecular) resonant coherent scattering.[11] If it is assumed that α is the fraction of the cross section for

 [redacted]

resonant scattering out of the beam, then the optical depth τ and volume emissivity η can be written as

$$\tau = \tau_o(1 + 2\alpha \frac{kT_s}{h\nu}), \qquad \eta = \eta_o\ (1 + 2\alpha \frac{kT_r}{h\nu}),$$

where τ_o and η_o are the values for the case of no scattering, and T_s and T_r are the excitation and radiation temperatures, respectively. The scattering parameter α is a function of the density of scatterers and the transition probability of the line and, therefore, will be different for each line. It follows that the ratio of intensities of the OH lines will be in disagreement with the ratios computed with scattering neglected. Furthermore, since α is a function of the position of the gas cloud relative to the continuum radio source, α may vary within the galaxy, and the line intensity ratios will vary accordingly. Note, also, that for T_s of the order of 1^oK the optical depth may be as much as an order of magnitude greater than previously supposed. This may have a consequence for the problem of detecting weak radio lines, such as $O^{18}H^1$. To the extent that the radiation field is nonisotropic in intergalactic space, the scattering effect may force a reinterpretation of attempts to detect the intergalactic medium by a 21-cm absorption.[12,13]

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TABLE I

COMPUTED FREQUENCIES OF OH Λ-DOUBLET TRANSITIONS, INCLUDING HYPERFINE STRUCTURE, FOR VARIOUS STATES AND ISOTOPIC SPECIES

Isotopic Species	State	Transition $j \rightarrow i$	Frequency Mc/s	Relative Intensity	A_{i-j} sec^{-1}
$O^{16}H^1$	$^2\Pi_{3/2}$, J = 3/2	F = 2 → 1	1612.201 ± 0.017	1	4.50×10^{-12}
		F = 1 → 1	1665.357 ± 0.007	5	2.47×10^{-11}
		F = 2 → 2	1667.402 ± 0.007	9	2.66×10^{-11}
		F = 1 → 2	1720.559 ± 0.024	1	3.24×10^{-12}
	$^2\Pi_{3/2}$, J = 5/2	F = 3 → 2	6017.2 ± 1.0	1	4.17×10^{-11}
		F = 2 → 2	6031.2 ± 1.0	14	5.92×10^{-10}
		F = 3 → 3	6035.2 ± 1.0	20	6.03×10^{-10}
		F = 2 → 3	6049.1 ± 1.0	1	[illegible].03 $\times 10^{-11}$
	$^2\Pi_{1/2}$, J = 1/2	F = 1 → 0	4699 ± 4.0	1	[illegible].56 $\times 10^{-10}$
		F = 1 → 1	4717 ± 4.0	2	1.73×10^{-10}
		F = 0 → 1	4810 ± 4.0	1	9.10×10^{-11}
$O^{16}H^2$	$^2\Pi_{3/2}$, J = 3/2	F = 5/2 → 5/2	310.24 ± 0.10	10	1.32×10^{-13}
		F = 3/2 → 3/2	310.06 ± 0.10	4.3	8.45×10^{-14}
		F = 1/2 → 1/2	309.97 ± 0.10	2.2	8.74×10^{-14}
$O^{18}H^1$	$^2\Pi_{3/2}$, J = 3/2	F = 2 → 1	1584.3 ± 0.2	1	4.30×10^{-12}
		F = 1 → 1	1637.3 ± 0.2	5	2.36×10^{-11}
		F = 2 → 2	1639.3 ± 0.2	9	2.54×10^{-11}
		F = 1 → 2	1692.3 ± 0.2	1	3.10×10^{-12}