Fine Structure and Isotope Shift of the $3s4d\ ^3D$ - $3s3p\ ^3P$, $3s5d\ ^3D$ - $3s3p\ ^3P$ and $3p^2\ ^3P$ - $3s3p\ ^3P$ Transitions of MgI.

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Summary. — We report the measurements of the $^3D(3s4d)$ - $^3P(3s3p)$, $^3D(3s5d)$ - $^3P(3s3p)$, and $^3P(3p^2)$ - $^3P(3s3p)$ transition frequency of MgI, the fine-structure separation and isotope shift between ^{24}Mg and ^{26}Mg . The measurements have been performed in a metastable atomic beam; a good agreement is found for data already existing in the literature. The accuracy of the measurements reported in this paper is mainly limited by the Doppler broadening of the I_2 transitions used as a reference and by the precision in the knowledge of the related wavelengths.

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1. – Introduction.

High-resolution spectroscopic studies of the first-excited states of Mg have been performed mainly in recent years; the fine-structure splittings of the metastable triplet $^3P^{(0)}$ are reported in [1,2], the isotope shifts and hyperfine splittings in [3-5]. Moreover, the isotope shift and hyperfine splittings of the following transitions have been measured: $3s4s\ ^3S$ - $3s3p\ ^3P$ [6,7], the $3s3d\ ^3D$ - $3s3p\ ^3P$ [8,9], the $3s4d\ ^3D$ - $3s3p\ ^3P$ [9] and $3s^2\ ^1S_0$ - $3s3p\ ^1P_1$ [10].

The transitions between the terms $^3P(3p^2)$, $^3D(3s4d)$, and $^3D(3s5d)$, and the term $^3P^{(0)}(3s3p)$ of MgI fall in the (277 ÷ 310) nm wavelength range, covered by frequency duplication of the rhodamine dyes.

A high-resolution investigation of these terms is interesting in order to complete the literature data. In fact, except for the $^3D(3s4d)$ fine-structure splittings, already cited above, the major work on the matter remains the one of Risberg [11] who measured about 160 lines of MgI and whose data make the body of a critically compiled collection of energy levels of MgI [12]. That work was performed with classical hollow-cathode discharge lamps and isotope shifts were not resolved. We have performed the measurements in a metastable atomic beam which assures a sub-Doppler resolution to the experiment. The source of radiation is a commercial

ring dye-laser equipped with an intracavity nonlinear crystal of KDP for second-harmonic generation.

2. – Experimental set-up.

The metastable Mg beam used in the experiment has been described elsewhere[13]. Here we recall simply that the efficiency of production of metastable atoms reaches 40%; a fraction of the atoms in the beam, therefore, is left in the ground state, thereby making possible also measurements on the 1S_0 - 1P_1 resonance line whose wavelength falls in the same spectral interval of the transitions which are of major interest in the present work.

The interaction between the atomic beam and the laser radiation occurs downstream 0.5 m from the source of metastable atoms; in that region, a static magnetic field of 2 G defines the quantization axis and a photomultiplier immediately above the interaction zone detects the fluorescence of the atomic beam. The laser employed is a commercial ring dye-laser stabilized to an external reference cavity and pumped by an Ar^+ laser which can deliver up to 8 W at 514 nm.

We used the rhodamine 110 dye for the 3P - $^3P^{(0)}$ lines and the rhodamine 6G for the 3D - $^3P^{(0)}$ lines and the resonance line.

The dye-laser is provided with an intracavity KDP nonlinear crystal and can deliver up to 6 mW CW at the second-harmonic frequency when it is tuned in correspondence with the top of the gain curve of R110. In this experiment, however, the UV power density was kept below the saturation level for the relevant transitions ($\sim 1 \text{ mW/cm}^2$).

A fraction of the light at the fundamental frequency is sent both to a commercial wavelength meter for the coarse tuning of the dye-laser and to an I_2 cell at room temperature ($T \sim 21^\circ\text{C}$). The linear absorption lines of I_2 are used as frequency references[14]: for each Mg transition we look for the nearest iodine absorption and record it together with the atomic beam fluorescence *vs.* the laser frequency.

3. – Results.

The transitions of concern in this work are schematically shown in fig. 1: the corresponding wavelengths are indicated as well.

For each term we have examined all the transitions; however, we report the wavelengths and isotope shifts for one component only, because the others can easily be deduced from the fine structure of the terms involved.

Within the accuracy limits of the experiment we have not observed any dependence of the isotope shifts from the angular quantum number J .

In table I we summarize the results of the measurements concerning the fine structure and the isotope shifts.

For each term we report also the absolute wavelength of one transition and the distance of the relevant line from the second harmonic of the nearest I_2 reference absorption; the assignment of the I_2 line is also indicated. The values quoted in the literature are reported too, and we find a good agreement with previous works[12].

As stated before, the fine-structure separation of the $^3D(3s4d)$ term is already well known and the existing data[9,12] have been used for the calibration of the scan

Fig. 1. – Schematics of the MgI energy levels of concern in this work. The transitions reported in table I and the relative wavelengths are indicated.

width of the dye-laser. This turns into a smaller error for the isotope separation of this term, as compared to the other two.

In fig. 2 we report a record of the fluorescence signal of the $^3P_2(3s3p)$ - $^3D(3s5d)$ transitions corresponding to a nominal scan width of 4 GHz; the equivalent video bandwidth is 1 Hz. One can see directly from the figure the fine-structure separation of the 3D term.

Here the calibration of the frequency scan width has been done with respect to the I_2 linear absorptions, and the Doppler broadening of the latter turns into a ± 40 MHz absolute error for the quoted results.

The linewidths of the observed transitions are mainly due to the radiative lifetime

TABLE I. – Summary of the measurements concerning the $^3D(3s4d)$, $^3D(3s5d)$ and $^3P(3p^2)$ terms. Δ^{26-24} is the isotope shift between ^{26}Mg and ^{24}Mg .

	$^3P_1^{(0)}(3s3p)$ - $^3D_1(3s4d)$	$^3P_1^{(0)}(3s3p)$ - $^3D_2(3s5d)$	$^3P_1^{(0)}(3s3p)$ - $^3P_0(3p^2)$
$\lambda^{-1}(\text{cm}^{-1})$	32321.867 ± 0.008 $32321.871 \pm 0.02^{(a)}$	35097.782 ± 0.008 $35097.784 \pm 0.02^{(a)}$	35942.300 ± 0.008 $35942.31 \pm 0.02^{(a)}$
I_2	P97(10-3)	P102(20-1)	R32(21-0)
$\nu(^{24}\text{Mg}) - 2\nu(I_2)$ (GHz)	-1.68 ± 0.15	3.16 ± 0.15	2.16 ± 0.15
Δ^{26-24} (MHz)	420 ± 20	650 ± 40	1810 ± 80
fine-structure splittings	3D_2 - 3D_3 (1146 $\pm$ 9) MHz $^{(b)}$ 3D_1 - 3D_3 (2377 $\pm$ 12) MHz $^{(b)}$	3D_2 - 3D_3 (883 $\pm$ 40) MHz 3D_1 - 3D_3 (1705 $\pm$ 40) MHz	3P_1 - 3P_0 (618.70 $\pm$ 0.3) GHz 3P_2 - 3P_1 (1215.31 $\pm$ 0.3) GHz

(a) Ref. [12].

(b) Ref. [9].

Fig. 2. - Record of the $^3D(3s5d)$ - $^3P_2(3s3p)$ fluorescence. The scan width is 4 GHz and the equivalent bandwidth is 1 Hz.

of the upper levels and to the residual Doppler broadening related to the atomic-beam divergence; a minor contribution may also be due to the frequency jitter of the laser radiation.

For the $^3P(3p^2)$ term we report in fig. 3 a record of the fluorescence corresponding to the $^3P_0(3s3p)$ - $^3P_1(3p^2)$ transition with the same equivalent video bandwidth as in fig. 2 and a scan width of 3.8 GHz. The calibrations have been performed with respect to the hyperfine structure of the $^3P^{(0)}(3s3p)$ level[3] of ^{25}Mg , when the laser is tuned on the $^3P_1(3s3p)$ - $^3P_0(3p^2)$ transition.

The hyperfine structure of ^{25}Mg is not resolved for the $^3P(3p^2)$ levels, being smaller than the natural linewidth; as we can see from the figure, however, the centre of gravity of the ^{25}Mg transition is shifted with respect to the even isotopes by the amount expected from the mass ratios.

By tuning the laser on the $^3P_1^{(0)}$ - 3P_2 transition at 277.7 nm and by monitoring at the same time the fluorescence on the $^3P_1^{(0)}$ - 1S_0 intercombination line at 457.1 nm, we have observed the depletion of the $^3P_1^{(0)}$ level by optical pumping: with a

Fig. 3. - Record of the $^3P_1(3p^2)$ - $^3P_0(3s3p)$ fluorescence. The scan width is 3.8 GHz and the equivalent bandwidth is 1 Hz.

UV power intensity of 1.5 mW/cm^2 , an optical pumping efficiency of 50% was reached.

It is worth to mention that the $^3P_1^{(0)} - ^3P_0$ transition is a strongly allowed one, the lifetime of the upper level being $\sim 2 \text{ ns}$, of the same order of the resonance line. Selection rules allow spontaneous decay of the 3P_0 level only to the $^3P_1^{(0)}$ state: a closed two-level system exists then between $^3P_1^{(0)}$ and 3P_0 , which makes this transition very interesting for the manipulation of the $^3P_1^{(0)}$ metastable atoms with resonant laser radiation.

Finally, we report briefly the results of the measurements on the $^1P_1 - ^1S_0$ resonance line, not quoted in table I:

$$\Delta^{26-24} = (1400 \pm 40) \text{ MHz}, \quad \lambda^{-1} = (35051.263 \pm 0.008) \text{ cm}^{-1}, \quad I_2: \text{R115 (20-1)};$$

they are in quite good agreement with the data reported in the literature [10].

4. - Conclusions.

The measurements performed improve the knowledge of these terms of MgI which was based only on a few experiments. For quantities already known we find a good agreement with the data reported in the literature; the final uncertainty ($\pm 3 \cdot 10^{-7}$) of the new data which constitute the original part of the present work is limited mainly by the Doppler broadening of the I_2 lines used as a reference and by the precision in the knowledge of their absolute wave numbers.

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