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Absolute polarization measurements and natural lifetime in the $7 S_{1/2}$ state of Cs

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Résumé. — Nous présentons des mesures par effet Hanle de la relaxation dans l'état $7 S_{1/2}$ du césium induite par collisions avec des atomes de césium ou des atomes de gaz tampon (hélium), en présence d'un champ électrique. Les résultats montrent que la relaxation de la polarisation électronique reste isotrope dans la configuration adoptée et justifient le procédé de calibration utilisé dans nos récentes mesures de violation de la parité sur la transition 6 S-7 S du césium. Nous obtenons aussi la durée de vie de l'état $7 S_{1/2}$: $\tau_{7S} = 48,5 \pm 0,5$ ns (et la section efficace de dépolarisation $\sigma_{CsHe} = (1,10 \pm 0,05) \times 10^{-15}$ cm²). Par suite la valeur semi-empirique de la polarisabilité scalaire de la transition 6 S-7 S devient $\alpha = -(265,1 \pm 2,5) a_0^3$.

Abstract. — We report Hanle effect measurements of the relaxation in the $7 S_{1/2}$ state of cesium by collisions with cesium or buffer gas (helium) atoms in an electric field. The results show the relaxation of the spin polarization to remain isotropic in the adopted configuration, and justify the calibration procedure used in our recent measurements of parity violation in the 6 S-7 S transition of cesium. We also obtain the lifetime of the $7 S_{1/2}$ state : $\tau_{7S} = 48.5 \pm 0.5$ ns (and the depolarization cross-section $\sigma_{CsHe} = (1.10 \pm 0.05) \times 10^{-15}$ cm²). Accordingly the semi-empirical value of the scalar polarizability of the 6 S-7 S transition becomes $\alpha = -(265.1 \pm 2.5) a_0^3$.

1. Introduction.

The primary motivation of the present work was to establish the *validity of the calibration procedure* used in our recent measurements of *parity violation* effects induced in cesium by weak neutral currents [1]. In this experiment, the signal of interest is a small electronic spin polarization P^{PV} . To eliminate the depolarization (typically ~ 10 -15 %) due to collisions as well as imperfections in the detection optics, a calibration is necessary. It is performed by measuring with the same optics a second electronic spin polarization $P^{(2)}$ whose value is accurately known from independent studies. However, $P^{(2)}$ happens to be created in a direction orthogonal to P^{PV} . Consequently, for the method to be valid *the relaxation by collisions has to be isotropic* in our experimental configuration.

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The results presented here, obtained by Hanle effect measurements, demonstrate isotropic relaxation. Extrapolation to zero buffer gas and atomic vapour pressure yields a precise determination of the lifetime τ_{7S} of the 7 S state of cesium, as well as the Cs-He (and Cs-Cs) collision cross-section. The comparison of the measured lifetime with the theoretical prediction is a test of the atomic model of cesium employed to interpret our parity violation measurements [2]. Besides, τ_{7S} is one of the input parameters for a semi-empirical determination of the 6 S-7 S Stark-induced electric dipole transition probability, following a procedure first proposed by J. Hoffnagle *et al.* [3]. Since our experimental value of τ_{7S} differs from these authors' result, the corresponding value of the scalar polarizability α is slightly modified.

2. Principle of the method.

2.1 HANLE EFFECT. — In order to detect with the same optics, i.e. in the same direction, two electronic polarizations created in orthogonal directions, Hanle rotation in a dc magnetic field was chosen as a convenient tool.

The evolution of the spin polarization $\mathfrak{F}$ of the $7S_{1/2}$ state under simultaneous effect of relaxation. Larmor precession in a magnetic field $\mathbf{H}$ and creation (by polarized optical excitation), can be described by the phenomenological equation :

$$\frac{d\mathfrak{F}}{dt} = -\frac{\mathfrak{F}}{T} + \gamma \mathfrak{F} \times \mathbf{H} + \frac{\mathbf{P}}{\tau}. \quad (1)$$

Here $\gamma = g_F \gamma_S$ (with $\gamma_S = -|e|/m$) depends on the hyperfine sublevel $F = I + \varepsilon/2$ ($I = 7/2$; $\varepsilon = \pm 1$) through $g_F = \varepsilon/(2I + 1)$ ⁽¹⁾. In the source term $\mathbf{P}/\tau$, τ is the decay time of the 7 S state population and $\mathbf{P}$ is the stationary value that would be obtained in zero magnetic field in the absence of depolarizing collisions (the relaxation rate $1/T$ then reduces to the decay rate $1/\tau$). The term $-\mathfrak{F}/T$ describes the relaxation, *assumed to be isotropic*. The relaxation rate $1/T$ is assumed to be independent of the magnetic field.

From equation (1), the stationary value of the polarization $\mathfrak{F}$ satisfies :

$$\mathfrak{F} + \mathfrak{F} \times (\mathbf{H}/\Delta H) = (T/\tau) \mathbf{P} \quad (2a)$$

where we have introduced the notation :

$$\Delta H = -1/\gamma T. \quad (2b)$$

Equations (2) show that the magnitude of $\mathbf{H}$ acts only through its ratio to the characteristic field ΔH (usually called « Hanle width »), irrespective of the direction of $\mathbf{H}$. Equations (2) also show that the source polarization $\mathbf{P}$ does not act directly, but is only affected by the factor (T/τ) . Since the total relaxation rate $1/T$ is the sum of the population decay rate τ^{-1} and of the collisional depolarization rate, the factor T/τ is always smaller than unity. This depolarization factor does not depend on the direction of $\mathbf{P}$.

This would not remain true, however, *if the collisional relaxation were anisotropic*. The quantity $1/T$ would become a matrix, and equations (2) would be replaced by :

$$\mathfrak{F} - \gamma \left[\frac{1}{T} \right]^{-1} (\mathfrak{F} \times \mathbf{H}) = \frac{1}{\tau} \cdot \left[\frac{1}{T} \right]^{-1} \cdot \mathbf{P}, \quad (3)$$

⁽¹⁾ The effect of the Cs nuclear spin can be described simply through this g -factor g_F . It can be shown that hyperfine mixing contributes only to corrections of second order in $\mu_B H/\hbar\omega_{hf}$, which remains $\lesssim 10^{-4}$ in the H range explored here.

Fig. 1. — 1a) Experimental configuration. $\vec{E}$: dc electric field. 1b) Components of the electronic polarization $\mathbf{P}$ (source term of Eq. (1)) created in the 7 S state.

which shows that both the Hanle width and the depolarization factor would become anisotropic quantities. Because of the isotropy of space, this possible anisotropy would have to originate in the particular (anisotropic) experimental configuration. Our configuration is represented in figure 1a. The 6 S-7 S transition is essentially Stark-induced by an electric field along y . It is excited by a single-mode laser beam propagating along z , which selects atoms of zero velocity component along z . Since the number of polarized Cs atoms in the 7 S state is negligibly small compared with the number of Cs atoms in the ground state or of He atoms, the relaxation by (polarized Cs)-(polarized Cs) collisions can be neglected. Consequently the *polarization* of the laser beam, which acts only as the source of the Cs polarization, plays no rôle in the relaxation process. We are led to study the relaxation of atoms with $v_z = 0$ in the electric field $\vec{E} \parallel y$. This configuration possesses two planes of symmetry, xy and yz . Therefore, in the anisotropic case the eigen-directions of the relaxation would be x , y and z , with respective relaxation rates T_x^{-1} , T_y^{-1} and T_z^{-1} .

In most measurements described below, the source polarization $\mathbf{P}$ is along the laser direction z , and the detection direction is x . From equation (3) the relation between the source polarization P_z and the measured signal $\mathcal{F}_x$ is then found to be :

$$\mathcal{F}_x = \frac{(H_y/\Delta H_y) + (H_x/\Delta H_x) + (H_z/\Delta H_z)}{1 + (H_x/\Delta H_x)^2 + (H_y/\Delta H_y)^2 + (H_z/\Delta H_z)^2} \cdot \frac{(T_x T_z)^{1/2}}{\tau} \cdot P_z. \quad (4a)$$

It involves three different Hanle widths :

$$\Delta H_x = -1/\gamma T_y^{1/2} T_z^{1/2}, \quad (4b)$$

$$\Delta H_y = -1/\gamma T_z^{1/2} T_x^{1/2}, \quad (4c)$$

$$\Delta H_z = -1/\gamma T_x^{1/2} T_y^{1/2}. \quad (4d)$$

These can be measured separately by varying one field component H_k ($k = x, y$ or z) while keeping the two other components constant, and fitting the observed dependence of $\mathcal{F}_x$ on H_k with equations (4). As we shall see below, they turn out to be experimentally equal (isotropic case). From their common value the spontaneous decay rate τ_7^{-1} can be deduced after removal of the collisional processes (Sect. 3.3.2).

2.2 EXPERIMENTAL PROCEDURE. — The apparatus represented in figure 2, is essentially the same as in our previous parity experiments [1]. A laser beam (along z) excites in a cesium vapour one $\Delta F = 0$ hyperfine component of the $6 S_{1/2}$ - $7 S_{1/2}$ transition. This transition is essentially Stark-induced in a dc electric field $\vec{E}$ (along y) orthogonal to the beam. A special polarization modulator modulates the polarization ϵ of the laser beam in such a way that the three polarized Stokes para-

Fig. 2. — Apparatus. M : polarization modulator; ϵ : laser polarization; CA : circular analyser; D : detector; LI : lock-in amplifiers.

meters $2 \operatorname{Im} \epsilon_x^* \epsilon_y$ (circularly polarized intensity), $|\epsilon_x|^2 - |\epsilon_y|^2$ (intensity polarized linearly along x or y) and $2 \operatorname{Re} \epsilon_x^* \epsilon_y$ (intensity polarized linearly along one or the other bisectrix of x and y) are labelled with different frequencies or phases [4]. To enhance the signals, for most measurements the laser beam performs a multipass in the sample cell [5].

In the electronic polarization $\mathbf{P}$ created in the $7S$ state three contributions are relevant ⁽²⁾ (Fig. 1b) :

i) Interference between the M_1 and Stark-induced E_1 transition amplitudes gives rise to a polarization $\mathbf{P}^{(1)}$ in the xy plane [6] (typical magnitude : $\sim 10^{-2}$ for a single pass of the laser beam ⁽³⁾). Its components $P_x^{(1)}$ and $P_y^{(1)}$ are respectively modulated like the components $|\epsilon_x^2| - |\epsilon_y^2|$ and $2 \operatorname{Re} \epsilon_x^* \epsilon_y$ of the linear polarization of the exciting light. Since these two quantities are expected and observed to be modulated with equal amplitudes, so are also $P_x^{(1)}$ and $P_y^{(1)}$.

ii) Interference between the scalar and vector parts of the Stark-induced E_1 amplitude [7] gives rise to a polarization $\mathbf{P}^{(2)}$ along the laser beam (typical magnitude $\sim 8 \times 10^{-2}$). It is modulated like the circularly polarized intensity $2 \operatorname{Im} \epsilon_x^* \epsilon_y$.

iii) In presence of a magnetic field $\mathbf{H}$ a hyperfine mixing induced polarization is created along $\mathbf{H}$ by direct excitation *via* the E_1 amplitude. This polarization $\mathbf{P}_{\text{hf}}$ is proportional to $\mathbf{H}$. (Typical values : $H \sim 10$ G, $P_{\text{hf}} \sim 10^{-2}$). It is modulated like $|\epsilon_x^2| - |\epsilon_y^2|$ ⁽⁴⁾.

The expressions and magnitudes of the three polarizations $\mathbf{P}^{(1)}$, $\mathbf{P}^{(2)}$ and $\mathbf{P}_{\text{hf}}$ are given in table I.

The x component $\mathcal{P}_x$ of the stationary polarization in the $7S$ state is measured *via* the circular polarization ratio of the $7S_{1/2}$ - $6P_{1/2}$ fluorescence light emitted in the x direction. The respective contributions of $P_x^{(1)}$ (or $\mathbf{P}_{\text{hf}}$), $P_y^{(1)}$ and $\mathbf{P}^{(2)}$ are easily distinguished by lock-in detection at the corresponding frequencies and phases. The final distinction between $P_x^{(1)}$ and $\mathbf{P}_{\text{hf}}$ (modulated with the same frequency and phase) is obtained by reversing the electric field $\mathbf{E}$ ($P_x^{(1)}$ is odd while $\mathbf{P}_{\text{hf}}$ is even) and the magnetic field ($P_x^{(1)}$ is even, $\mathbf{P}_{\text{hf}}$ is odd).

Three pairs of coils supply the three components of the dc magnetic field. The measurements essentially consist in recording the dependence of the various polarizations on the coil currents that produce H_x , H_y and H_z .

⁽²⁾ Here we neglect the tiny parity-violating contribution $\mathbf{P}^{\text{pv}}$, measured in Ref. [1], irrelevant in the present work.

⁽³⁾ Since this polarization $\mathbf{P}^{(1)}$ is odd under reversal of the laser beam direction, the related measurements were performed with a *single-pass* configuration of the laser beam.

⁽⁴⁾ This polarization $\mathbf{P}_{\text{hf}}$ will be studied in a forthcoming paper.

Table I. — 7 S state polarizations created in the excitation of the 6 S, $F \rightarrow 7$ S, F transition of cesium by Stark interference effects : $P^{(2)}$ and $P^{(1)}$ are created in absence of magnetic field, P_{hf} is induced by hf mixing in a field H . α and β are the scalar and vector polarizabilities ; M_1 is the magnetic dipole amplitude ; $g_F = \epsilon/(2I + 1)$ for the hf sublevel $F = I + \epsilon/2$ ($I = 7/2$; $\epsilon = \pm 1$) ; ω^{hf} (2 184 MHz) is the hfs of the 7 S state. Expected magnitudes of P_{hf} are computed for $H = 10$ gauss and of $P^{(1)}$ for $E = 500$ V/cm.

Theoretical expression (*)		Expected magnitudes		Incident light Pol. dependence
		4 $\rightarrow$ 4	3 $\rightarrow$ 3	
$P_x^{(1)}$	$\frac{2}{3}(1 + 2g_F)\frac{M_1}{\alpha E}\left(1 - g_F\frac{\beta}{\alpha}\right)$	5.05×10^{-3}	3.02×10^{-3}	$ \epsilon_y ^2 - \epsilon_x ^2$
$P_y^{(1)}$	—	—	—	$\text{Re}(\epsilon_x^* \epsilon_y)$
$P^{(2)}$	$-\frac{2}{3}(1 + 2g_F)\frac{\beta}{\alpha}$	8.45×10^{-2}	5.06×10^{-2}	$\text{Im}(\epsilon_x^* \epsilon_y)$
P_{hf}	$\epsilon\frac{4}{3}(1 - g_F)\frac{\mu_B H}{\hbar\omega_{\text{hf}}}$	7.49×10^{-3}	-9.62×10^{-3}	$ \epsilon_y ^2 - \epsilon_x ^2$

(*) For the sake of simplicity, terms of the order of β^2/α^2 ($\ll 1$) are omitted here.

3. Measurements and results.

3.1 MAGNETIC FIELD CALIBRATION. — The field/current ratio of each pair of coils was computed from the geometry of the coil. It was then checked by direct field measurements using a gaussmeter initially calibrated in the homogeneous field of a small reference solenoid (accuracy $\sim 1\%$). We take into account a possible slight magnetic susceptibility of the stainless steel capacitor plates that produce the electric field. We measure this by introducing a gaussmeter probe between the plates after opening the cell and removing the cesium. In the cell used for the measurements reported below, at the level of 3×10^{-3} no effect was detected for either H_x or H_y or H_z ⁽⁵⁾.

In addition, the component H_z along the laser beam was independently calibrated, using the atomic vapour as a probe, via the circular dichroism caused by hyperfine mixing [8]. The two values of H_z thus obtained are consistent :

$$H_z (\text{atoms}) = [1.022 \pm 0.01 (\text{stat}) \pm 0.02 (\text{syst.})] \times H_z (\text{G-meter}).$$

3.2 ISOTROPY OF THE RELAXATION. — To check the isotropy of the relaxation three types of tests were performed.

a) The first method essentially consists in checking that *the Hanle width does not depend on the direction of the magnetic field*, as expected in the isotropic case (Eqs. (2), in contrast with Eqs. (4)). We have investigated three magnetic field configurations. In each case a component H_y

⁽⁵⁾ Usually the modification of the magnetic induction is typically $\sim 1\%$. In one sample cell it accidentally attained 20 % in the direction normal to the plates : the resulting apparent anisotropy in the measured Hanle widths, which could have originated in anisotropic relaxation, was one of the motivations of the present work.

is applied and periodically reversed (actually in a random sequence). The H_y -odd fraction of the detected polarization $\mathcal{F}_x$ is recorded in the three following cases :

i) $H_x = H_z = 0$, $|H_y|$ is varied; ii) $H_z = 0$, $|H_y| = \text{constant}$, H_x is varied; iii) $H_x = 0$, $|H_y| = \text{constant}$, H_z is varied. In each case, the observed variation is fitted with the H_y -odd part of equation (4a), i.e.

$$(\mathcal{F}_x)_{H_y\text{-odd}} = \frac{(H_y/\Delta H_y)}{1 + (H_x/\Delta H_x)^2 + (H_y/\Delta H_y)^2 + (H_z/\Delta H_z)^2} \cdot \frac{(T_x T_z)^{1/2}}{\tau} \cdot P_z.$$

In the covered range (0 to $\sim 3 \Delta H$), no systematic deviation appears between the experimental data and the fitted curves ⁽⁶⁾. The width of the obtained dispersion curve (in case i) or absorption curve (in cases ii and iii) respectively yields ΔH_y , ΔH_x and ΔH_z , with a statistical uncertainty of about 0.3 %. Taking into account the field calibration uncertainties, the three Hanle widths are found to be equal :

$$\Delta H_x/\Delta H_y = 1.00 \pm 0.015; \quad \Delta H_z/\Delta H_y = 1.00 \pm 0.015.$$

This establishes the isotropy of the relaxation in our configuration.

b) The second test consists in *comparing the depolarization factors in two orthogonal directions*. The values of $\mathcal{F}_x$ associated with the source polarizations $P_x^{(1)}$ and $P_y^{(1)}$ (§ 2.2) are recorded as a function of H_z (with $H_x = H_y = 0$). In the isotropic case (Eqs. (2)), the expected variations are represented respectively by an absorption curve and by a dispersion curve of *same width* ΔH and of *same height*, since the source polarizations are of equal size. The results, shown in table II, agree with these predictions (on the contrary, in the anisotropic model of equations (4) the Hanle widths would still be equal but the ratio of the heights would be $(T_x/T_y)^{1/2}$). As expected, this width ΔH is found to be equal to the width ΔH_z obtained in § a) using the source polarization $P^{(2)}$.

c) The third test is not only a test of isotropic relaxation : it *checks directly the calibration procedure of our parity experiment*, irrespective of any relaxation model. In this experiment, the polarization to be measured (i.e. the parity violating polarization P^{pv}) was created along the detection direction x . Its measurement was calibrated by reference to the observed signal $\mathcal{F}_x$ associated in a Hanle field H_y with the source polarization $P^{(2)}$, whose value is accurately known from independent studies by several authors [9-11]. In the present test the polarization P^{pv} is replaced by the much larger polarization P_{hf} , created along x as well, in a field H_x of known

Table II. — *Results of Hanle effect measurements using $P^{(1)}$ as source polarization and a magnetic field H_z (Stark field $E = 500$ V/cm).*

Source Polarization	Curve shape	Fitted width (Gauss)	Fitted height
$P_x^{(1)}$	Lorentz absorption	11.16 ± 0.45	$(4.66 \pm 0.06) \times 10^{-3}$
$P_y^{(1)}$	Lorentz dispersion	10.33 ± 0.37	$(4.79 \pm 0.07) \times 10^{-3}$

⁽⁶⁾ This shows the effect of the nuclear spin to be negligible in the present problem, and justifies the simple description by Eq. (1). It also supports the assumption that the relaxation process is independent of the magnetic field.

magnitude. The experimental value of P_{hf}/H_x calibrated by the same method is then compared with the (accurate) theoretical prediction. Within the (mainly systematic) experimental uncertainty, the observed ratio $P_{\text{hf}}/H_x = (9.41 \pm 0.3) \times 10^{-4} \text{ G}^{-1}$ agrees with the theoretical prediction ($9.62 \times 10^{-4} \text{ G}^{-1}$, negligible uncertainty). This justifies the calibration procedure of the parity experiment. It also shows that the use of a judicious polarization standard can make *absolute* polarization measurements reliable, contrary to a sometimes encountered prejudice.

Although P_{hf} could have been chosen in place of $P^{(2)}$ to calibrate the parity experiment, $P^{(2)}$ appeared more judicious for several reasons : i) it is larger by one order of magnitude in a Hanle field ; ii) it is independent of the calibration of the field H ; iii) it has the same dependence upon the incident light polarization as P^{pv} .

Since the value of both $P^{(2)}(\parallel z)$ and $P_{\text{hf}}(\parallel x)$ are accurately known from independent studies, the present result also constitutes a third test of the isotropic relaxation model. Conversely, if isotropic relaxation is assumed, we can start from the theoretical value of P_{hf}/H_x and use the observed P_{hf} to calibrate the field H_x , with the atomic system as the probe. We obtain :

$$H_x(\text{atoms}) = (0.98 \pm 0.02(\text{syst.})). H_x(\text{G-meter}).$$

An interesting feature is that the possible systematic errors in the atomic measurements of H_z and H_x , which have the same origin, are predicted to be just opposite in relative magnitude. Thus we expect this systematic error to disappear in the product $H_x H_z(\text{atoms})$. Indeed this product turns out to be consistent with the product $H_x H_z(\text{G-meter})$ when only the statistical uncertainty ($\sim 1\%$) is taken into account. This gives confidence in our direct (G-meter type) calibration at the level of 1 %.

3.3 COLLISIONAL CROSS-SECTIONS AND 7S LIFETIME. — By measuring Hanle widths in as many different experimental conditions as we could, we have checked the absence of several possible extraneous causes of relaxation. We have found no effect at all of the electric field magnitude or of the laser intensity. The dependence of the Hanle widths on the Cs or He density does not depart from a linear one. The magnetic field dependences do not deviate from Lorentz curves. In conclusion, we have no indication of any relaxation mechanism other than binary Cs-He and Cs-Cs collisions. Consequently, the total relaxation rate T^{-1} can be written as :

$$T^{-1} = \tau_{7S}^{-1} + n_{\text{He}} \sigma_{\text{CsHe}} \bar{v}_{\text{CsHe}} + n_{\text{Cs}} \sigma_{\text{CsCs}} \bar{v}_{\text{CsCs}}. \quad (5)$$

Here τ_{7S} is the radiative lifetime of the 7 S state : n_A ($A = \text{He or Cs}$) is the number of A atoms per unit volume : $\bar{v}_{\text{CsA}}$ is the average relative velocity of a Cs atom and an A atom, equal to :

$$\bar{v}_{\text{CsA}} = 2 \left[\frac{2}{\pi} kT \left(\frac{1}{m_{\text{Cs}}} + \frac{1}{m_A} \right) \right]^{1/2}; \quad (6)$$

σ_{CsA} is then by definition the depolarization cross-section of the 7 S state of cesium by collisions with A atoms. By varying the helium pressure, i.e. n_{He} , one obtains σ_{CsHe} ; by varying the temperature, i.e. $n_{\text{Cs}} \bar{v}_{\text{CsCs}}$, one obtains (in principle) σ_{CsCs} ; by extrapolating to zero He and Cs pressure one obtains τ_{7S}^{-1} . In all cases the total relaxation rate T^{-1} was deduced from Hanle width measurements (Eq. (2b)) corresponding to the source polarization $P^{(2)}$, which offers the best S/N ratio.

3.3.1 Cs-He and Cs-Cs cross-sections. — The He pressure was varied between 0.01 and 0.43 torr, at a fixed temperature of 356 K, corresponding to a Cs pressure of $\sim 1.8 \times 10^{-4}$ torr. (At this low Cs pressure the contribution of Cs-Cs collisions to the Hanle width is only 0.1 %, yet the S/N ratio remains good.) The observed variation (Fig. 3) yields :

$$\sigma_{\text{CsHe}} = (1.10 \pm 0.05) \times 10^{-15} \text{ cm}^2. \quad (7)$$

Fig. 3. — Hanle width *versus* He pressure ($T = 356 \text{ K}$, $n_{\text{Cs}} \sim 5 \times 10^{12} \text{ at/cm}^3$). The arrow shows the He pressure at which the data of Fig. 4 were obtained.

The uncertainty arises mainly from the He pressure measurement.

The Cs pressure was then varied by varying the temperature between 353 and 424 K, at a fixed He pressure of $\sim 0.028 \text{ torr}$. (At this low He pressure, the contribution of Cs-He collisions to the Hanle width is only 0.5 %⁽⁷⁾.) The observed dependence of the Hanle width on $n_{\text{Cs}} T^{1/2}$ ($\propto n_{\text{Cs}} \bar{v}_{\text{CsCs}}$), shown in figure 4, yields :

$$\sigma_{\text{CsCs}} \sim 1.15 \times 10^{-13} \text{ cm}^2, \quad (8)$$

with a systematic uncertainty (from the pressure estimation⁽⁸⁾) of perhaps 30-40 %. This result agrees with the more accurate value of J. Hoffnagle *et al.* [3], $(1.29 \pm 0.05) \times 10^{-13} \text{ cm}^2$.

3.3.2 τ_{7S} lifetime. — The spontaneous decay rate τ_{7S} was deduced by extrapolating the He pressure to zero (Fig. 3), then correcting for the small residual Cs-Cs broadening ($\sim 0.1 \%$ at 356 K) deduced from figure 4. We thus obtain the natural Hanle width $\Delta H = 9.38 \pm 0.01 \text{ G}$, yielding :

$$\tau_{7S} = 48.5 \pm 0.5 \text{ ns}. \quad (9)$$

This corresponds to an oscillator strength

$$f_{6P,7S} = -0.633 \pm 0.007.$$

(⁷) Since the observation region is a short heated section in the middle of a long, cool, closed sample tube, when the temperature of the observation region is varied the helium *pressure* remains practically constant, but the helium *density* and the Cs-He relative velocity vary, and so does also the contribution of Cs-He collisions to the Hanle width. This effect, which does not exceed $\sim 1 \%$ of the Cs-Cs cross-section, was corrected for.

(⁸) *Relative* pressures are measured accurately from the observed fluorescence intensity, but the *absolute* pressure is more difficult to estimate, because of the dynamical pressure regime in our cell (competition between evaporation from the liquid reserve and diffusion towards the cooled ends of the tube).

Fig. 4. — Hanle width versus $n_{\text{Cs}} T^{1/2}$ (transposed to $P_{\text{He}} = 0$). The data were obtained at $P_{\text{He}} = 0.028$ torr, then corrected for the (slightly temperature dependent) contribution of Cs-He collisions (see footnote of § 3.3.1). The arrow shows the temperature at which the data of Fig. 3 were obtained.

Our value of τ_{7S} disagrees with that of Hoffnagle *et al.* [3] (53.6 ± 1.2 ns) but turns out to be in better agreement with the less accurate values of Marek [12] (49 ± 4 and 47 ± 5 ns). It also agrees with the value (48.35 ns) predicted by the theoretical model using the semi-empirical Norcross potential and an electric dipole operator corrected for shielding, developed to predict the parity violation effect in the 6 S-7 S transition of Cs [2]. The Norcross model was chosen because it successfully predicts the oscillator strengths of many members of the Cs $6^2S_{1/2}$ - $n^2P_{1/2,3/2}$ series [13].

3.4 CONSEQUENCES. — The value of τ_{7S} obtained by Hoffnagle *et al.* was used as an input parameter to determine the scalar and vector polarizabilities α and β of the 6 S-7 S transition, first by Hoffnagle *et al.* [3], then by Watts *et al.* [14], and somewhat more rigorously by Bouchiat and Piketty [15]. Using the slope $d\alpha/d\tau = 1.44 a_0^3/\text{ns}$ of the last authors [16] (which nearly coincides with that of Hoffnagle's calculation [3]) we conclude that our result (9) implies a correction of 3 % to α and β . This leads to

$$\alpha = -(265.1 \pm 2.5) a_0^3; \quad \beta = (26.8 \pm 0.5) a_0^3$$

providing a test of the theoretical values [2] : ($\alpha = -257.7 a_0^3$; $\beta = 27.3 a_0^3$). The primary interest of an accurate determination of these parameters lies in the rôle of standards attributed to the Stark-induced amplitudes αE and βE to calibrate all the other amplitudes of the 6 S-7 S transition, in particular the parity violating [1] and magnetic dipole [9, 17, 18] amplitudes.

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