

## CIRCULAR DICHROISM OF ANGULAR DISTRIBUTIONS OF PHOTOELECTRONS EMITTED FROM HEAVY POLARIZED ALKALI ATOMS\*

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The angular distributions of photoelectrons, emitted from the ground state of polarized heavy alkali atoms, are predicted to depend on the helicity of the photon. The effects should occur, in the purely electric dipole approximation, for photon energies from the region of so-called nonzero minimum of the photoionization cross-section. Formulae are proposed for experimental determination of the frequency-dependence of Fano's parameter  $x$ .

### 1. Introduction

Circular dichroism, meaning a dependence of the absorption coefficient on whether the light is right or left circularly polarized, is traditionally [1-3] related with the presence of an interferential term of the electric dipole-magnetic dipole type in the expression for the absorption coefficient. The term in question is of the form [4]:

$$\text{Im} [\langle \phi_f | \vec{e}_\pm \cdot \vec{r} | \phi_i \rangle^* \langle \phi_f | \hat{L} \cdot i(\vec{K}_{ph} \times \vec{e}_\pm) | \phi_i \rangle], \quad (1)$$

with:  $\phi_i, \phi_f$  — the wave functions of the system in the initial and final state, respectively;  $\vec{e}_\pm$  — the unit circular polarization vector of the photon;  $\vec{K}_{ph}$  — the unit vector of the photon propagation direction;  $\vec{r}$  — the resultant positional vector of all electrons of the system;  $\hat{L}$  — their resultant angular momentum operator; and  $i^2 = -1$ . For a photon propagating along the Z-axis,  $\vec{e}_\pm = (1/\sqrt{2})(\vec{i} \pm i\vec{j})$ , where the upper and lower sign refers, respectively, to right and left circular polarization, defined in accordance with the angular momentum convention.

Circular dichroism in discrete absorption (bound-bound transitions) is a long known effect [5]. By Eq. (1), it can occur only if the molecule has neither a centre or a plane of symmetry. Whereas if one of these symmetry elements is present the states  $\phi_i$  and  $\phi_f$  can be classified as even or odd and, since  $\vec{e}_\pm \cdot \vec{r}$  has non-zero matrix elements between states

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of opposite parity and  $\hat{L} \cdot i(\vec{K}_{\text{ph}} \times \vec{e}_{\pm})$  has non-zero matrix elements between states of the same parity, no two states  $\phi_i$  and  $\phi_f$  exist for which  $\langle \phi_f | \vec{e}_{\pm} \cdot \vec{r} | \phi_i \rangle$  and  $\langle \phi_f | \hat{L} \cdot (\vec{K}_{\text{ph}} \times \vec{e}_{\pm}) | \phi_i \rangle$  differ from zero simultaneously.

Circular dichroism in the region of continuous absorption (bound-free transitions) is a manifestly novel problem. The possibility of its occurrence and observation for chiral molecules or oriented unchiral ones with definite parity eigen-states has recently been considered by Ritchie [4], [6]. Of particular interest is Ritchie's conclusion [4] that circular dichroism should be apparent in the angular distributions of photoelectrons, emitted by oriented molecules having a centre or plane of symmetry. The difference, calculated by Ritchie, between the differential photoionization cross-sections for right and left circularly polarized light results i.a. from the form of the photoelectron wave function which is a sum of even as well as odd partial waves making possible the existence of an interferential term of the electric dipole-magnetic dipole type even in the case of molecules with a centre or a plane of symmetry. However this effect vanishes on integration over all possible directions of photoemission. According to Ritchie, the dichroism of angular distributions "vanishes for atoms owing to the independence of the radial wave function from the magnetic quantum number  $m$ , and thus the radial orthogonality for wave functions of different  $m$ ".

What we are aimed at proving is at variance with the last conclusion of Ritchie — in fact we shall show that circular dichroism can be exhibited by the angular distributions of photoelectrons from atoms too, especially heavy atoms of alkali metals, provided they are polarized and if spin-orbit perturbation is taken into account in the  $P$  states of their continuous spectrum. The simultaneous fulfilment of these two conditions causes that not only the angular distributions but moreover total photoionization cross-section is dependent on whether the circularly or elliptically polarized light is right or left polarized. Obviously, for reasons of symmetry, the interferential term (1) cannot be responsible for this effect. In the case of continuous absorption of polarized alkali atoms circular dichroism emerges in the purely electric-dipole approximation.

## 2. Theory

### 2.1. The differential photoionization cross-section for alkali atoms

In an earlier paper [7], we proposed a formula for the angular distributions of photoelectrons, emitted from the ground state  $n_0^2S_{1/2}$  of alkali atoms versus the polarization and helicity state of the photon, the degree of electronic polarization of the atom, the orientation of the wave vector and polarization ellipse of the photon with respect to the direction of electronic polarization of the atom, and the Fano parameter  $x$ . With the notation used in Ref. [7], the differential photoionization cross-section  $d\sigma/d\Omega_{\vec{k}}$  for circularly or elliptically polarized light averaged over electron spin orientations in the initial state  $n_0^2S_{1/2}$  and summed over electron spin orientations in the continuum, is of the form:

$$\frac{d\sigma}{d\Omega_{\vec{k}}} = \frac{\pi^2}{9} \frac{a^3}{\lambda} \frac{(AR)^2}{1+\kappa^2} [A_2 + B_2(\varphi_{\vec{k}}) \sin^2 \vartheta_{\vec{k}} + C_2(\varphi_{\vec{k}}) \sin 2\vartheta_{\vec{k}}], \quad (2)$$

where

$$A_2 = 2(1 + \kappa^2) + 2(x^2 - 1) [1 - (1 - \kappa^2) \cos^2 \phi] \sin^2 \delta \mp 4P_{\text{at}} \kappa \cos \delta, \quad (3)$$

$$B_2(\varphi_{\vec{k}}) = (x^2 - 1) \{1 + \kappa^2 + (1 - \kappa^2) [\sin 2\phi \sin 2\varphi_{\vec{k}} \cos \delta - \cos 2\phi \cos 2\varphi_{\vec{k}}] \\ - [1 - (1 - \kappa^2) \cos^2 \phi] (3 + \cos 2\varphi_{\vec{k}}) \sin^2 \delta\} \pm 4(1 + x)P_{\text{at}} \kappa \cos \delta, \quad (4)$$

$$C_2(\varphi_{\vec{k}}) = -2 \sin \delta \{(x^2 - 1) [(1 - (1 - \kappa^2) \cos^2 \phi) \cos \varphi_{\vec{k}} \cos \delta \\ + (1/2)(1 - \kappa^2) \sin 2\phi \sin \varphi_{\vec{k}}] \pm (1 + x)P_{\text{at}} \kappa \cos \varphi_{\vec{k}}\}. \quad (5)$$

Above,  $a$  is the Bohr radius, and  $\lambda, \kappa$  the wavelength and ellipticity parameter of the incident light wave:  $\kappa = 1$  for circular and  $0 < \kappa < 1$  for elliptical polarization. Where a double sign ( $\pm$ ) or ( $\mp$ ) occurs in (3), (4), (5), the upper sign always denotes right sense and the lower sign left sense polarization of light. The Fano parameter  $x$  characterizes the spin-orbit perturbation of the photoelectron wave functions in  $P$  states and is related with the parameter  $\Delta R$  as follows  $x \sim 1/\Delta R$  [8]. If radial functions of the photoelectron are spin-orbitally unperturbed  $\Delta R = 0$ , which is equivalent to  $x = \infty$ . The degree of electronic polarization  $P_{\text{at}}$  of the beam of alkali atoms is defined as  $P_{\text{at}} = P_{+1/2} - P_{-1/2}$  where  $P_{+1/2}$  and  $P_{-1/2}$  are the population probabilities of the states  $n_0^2 S_{1/2}(+1/2)$  and  $n_0^2 S_{1/2}(-1/2)$ , in which the projection of the spin of the optical electron onto the quantization direction is, respectively,  $+1/2$  and  $-1/2$ . The angles  $\delta$  and  $\phi$  define the experimental geometry and are of relevance essentially only if polarized atoms are subject to ionisation. On the assumption that the atoms are polarized in the direction of the  $Z$ -axis and that the photons propagate in the  $XZ$ -plane, the angle  $\delta$  is that between the wave vector of the photon and the direction of electronic polarization of the atom; the angle  $\phi$  is that between the larger semi-axis of the light polarization ellipse and the  $Y$ -axis. The angles  $\vartheta_{\vec{k}}$  and  $\varphi_{\vec{k}}$  describe the orientation of the photoelectron wave vector  $\vec{k}$ . For polarized atoms, which are of interest to us, the polar angle  $\vartheta_{\vec{k}}$  is defined with respect to the direction of electronic polarization of the atom and the azimuth  $\varphi_{\vec{k}}$  with respect to the  $X$ -axis, lying in the plane defined by the directions of atom polarization and photon propagation. We note that formula (2) was derived on the assumption of purely electric-dipole coupling between the atoms and photons.

## 2.2. Circular dichroism of angular photoelectron distributions

The effect is related with the presence of a double sign ( $\pm$ ) or ( $\mp$ ) in formulae (3), (4) and (5). It is worth noting that the double sign in these formulae is always accompanied by a factor of the form  $(\Delta R)^2 f(x) P_{\text{at}} \sim (f(x)/x^2) P_{\text{at}}$ , where  $f(x)$  is at the most a linear function of the Fano parameter  $x$ . The factor is of such a form that the angular distributions of photoelectrons, emitted from the ground state of alkali atoms, can exhibit circular dichroism if simultaneously,  $P_{\text{at}} \neq 0$  and  $x$  is finite i.e. if the atoms subject to ionization are polarized and if the energy of the photon absorbed is such that the spin-orbit perturbation of the wave functions of the electron in  $P$  states of the continuous spectrum of heavy alkali atoms (heavier than lithium) represents a non-negligible effect. Now this is the case for

frequencies from the region of the non-zero minimum of the photoionization cross-section observed for all alkali atoms except lithium [9].

A measure of the magnitude of the dichroism under consideration is conveniently provided by the function  $D(\vartheta_{\vec{k}}, \varphi_{\vec{k}})$  defined as follows:

$$D(\vartheta_{\vec{k}}, \varphi_{\vec{k}}) = \frac{d\sigma^{(r)}/d\Omega_{\vec{k}} - d\sigma^{(l)}/d\Omega_{\vec{k}}}{d\sigma^{(r)}/d\Omega_{\vec{k}} + d\sigma^{(l)}/d\Omega_{\vec{k}}}, \quad (6)$$

where  $(r)$  and  $(l)$  denote, respectively, right and left circularly polarized light. The function  $D(\vartheta_{\vec{k}}, \varphi_{\vec{k}})$  defines the circular dichroism for the photoemission direction  $\vartheta_{\vec{k}}, \varphi_{\vec{k}}$ ; its variability interval is  $\langle +1, -1 \rangle$ . If  $|D(\vartheta_{\vec{k}}, \varphi_{\vec{k}})| = 1$ , either  $d\sigma^{(r)}/d\Omega_{\vec{k}}$  or  $d\sigma^{(l)}/d\Omega_{\vec{k}}$  vanishes identically. Whereas if  $D(\vartheta_{\vec{k}}, \varphi_{\vec{k}}) = 0$ , the flux of photoelectrons emitted in the direction  $\vartheta_{\vec{k}}, \varphi_{\vec{k}}$  is independent of the photon helicity. With regard to the definition (6) and the expressions (2)–(5) we find

$$D(\vartheta_{\vec{k}}, \varphi_{\vec{k}}) = 2P_{\text{at}}\kappa \frac{A_3 + B_3 \sin^2 \vartheta_{\vec{k}} + C_3(\varphi_{\vec{k}}) \sin 2\vartheta_{\vec{k}}}{A_4 + B_4(\varphi_{\vec{k}}) \sin^2 \vartheta_{\vec{k}} + C_4(\varphi_{\vec{k}}) \sin 2\vartheta_{\vec{k}}}, \quad (7)$$

where

$$A_3 = -2 \cos \delta, \quad (8)$$

$$B_3 = 2(1+x) \cos \delta, \quad (9)$$

$$C_3(\varphi_{\vec{k}}) = -(1+x) \sin \delta \cos \varphi_{\vec{k}}, \quad (10)$$

$$A_4 = 2(1+\kappa^2) + 2(x^2-1) [1 - (1-\kappa^2) \cos^2 \phi] \sin^2 \delta, \quad (11)$$

$$B_4(\varphi_{\vec{k}}) = (x^2-1) \{1 + \kappa^2 + (1-\kappa^2) [\sin 2\phi \sin 2\varphi_{\vec{k}} \cos \delta - \cos 2\phi \cos 2\varphi_{\vec{k}}] - [1 - (1-\kappa^2) \cos^2 \phi] (3 + \cos 2\varphi_{\vec{k}}) \sin^2 \delta\}, \quad (12)$$

$$C_4(\varphi_{\vec{k}}) = -2(x^2-1) \sin \delta \{ [1 - (1-\kappa^2) \cos^2 \phi] \cos \varphi_{\vec{k}} \cos \delta + (1/2) (1-\kappa^2) \sin 2\phi \sin \varphi_{\vec{k}} \}. \quad (13)$$

The complicated angular structure of the coefficients  $A_4, B_4 \dots$  simplifies considerably in the case of so-called parallel geometry, for which  $\delta = 0$  and  $\phi = \pi/2$  so that light beam propagates along the polarization direction of the atoms  $\parallel Z$ , and the axes  $X$  and  $Y$  coincide with larger and, respectively, smaller semi-axis of the light polarization ellipse. For  $\delta = 0$  and  $\phi = \pi/2$ , only  $B_4$  is dependent on the azimuth  $\varphi_{\vec{k}}$ , and this by way of the function  $\cos 2\varphi_{\vec{k}}$ , but ceases to depend on  $\varphi_{\vec{k}}$  if the light is completely circularly polarized. At parallel geometry and complete circular polarization of light the circular dichroism function of angular distribution of photoelectrons is

$$\left[ \frac{D^c(\vartheta_{\vec{k}})}{P_{\text{at}}} \right]_{\parallel} = 2 \frac{(x+1) \sin^2 \vartheta_{\vec{k}} - 1}{(x^2-1) \sin^2 \vartheta_{\vec{k}} + 2}, \quad (14)$$

where  $\vartheta_{\vec{k}}$  is now the angle between photon propagation direction  $\parallel Z$  and the photoelectron emission direction. Calculations by Weisheit and Dalgarno [10], as well as the

experiment of Baum et al. [8] on potassium, rubidium and cesium have shown that for certain energies of the photon the Fano parameter  $x$  can take values as low as e.g. 0,  $\pm 1$ , pointing to an essential role of spin-orbit effects in the continuous spectrum of alkali atoms. For those three values of  $x$ , as well as  $x = 10$ , Fig. 1 gives the function  $[D^c/P_{at}]_{\parallel}$  versus the photoemission angle  $\vartheta_{\vec{k}}$ . In the limiting case  $x \rightarrow \infty$  i.e. the absence of spin-orbit

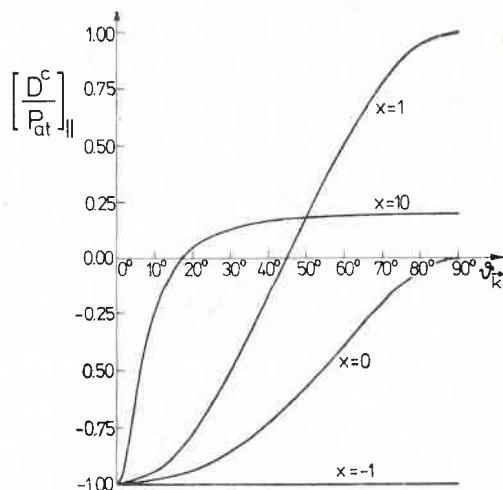


Fig. 1. Circular dichroism function  $D(\vartheta_{\vec{k}})$  of angular photoelectron distributions, for parallel geometry.  $\vartheta_{\vec{k}}$  is the angle between the direction of photoelectron emission and that of photon propagation

perturbation of the photoelectron function in  $P$  states, one has  $[D^c(\vartheta_{\vec{k}})/P_{at}]_{\parallel} = 0$ . This is what should be expected for atoms of lithium. The phenomenon of circular dichroism of the angular photoelectron distribution predicted in this paper should be the most easy to detect in the case of cesium atoms. In fact, of all alkalis, cesium exhibits [8] the largest spin-orbit perturbation in the continuum, throughout a rather wide wavelength range of the light used to produce the photoeffect. The photon energies  $\hbar\omega$  leading, for cesium, to values of  $x = 0, \pm 1$  can be calculated from the simple empirical formula of Baum et al. [8]:

$$x_{Cs} = 3(4.53 - \hbar\omega), \quad (15)$$

where  $\hbar\omega$  is in electron-volts. In terms of electromagnetic wavelength,  $x_{Cs} = -1$  at  $\lambda \cong 2570 \text{ \AA}$ ;  $x_{Cs} = 0$  at  $\lambda \cong 2740 \text{ \AA}$ ; and  $x_{Cs} = 1$  at  $\lambda \cong 2970 \text{ \AA}$ . In accordance with our earlier paper [7], this is the region of the predicted, anomalous angular photoelectron distributions.

The phenomenon of circular dichroism of angular photoelectron distributions can be applied for the experimental determination of the dependence of the Fano parameter  $x$  on frequency. This requires the measurement of the function  $D(\vartheta_{\vec{k}}, \varphi_{\vec{k}})$ , defined by Eq. (6), for a given direction of observation  $\vartheta_{\vec{k}}, \varphi_{\vec{k}}$  versus the light frequency. Eq. (7) leaves the experimenter with a good deal of freedom as regards the experimental geometry. We would, however, recommend that  $D(\vartheta_{\vec{k}}, \varphi_{\vec{k}})$  be measured for the directions  $\vartheta_{\vec{k}} = 0, \vartheta_{\vec{k}} = \pi/2$



and  $\vartheta_{\vec{k}} = 54.73^\circ$  ( $\cos^2 54.73^\circ = 1/3$ ). When measuring in the direction  $\vartheta_{\vec{k}} = 0^\circ$ , the angle  $\delta$  between the atomic polarization and photon propagation directions can assume arbitrary values, except 0 and  $\pi/2$ . Whereas when carrying out observation in the direction  $\vartheta_{\vec{k}} = \pi/2$  or  $\vartheta_{\vec{k}} = 54.73^\circ$ , the parallel geometry ( $\delta = 0$ ) should be recommended. Assuming the light as completely circularly polarized, the following simple expressions give  $D(\vartheta_{\vec{k}})$  as a function of  $x$  for the above proposed directions of observation:

i) at observation in the direction  $\vartheta_{\vec{k}} = 0$

$$\frac{D^\circ(0)}{P_{\text{at}}} = -\frac{2 \cos \delta}{2 + (x^2 - 1) \sin^2 \delta}; \quad \delta \neq 0, \pi/2, \quad (16)$$

ii) at observation in the direction  $\vartheta_{\vec{k}} = \pi/2$ , at parallel geometry ( $\delta = 0$ )

$$\left[ \frac{D^\circ(\pi/2)}{P_{\text{at}}} \right]_{\parallel} = \frac{2x}{x^2 + 1}, \quad (17)$$

iii) at observation in the direction  $\vartheta_{\vec{k}} = 54.73^\circ$ , at parallel geometry ( $\delta = 0$ )

$$\left[ \frac{D^\circ(54.73^\circ)}{P_{\text{at}}} \right]_{\parallel} = \frac{2x - 1}{x^2 + 2}. \quad (18)$$

With Eqs. (16)–(18) we eliminate  $P_{\text{at}}$  and are thus able to determine by experiment the Fano parameter  $x$  for a given energy of the photon even when not knowing the degree of electronic polarization of the atom.

### 2.3. Total photoionization cross-section versus photon helicity

Within the framework of Ritchie's theory [4] for nonchiral, definite-parity eigenstate oriented molecules, based on the interferential term (1), circular dichroism concerned angular distributions of photoelectrons only. In our theory for polarized alkali atoms, ionized from their ground state, the total cross-section too is dependent on the helicity of the photon, as proved by the presence of the double sign ( $\pm$ ) in the formula:

$$\sigma = \int (d\sigma/d\Omega_{\vec{k}}) d\Omega_{\vec{k}} = \sigma_{\text{S}} \left( 1 \pm \frac{2\kappa}{1 + \kappa^2} \frac{2x - 1}{x^2 + 2} P_{\text{at}} \cos \delta \right), \quad (19)$$

where

$$\sigma_{\text{S}} = \left( \frac{2\pi}{3} \right)^3 \frac{a^3}{\lambda} (\Delta R)^2 (x^2 + 2) \quad (20)$$

is Seaton's [11] cross-section for unpolarized alkali atoms. On defining, by analogy to (6), the circular dichroism function  $D$  for all photoelectrons emitted into the full body angle  $4\pi$  as follows:

$$D = \frac{\sigma^{(r)} - \sigma^{(l)}}{\sigma^{(r)} + \sigma^{(l)}} \quad (21)$$

we have by (19):

$$D = \frac{2\kappa}{1+\kappa^2} \frac{2x-1}{x^2+2} P_{\text{at}} \cos \delta. \quad (22)$$

In particular, assuming parallel geometry of the experiment and complete circular polarization of the light, Eq. (22) goes over into the formula of Baum et al. [8]. Let us note that for  $\delta = 0$  and  $\kappa = 1$  the right-hand terms of (22) and (18) are the same. The identity:

$$[D^\circ(54.73^\circ)]_{\parallel} = [D^\circ]_{\parallel} \quad (23)$$

is a direct consequence of the relation:

$$\left( \frac{d\sigma_{\parallel}^\circ}{d\Omega_{\vec{k}}} \right)_{\theta_{\vec{k}} = 54.73^\circ} = \frac{\sigma_{\parallel}^\circ}{4\pi}, \quad (24)$$

fulfilled for the magical angle  $\theta_{\vec{k}} = 54.73^\circ$  under conditions of parallel geometry. In laboratory practice, the identity (23) permits the reduction of measurements of the circular dichroism function of all photoelectrons emitted to the measurements of that of the photoelectrons emitted in the magical direction.

### 3. Final remarks

Let us now consider the phenomenon of circular dichroism in the region of continuous absorption from the viewpoint of the photon, rather than from that of the photoelectron. The function  $D$ , defined by Eq. (21), should in principle be accessible to experimental determination not only by detection of photoelectrons or positive ions, but as well by an analysis of the light emerging from the volume in which photoionization of polarized alkali atoms took place. Since the photoionization cross-section for polarized atoms is dependent on the helicity of the photon, the photoionization losses in light intensity have to differ for light beams circularly polarized in opposite senses. On the assumption that the losses are due to photoionization only, the usual Lambert-Beer formula leads to the following expression for  $D$ :

$$D = \frac{\ln(I^{(l)}/I^{(r)})}{\ln(I_0^2/I^{(l)}I^{(r)})}, \quad (25)$$

where  $I^{(l)}$  and  $I^{(r)}$  are, respectively, the intensities of a left and a right circularly polarized beam on passing through the photoionized volume, whereas  $I_0$  is the beam intensity prior to the photoionization process by assumption identical for the two beams.  $I^{(l)}$  and  $I^{(r)}$  differ the most strongly in the case of parallel geometry.

Circular dichroism, related with bound-free transitions of polarized atoms of potassium, rubidium and cesium should reveal itself by an elliptisation of linearly polarized light, used to produce the photoeffect. This is in accordance with the principles of classical optics [5], by which the unequal extinction of two oppositely circularly polarized

components leads to an ellipticity of the emergent beam, with an ellipticity parameter  $\kappa_t = (E^{(l)} - E^{(r)}) \times (E^{(l)} + E^{(r)})^{-1}$ , where  $E$  is the amplitude of the respective component on passing through the dichroic medium. In the case of photoionization transitions,

$$\kappa_t = \operatorname{tgh} \left[ \frac{1}{4} \varrho l (\sigma^{(r)} - \sigma^{(l)}) \right] = \frac{1}{4} \varrho l (\sigma^{(r)} - \sigma^{(l)}) + \dots, \quad (26)$$

with:  $\varrho$  — the density of atoms, and  $l$  the thickness of the light absorbing layer.

The creation of free electrons in the irradiated gas volume should, moreover, cause negative variations in light refractive index. The variations differ for the two opposite senses of circular light polarization, since by (19) photons of opposite helicity generate different amounts of photoelectrons. Hence, if the incident light wave was linearly polarized, the principal axis of the light polarization ellipse will no longer coincide with the electric vector direction of the incident beam on emerging from the medium but will undergo a rotation by approximately an angle of:

$$\varphi = \frac{\pi l}{\lambda} (\Delta n^{(l)} - \Delta n^{(r)}) \cong \frac{1}{2} r_e \varrho l F \tau (\sigma^{(r)} - \sigma^{(l)}) \text{ [rad]}, \quad (27)$$

where  $r_e = e^2/mc^2$  is the classical radius of the electron,  $F$  the incident photon flux, in photons per  $\text{cm}^2\text{s}$ , and  $\tau$  the time of interaction of an individual atom with the light wave. In particular, if a homogeneous magnetic field  $\vec{H}$  is the agent polarizing the atoms in their ground state, with regard to

$$P_{\text{at}} = \operatorname{tgh} (\mu_B H/kT) = \mu_B H/kT + \dots \quad (28)$$

we obtain

$$\varphi = V l H \cos \delta \quad (29)$$

i.e., from a formal viewpoint, the formula for Faraday rotation of the light polarization plane, with the Verdet constant:

$$V = \left( \frac{2\pi}{3} \right)^3 \frac{\mu_B}{kT} a^3 \varrho r_e \tau F (\Delta R)^2 (2x - 1), \quad (30)$$

$\mu_B$  being Bohr's magneton and  $kT$  the thermal energy. It should be stressed that this predicted optical activity of the gas of alkali atoms, polarized in their ground state, is related with the creation of photoelectrons in the process of photoionization transitions — and not with transitions between states of the discrete spectrum. The activity, emerging in purely electric dipole approximation, vanishes if spin-orbit perturbation of the radial electron wave-functions in  $P$ -states of the continuous spectrum is absent ( $V = 0$  if  $x = \infty$ ).

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