THE ZEEMAN EFFECT

REFERENCES

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INTRODUCTION

It is well known that an atom can be characterized by a unique set of discrete energy states. When excited through heating or electron bombardment in a discharge tube, the atom makes transitions between these quantized energy states and emits light. The emitted light forms a discrete spectrum, reflecting the quantized nature of the energy states or energy levels. In the presence of a magnetic field, these energy levels can shift. This effect is known as the Zeeman effect. The origin of Zeeman effect is the following. In an atomic energy state, an electron orbits around the nucleus of the atom and has a magnetic dipole moment associated with its angular momentum. In a magnetic field, it acquires an additional energy just as a bar magnet does and consequently the original energy level is shifted. The energy shift may be positive, zero, or even negative, depending on the angle between the electron magnetic dipole moment and the field.

Due to Zeeman effect, some degenerate energy levels will split into several non-degenerate energy levels with different energies. This allows for new transitions which can be observed as new spectral lines in the atomic spectrum. In this experiment we will study Zeeman effect in neon and mercury for which the theory of Zeeman effect is somewhat more tractable.

Non-relativistic quantum theory accounts for only one type of angular momentum called orbital angular momentum. The Hamiltonian for an electron with angular momentum $\vec{\ell}$ has an additional term $\mu_B \vec{\ell} \cdot \vec{H}$ when a weak uniform magnetic field $\vec{H}$ is turned on. μ_B is a constant called the Bohr magneton. First order perturbation theory tells us that energy levels are shifted by

$$\Delta E = \mu_B M_\ell H \qquad [1]$$

where M_ℓ is the quantum number for the component of $\vec{\ell}$ along the field. If an atom had only a single electron and the electron had only "orbital" angular momentum, then Eq. 1 would represent the Zeeman shift.

But electrons also have a different type of angular momentum called intrinsic spin angular momentum, $\vec{\mathbf{s}}$. Spin emerges naturally only in relativistic quantum theories, but it can be shown that inserting a term $g_s \mu_B \vec{\mathbf{s}} \cdot \vec{H}$ (where $g_s \approx 2$) into the non-relativistic Hamiltonian gives the correct behavior of spin in a weak field. The first-order perturbation theory gives a corresponding energy shift of

$$\Delta E = \mu_B g_s M_s H \qquad [2]$$

The shift is analogous to that due to orbital angular momentum, except for the constant factor of g_s. The energy shift for a particular state depends only on M_s (M_ℓ for the orbital case) for that state. If an atom had only a single electron and the electron had only "intrinsic spin" angular momentum, then Eq. 2 would represent the Zeeman shift.

Atoms typically have many electrons and are characterized by a total angular momentum $\vec{\mathbf{J}}$ which is the sum of all spin and orbital angular momenta. Though more complicated now, the energy shift is usually expressed in a similar looking form to Eqs. 1 and 2.

$$\Delta E = \mu_B g M_J H \qquad [3]$$

The important difference is that g depends on the particular state of interest, as does M_J.

By observing the spectra of neon and mercury we will be able to experimentally determine the g-factors for certain states. The values will be compared to the theoretical (Landé) g-factors, derived in the following section

THEORY

A. Atomic States in Zero Field

Each of the n electrons in an atom has orbital $\vec{\ell}_i$ and spin $\vec{\mathbf{s}}_i$ angular momentum. The sum of all these is the total angular momentum of the atom (ignoring the nucleus).

$$\vec{\mathbf{J}} \equiv \vec{\mathbf{L}} + \vec{\mathbf{S}} \qquad [4]$$

$$\vec{\mathbf{L}} \equiv \sum_{i=1}^{n} \vec{\ell}_i \qquad [5]$$

$$\vec{\mathbf{S}} \equiv \sum_{i=1}^{n} \vec{\mathbf{s}}_i \qquad [6]$$

NOTE: The convention used here is that angular momentum operators are dimensionless. For example $\vec{\ell} \equiv \vec{\mathbf{r}} \times \vec{\mathbf{p}}/\hbar$.

NOTE: Operators are shown in boldface.

NOTE: Gaussian units are used.

The atomic Hamiltonian in no field will be labeled $\mathbf{H_0}$. In the absence of external torques on the atom, the total angular momentum $\vec{\mathbf{J}}$ is conserved (i.e. $\vec{\mathbf{J}}$ commutes with $\mathbf{H_0}$) and energy eigenstates can be constructed which are also eigenstates of $\vec{\mathbf{J}}^2$ and $\mathbf{J}_z$, where the direction chosen for the z-axis is arbitrary. Each eigenstate can be labeled by quantum numbers J and M_J, where

$$<JM_J|\,\vec{\mathbf{J}}^2\,|JM_J> = J(J+1) \quad \text{and} \quad <JM_J|\,\mathbf{J}_z\,|JM_J> = M_J \qquad [7]$$

In principal there are terms in the Hamiltonian that represent interactions between the individual angular momenta of the electrons. As a result, the individual angular momenta, as well as $\vec{\mathbf{L}}$ and $\vec{\mathbf{S}}$, need not be conserved (i.e. need not commute with $\mathbf{H_0}$). However, these interactions are small effects in many atoms. We will employ the usual approximation, called L-S coupling (or Russel-Saunders coupling), which assumes that the individual orbital angular momenta couple to produce a net orbital angular momentum $\vec{\mathbf{L}}$ which has a constant magnitude, but non-constant direction. Similarly the individual spins form a net spin $\vec{\mathbf{S}}$ which also has a constant magnitude. (This approximation is found to break down for large Z atoms.) Within this approximation, each eigenstate can be constructed with the form $|JLSM_J>$ with energy $E_0(JLS)$ degenerate in M_J, where

$$<JLSM_J|\,\vec{\mathbf{L}}^2\,|JLSM_J> = L(L+1) \quad \text{and} \quad <JM_J|\,\vec{\mathbf{S}}^2\,|JM_J> = S(S+1) \qquad [8]$$

Note that these states are not eigenstates of $\mathbf{S}_z$ or $\mathbf{L}_z$.

B. Atomic States in Non-Zero Field - Zeeman Effect

Now we will outline how Eq. 3 for the Zeeman energy shift can be derived. Within the L-S coupling model, the atomic Hamiltonian in a weak, uniform magnetic field is

$$\mathbf{H} = \mathbf{H_0} + \mu_B(\vec{\mathbf{L}} + g_s\vec{\mathbf{S}})\cdot\vec{H} \qquad [9]$$

where μ_B is called the Bohr magneton. It is usually most convenient to choose the z-axis so that $\vec{H} = H\hat{z}$, and we will do so in the discussion that follows. First order perturbation theory gives energy shifts

$$\Delta E(JLSM_J) = \mu_B \langle JLSM_J| \mathbf{L}_z + g_s \mathbf{S}_z |JLSM_J\rangle H \quad [10]$$

If the new term in the Hamiltonian (Eq. 9) were simply proportional to $\mathbf{J}_z = \mathbf{L}_z + \mathbf{S}_z$ rather than $\mathbf{L}_z + g_s \mathbf{S}_z$, then the energy shift would be simple and exactly analogous to Eq. 1. That is not the case however. The matrix elements in Eq 10 cannot be easily evaluated in their present form since the states are not eigenstates of $\mathbf{L}_z$ and $\mathbf{S}_z$. However, it can be shown that

$$\langle JLSM_J| \vec{\mathbf{L}} + g_s \vec{\mathbf{S}} |JLSM_J\rangle = \langle JLSM_J| g(JLS) \vec{\mathbf{J}} |JLSM_J\rangle \quad [11]$$

(using the Wigner-Eckart theorem for example), where g(JLS) is the Landé g-factor for a (JLS) state. With this simplification

$$\Delta E(JLSM_J) = \mu_B g(JLS) \langle JLSM_J| \mathbf{J}_z |JLSM_J\rangle H = \mu_B g(JLS) M_J H \quad [12]$$

As a result, each state has energy

$$E(JLSM_J) = E_0(JLS) + \mu_B g(JLS) M_J H \quad [13]$$

which has the form of Eq. 3. The exact dependence of g on J, L, and S will be discussed below in section III-D.

The effect of the Zeeman shifts can be seen experimentally. If a particular transition in the absence of an applied field produces radiation at frequency ν_0, then the frequency in the presence of a field will be given by

$$h\nu = h\nu_0 + \mu_B g(JLS) M_J H - \mu_B g(J'L'S') M_J' H \quad [14]$$

The primed symbols refer to the lower state and the unprimed to the upper state.

C. Selection Rules

Conservation laws determine which transitions can occur ("allowed") and which can't ("forbidden"). The allowed transitions are specified by a set of conditions called selection rules. The selection rules for these states are given below without derivation.

$$\Delta \ell = \pm 1 \quad [15]$$
$$\Delta L = 0, \pm 1 \quad [16]$$
$$\Delta S = 0 \quad [17]$$
$$\Delta J = 0, \pm 1 \quad [18]$$
$$\Delta M_J = 0, \pm 1 \quad [19]$$

NOTE: $\Delta M_J = \pm 1$ transitions are called σ transitions, while $\Delta M_J = 0$ transitions are called π transitions.

There are additional conditions as well: (1) π transitions between levels both of which have $M_J = 0$ are forbidden if the sum of the J values of upper and lower states is even and (2) J = 0 to J = 0 transitions are forbidden.

It should be noted that the selection rules above only apply to a type of transition called an electric-dipole transition, which is the dominant type. Only "allowed" electric-dipole transitions can occur. However, transitions which are "forbidden" by the electric-dipole selection rules may still take place as other types of transitions. These events are less common and we will ignore them here.

D. Landé g-factor

A simple argument can be given for the value of g(JLS). Within the L-S coupling approximation, $\vec{\mathbf{L}}$ and $\vec{\mathbf{S}}$ are assumed to be individually conserved in magnitude but not direction. Their components parallel to $\vec{\mathbf{J}}$ must add to a constant value, but their components perpendicular to $\vec{\mathbf{J}}$ are constantly fluctuating. This means that the only part of $\vec{\mathbf{L}}$ that contributes to the Zeeman effect is its component along $\vec{\mathbf{J}}$, namely

$$\frac{<\vec{\mathbf{L}}\cdot\vec{\mathbf{J}}>}{<\vec{\mathbf{J}}^2>}\,\vec{\mathbf{J}} \qquad [20]$$

NOTE: $<\mathbf{O}>$ stands for $<JLSM_J|\,\mathbf{O}\,|JLSM_J>$.

Similarly, the only part of $\vec{\mathbf{S}}$ that contributes is

$$\frac{<\vec{\mathbf{S}}\cdot\vec{\mathbf{J}}>}{<\vec{\mathbf{J}}^2>}\,\vec{\mathbf{J}} \qquad [21]$$

Then the energy shift, Eq. 10 can be replaced by

$$\Delta E = \mu_B \frac{<\vec{\mathbf{L}}\cdot\vec{\mathbf{J}}> + g_0<\vec{\mathbf{S}}\cdot\vec{\mathbf{J}}>}{<\vec{\mathbf{J}}^2>} M_J H \qquad [22]$$

Problem 1 Show that Eq. 22 implies that the Landé g-factor is

$$g(JLS) = \frac{J(J+1)+L(L+1)-S(S+1)}{2J(J+1)} + g_s \frac{J(J+1)+S(S+1)-L(L+1)}{2J(J+1)} \qquad [23]$$

In this experiment, certain transitions of neon and mercury atoms will be studied. This section deals with the application of L-S coupling to the particular states involved. All of the spectral lines under consideration in this experiment correspond to allowed transitions, as far as the selection rules are concerned.

E. States of Neon (Ne) and Mercury (Hg)

First consider neon. The 10 electrons in a neutral neon atom have a ground-state configuration $1S^2 2S^2 2P^6$. The n = 1 and 2 shells are closed and as such the atom has S = L = J = 0, making the ground state $^1S_0$ in spectroscopic notation.

NOTE: For a given (JLS) state the notation is $^{2S+1}X_J$, where X=S means L=0, X=P means L=1, X=D means L=2, etc.

The transitions to be studied in neon are between initial states with one electron excited to a 3P level and final states with one electron excited to a 3S level (not transitions to the ground state). These transitions are simple to study theoretically, because the neon atom can then be treated as a pair of particles — a hole in the n = 2 shell and an electron in the n = 3 shell. In this manner, all 9 unexcited electrons are treated as a single particle, a hole. If we label the excited electron as particle 1 and the hole as particle 2, the upper level for the transitions ($2P^5 3P^1$) has $\ell_1 = 1$, $s_1 = 1/2$, $\ell_2 = 1$, and $s_2 = 1/2$. The lower level for the transitions ($2P^5 3S^1$) has $\ell_1 = 0$, $s_1 = 1/2$, $\ell_2 = 1$, and $s_2 = 1/2$.

Now consider mercury. The electrons have a ground-state configuration $1S^2 2S^2 2P^6 3S^2$ ... $6S^2$. The transitions to be studied are between states with one excited electron. The initial and final configurations are $6S^1 7S^1$ and $6S^1 6P^1$, respectively. These mercury transitions are similar to neon in that the angular momentum involves just two particles. If we label the excited electron as particle 1 and the other electron as particle 2, the upper level for the transitions ($6S^1 7S^1$) has $\ell_1 = 0$, $s_1 = 1/2$, $\ell_2 = 0$, and $s_2 = 1/2$. The lower level for the transitions ($6S^1 6P^1$) has $\ell_1 = 1$, $s_1 = 1/2$, $\ell_2 = 0$, and $s_2 = 1/2$.

For these two-particle states the total orbital angular momentum (Eq. 5) is simply

$$\vec{\mathbf{L}} = \vec{\ell}_1 + \vec{\ell}_2 \qquad [24]$$

This is an operator equation. In terms of the eigenvalues it results in the triangle condition,

$$|\ell_1 - \ell_2| \leq L \leq \ell_1 + \ell_2 \qquad [25]$$

Thus, for the neon $2P^5 3P^1$ configuration, the possible values of L are 0, 1, and 2, resulting in S, P, and D states. The $2P^5 3S^1$ configuration can only lead to a P state. For mercury, the $6S^1 7S^1$ configuration leads to an S state, while $6S^1 6P^1$ leads to a P state.

In L-S coupling, the total spin (Eq. 6) is

$$\vec{\mathbf{S}} = \vec{\mathbf{s}}_1 + \vec{\mathbf{s}}_2 \qquad [26]$$

with triangle rule,

$$|s_1 - s_2| \leq S \leq s_1 + s_2 \qquad [27]$$

Therefore, all states under consideration have S = 0 or 1, giving rise to singlet and triplet states.

Finally, L and S are coupled to J with a final triangle rule

$$|L - S| \leq J \leq L + S \qquad [28]$$

E. Transitions Studied in this Experiment

Problem 2 For the neon green line at 585 nm, where the upper state is $^1S_0$ (S=0, L=0, J=0) and the lower state is $^1P_1$ (S=0, L=1, J=1), show that the frequency of the $\Delta M_J = +1$ transition is

$$\nu_{0\rightarrow 1} = \nu_0 - g(J'L'S')\,\mu_B H_z/h \qquad [29]$$

while that of the $\Delta M_J = -1$ transition is,

$$\nu_{0\rightarrow -1} = \nu_0 + g(J'L'S')\,\mu_B H_z/h \qquad [30]$$

Also, show that the $\Delta M_J = 0$ frequency is unaffected by the magnetic field.

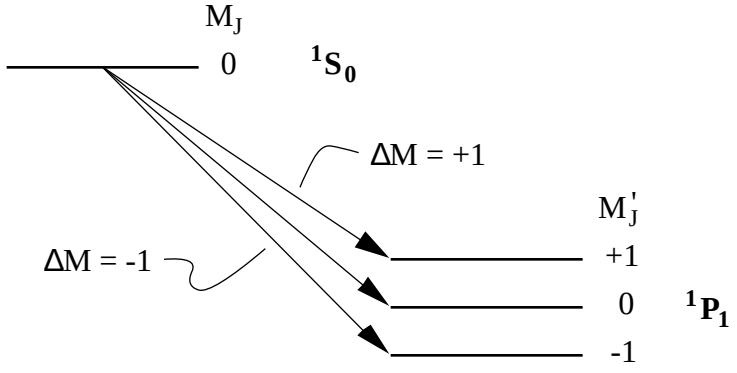

Fig. 1 Zeeman splitting of the neon 585-nm line

Problem 3 For the neon red line at 603 nm, where the upper state is $^3P_1$ (S=1, L=1, J=1) and the lower state is $^3P_1$ (S=1, L=1, J=1), show that the frequencies of the $\Delta M_J = +1$ transitions are

$$\nu_{0\rightarrow 1} = \nu_0 - g(J'L'S')\,\mu_B H_z/h \quad [31]$$

$$\nu_{-1\rightarrow 0} = \nu_0 - g(JLS)\,\mu_B H_z/h \quad [32]$$

while that of the $\Delta M_J = -1$ transitions are

$$\nu_{1\rightarrow 0} = \nu_0 + g(JLS)\,\mu_B H_z/h \quad [33]$$

$$\nu_{0\rightarrow -1} = \nu_0 + g(J'L'S')\,\mu_B H_z/h \quad [34]$$

The frequencies of the $\Delta M_J = 0$ transitions are

$$\nu_{1\rightarrow 1} = \nu_0 + [g(JLS) - g(J'L'S')]\,\mu_B H_z/h \quad [35]$$

$$\nu_{-1\rightarrow -1} = \nu_0 - [g(JLS) - g(J'L'S')]\,\mu_B H_z/h \quad [36]$$

The $\nu_{0\rightarrow 0}$ is absent since it is forbidden.

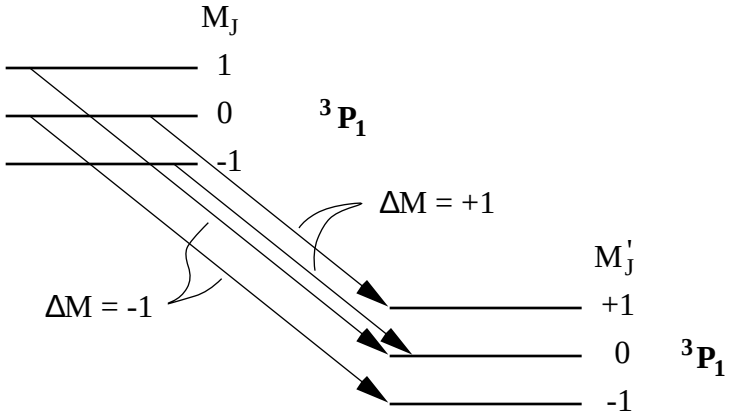

Fig. 2 Zeeman splitting of the neon 603-nm line

Problem 4 Compute the predicted g-factors for all of the neon states analyzed above.

Problem 5 (OPTIONAL) For the mercury green line at 546 nm, where the upper state is $^3S_1$ (L=0, S=1, J=1) and the lower state is $^3P_2$, (L=1, S=1, J=2), show that the possible $\Delta M_J = +1$ transitions are

$$\nu_{1\to 2} = \nu_0 - [2g(J'L'S') - g(JLS)]\,\mu_B H_z/h \quad [37]$$

$$\nu_{0\to 1} = \nu_0 - g(J'L'S')\,\mu_B H_z/h \quad [38]$$

$$\nu_{-1\to 0} = \nu_0 - g(JLS)\,\mu_B H_z/h \quad [39]$$

while the $\Delta M_J = -1$ transitions are

$$\nu_{1\to 0} = \nu_0 + g(JLS)\,\mu_B H_z/h \quad [40]$$

$$\nu_{0\to -1} = \nu_0 + g(J'L'S')\,\mu_B H_z/h \quad [41]$$

$$\nu_{-1\to -2} = \nu_0 + [2g(J'L'S') - g(JLS)]\,\mu_B H_z/h \quad [42]$$

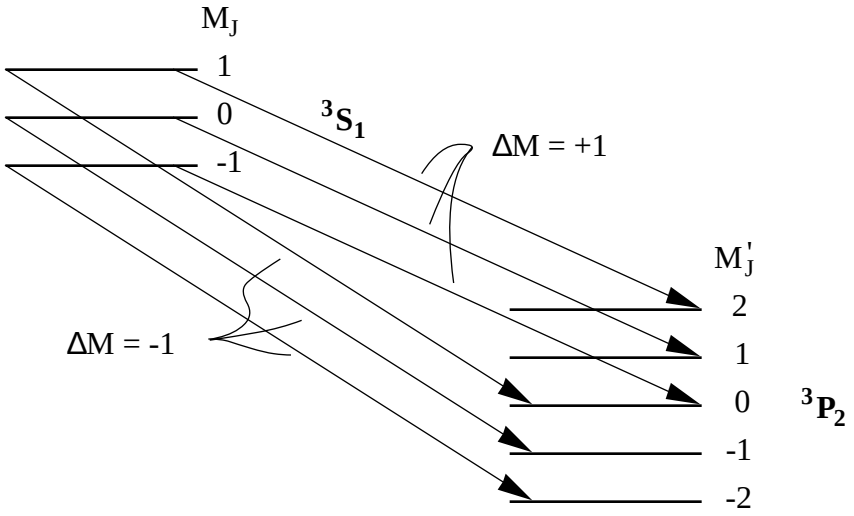

Fig. 3 Zeeman splitting of the mercury 546-nm line

F. Polarization of the Emitted Light

When an atom undergoes a π transition ($\Delta M_J = 0$), its angular momentum about the z-axis does not change. The atom satisfies this requirement by having its optically active electron oscillate along the z-axis, thereby giving rise to an electric field polarized in this direction.

On the other hand, when the atom undergoes a σ transition ($\Delta M_J = \pm 1$), its optically active electron performs a rotary motion in the x-y plane in order that the photon emitted carry angular momentum about the z-axis. The electric field then lies predominately in the x-y plane. Seen edge on, this constitutes a linear polarization perpendicular to the z-axis.

Using a linear polarizer then one can separate these two types of transitions.

EXPERIMENT

Observe the Zeeman effect in the two lines of neon analyzed above. Compare the g-factors calculated from fringe matching with those predicted on the basis of L-S coupling.

Note that L-S coupling is an imperfect model for neon. In particular, the g-factor of the $^3P_1$ state of neon is poorly predicted. A better calculation by Shortley (Physical Review 47, 295 (1935)) gives a value of 1.34. However, the remaining neon states under consideration have g-factors not very different from the Landé g-factors predicted by L-S coupling.

Optional experiment: get your TA or instructor to change the light source from neon to mercury. DON'T ATTEMPT TO MAKE THIS CHANGE YOURSELF. THE LIGHT SOURCES ARE VERY DELICATE! Then observe the green line in mercury. Compare your g-factors with those predicted by L-S coupling.

A. Apparatus

The central analytical device in this experiment is an etalon, which is a slab of quartz (thickness: d = 6.029 mm, index of refraction: n = 1.46) having the two opposing sides accurately parallel. On these sides is deposited a reflecting material. The etalon is housed in a stainless steel tube and should not be removed from it. DO NOT TOUCH THE REFLECTING SURFACES OF THE ETALON!

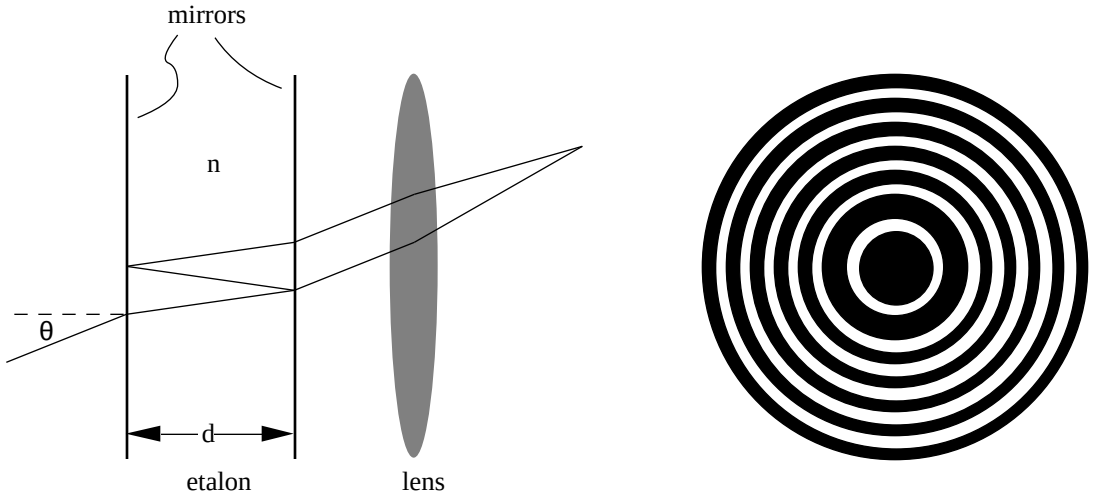

Fig. 4 (a) Light path through an etalon; (b) Fringe pattern.

The etalon (Fig. 4a) generates a series of circular interference fringes as shown in Fig. 4b. The location of these fringes is given by the condition

$$\sqrt{1 - \frac{\sin^2\theta}{n^2}} = \frac{m\lambda}{2nd} \qquad [43]$$

where d is the etalon thickness, λ is the wavelength in free space, n in the index of refraction of the etalon and m is an integer called the "order of interference". Eq. 43 can be derived from the geometry shown in Fig. 4a. Successive fringes differ in m by one, but the center most fringe does not have an m of zero. Setting θ equal to zero in Eq. 43 defines the smallest value of m, which is generally a large number.

After the light leaves the etalon, it passes through a linear polarizer. There are in fact two linear polarizers, one above the other, so that the upper half of the field of view has one polarization, the lower half the other. One should arrange the polarizer orientation so that the upper half of the field of view is polarized parallel to the z-axis, the lower half, perpendicular to it.

For the neon green line at 585 nm, there will be one π transition which (according to Eq. 3) will be unaffected by the magnetic field. Thus in the upper half of the field of view the fringe pattern will not change as the magnetic field is applied. Also there are two σ transitions, one of which, according to Eq. 29, decreases in frequency as the magnetic field is increased. The other, according to Eq. 30, increases in frequency. Now a transition that decreases in frequency must increase in wavelength, and as seen in Eq. 43 must increase in angle θ. That is, it moves outward in the fringe pattern. A transition that increases in frequency moves inward in the fringe pattern.

Therefore, a single fringe of the neon green line must be unchanged in the upper half of the field of view, but split in two in the lower half. The right-hand part of the fringe, where it crosses the horizontal axis, must look as shown in Fig. 5.

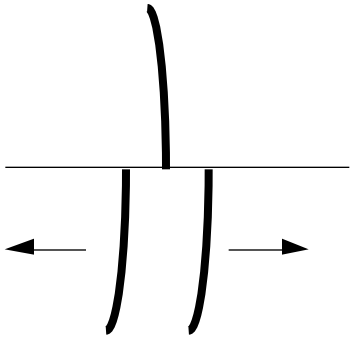

Fig. 5 Split fringe pattern. The arrows indicate the direction the fringe moves as the magnetic field increases.

Problem 6 Sketch the fringe pattern that a single fringe breaks into for the neon 603 nm line. Optional: sketch the fringe pattern for the neon 640-nm line and for the mercury 546 nm line.

Turning back to the neon green line, if one fringe component moves outward and the other moves inward, there will be a field at which the outward moving component of one fringe will exactly overlap the inward-moving fringe from the next order outwards. It is this magnetic field that is to be measured.

When an exact overlap occurs, there are two frequencies at the same angle θ, and therefore using Eq. 43,

$$m\lambda_a = (m \pm 1)\,\lambda_b \qquad [44]$$

where λ_a and λ_b are the wavelengths of the two fringes being overlapped.

Problem 7 Show that the frequency difference between the two green lines of neon being overlapped is

$$\Delta\nu = \frac{c}{2nd}\,\frac{1}{\sqrt{\frac{1-\sin^2\theta}{n^2}}} \quad \underset{\theta<<1}{\rightarrow} \quad \frac{c}{2nd} \qquad [45]$$

and that the exact overlap that occurs with the neon green line gives

$$\Delta\nu = 2g(J'L'S')\mu_B H_z/h \approx \frac{c}{2nd} \qquad [46]$$

Eq. 46 can be solved for g(J'L'S'). Once H_z has been measured, g(J'L'S') can be calculated.

The neon line at 603 nm has g(J'L'S') almost equal to g(JLS), with g(J'L'S') slightly larger. Furthermore, the σ lines are not resolved due to the broadening caused by the Doppler effect, coupled with the fact that the g-factors are almost equal. However, a matching of the σ lines of adjacent orders can be done as before: the match occurs when the overlapped line is the narrowest. But in this case, the outermost line of one order is matching the innermost line of the adjacent order. Hence, the matching condition, analogous to Eq. 46 is

$$\Delta\nu = [g(JLS) + g(J'L'S')]\,\frac{\mu_B H_1}{h} = \frac{c}{2nd} \qquad [47]$$

where H_1 is the magnetic field at which the matching occurred. This equation gives a relation between g(JLS) and g(J'L'S').

Another relation can be obtained by increasing the magnetic field until the π lines match the σ lines as well as possible. What this means is that each of the π lines matches the average of the σ lines from the adjacent orders. At this magnetic field H_2, one has the matching condition

$$[3g(J'L'S') - g(JLS)] \frac{\mu_0 H_2}{h} = \frac{c}{nd} \qquad [48]$$

This equation, together with Eq. 47, allows one to solve for g(JLS) and g(J'L'S') separately.

If the optional experiment with the mercury green line at 546 nm is being performed, then consider the following:

> The green line of mercury at 546 nm has fringes for the s transitions that vary widely in intensity. Of the three outward-moving fringes, the intensities are in the ratio 6:3:1 moving from the inside out. That is, the brightest fringes are associated with the $\nu_{1 \to 2}$ and $\nu_{-1 \to -2}$ transitions.
>
> There are two very easily seen overlaps possible with this spectral line. The first is where the three fringes from one order exactly overlap the three fringes from the adjacent order, giving a pattern of three very distinct fringes with almost the same intensity.

Problem 8 Find the analog of Eq. 46 for this case.

> The second overlap that is easy to recognize is when the two bright fringes of one order (those of relative intensity 6 and 3) exactly overlap the two bright fringes of the adjacent order. Then the overlapped fringes have relative intensity 9 while the left-over fringe on each side has relative intensity 1 and is dim enough to hardly be seen. Thus the pattern that is observed is a bright pair of overlapped fringes.

Problem 9 Find the analog of Eq. 46 for this case.

> From the magnetic field values at which these two overlaps occur, the values of g(JLS) and g(J'L'S') can be calculated.

B. Apparatus Notes

Magnet and power supply
Bell gauss meter, model 4048
Etalon telescope
Neon lamp on mounting stand, with power supply and variac
Mercury 202 lamp and power supply

MAGNET POWER SUPPLY

The magnet power supply has no air interlock. WHEN YOU TURN IT ON, CHECK THAT THE BALL RISES IN THE PLASTIC CYLINDER ON THE FRONT OF THE SUPPLY! If it doesn't rise, turn off the unit and get help.

GAUSS METER

The gauss meter has a delicate Hall effect probe. BE CAREFUL NOT TO DAMAGE IT! Read the meter's instructions to see how to calibrate it. Place the probe in the magnetic field close to the lamp, so as to minimize errors due to field inhomogeneities.

NEON LAMP

The power supply operates at very high voltages. DON'T TAKE APART THE SUPPLY OR THE LAMP HOLDER WITHOUT GETTING ASSISTANCE!

To light the lamp, turn the variac to zero, throw the switch on and turn up the variac until the discharge starts. One wants the spectral lines to not be power broadened, so one should use as low a voltage as possible. However, the magnetic field disturbs the plasma in the lamp and often causes the lamp to go out as the field is increased. The remedy is to turn up the variac with the magnetic field on until the lamp lights.

ETALON TELESCOPE

Insert the appropriate filter in the holder. DO NOT TOUCH THE GLASS OF THE FILTER, BUT HOLD IT BY THE METAL PARTS ONLY! The filter holder has been adjusted to the optimum angle – do not change it without consulting your TA or instructor. DO NOT DROP THE FILTER!

Move the telescope from side to side to get the brightest pattern. If it is not vertically centered, push or pull the pin sticking out of the bottom of the telescope. This pin is attached to the etalon, and allows one to adjust its position without removing it from the telescope.

Do not remove the etalon from the telescope without help. DON'T TOUCH THE MIRRORED SURFACES OF THE ETALON UNDER ANY CIRCUMSTANCES! Under normal operation of the experiment, the etalon need not have any adjustment beyond pushing or pulling the pin at the bottom.

If the fringe pattern is not horizontally centered, adjust the knurled screw at the far end of the telescope.

Check that the polarizer is inserted with a horizontal arrow and a vertical down-pointing arrow facing the viewer. This causes the polarizer to deliver the linear polarizations discussed above.

MERCURY 202 LAMP

If you plan to do the optional experiment, get the TA or instructor to change lamps for you. The Hg^{202} lamp is very fragile and cannot be replaced (the manufacturer is no longer in business). The lamp power supply should be operated as follows:

- Set the intensity control to 60.
- Position the probe of an oscilloscope close to the coil in the lamp holder. Don't connect the probe to anything – a pickup signal is desired. Adjust the probe position until an rf signal from the coil is observed.
- Adjust the position of the tuning plunger on the lamp holder until the rf signal on the oscilloscope is maximized.
- Wait until the lamp lights. This can take 1 to 5 minutes. If the lamp does not light within 5 minutes, get assistance from the TA, instructor, or John McGrath.
- Adjust the tuning plunger for maximum brightness.

The Hg^{202} lamp is made of quartz, which is transparent in the ultraviolet, so considerable ultraviolet radiation is emitted, since mercury has a strong line at 254 nm. THIS RADIATION CAN DAMAGE YOUR EYES, SO NEVER LOOK AT THE LAMP EXCEPT THROUGH A PIECE OF GLASS OR PLASTIC! If you wear eyeglasses, these

will give protection. Likewise, the glass lens in the eyepiece of the etalon telescope will also protect you.

The filters for this line are colored glass. Use both greenish filters together.

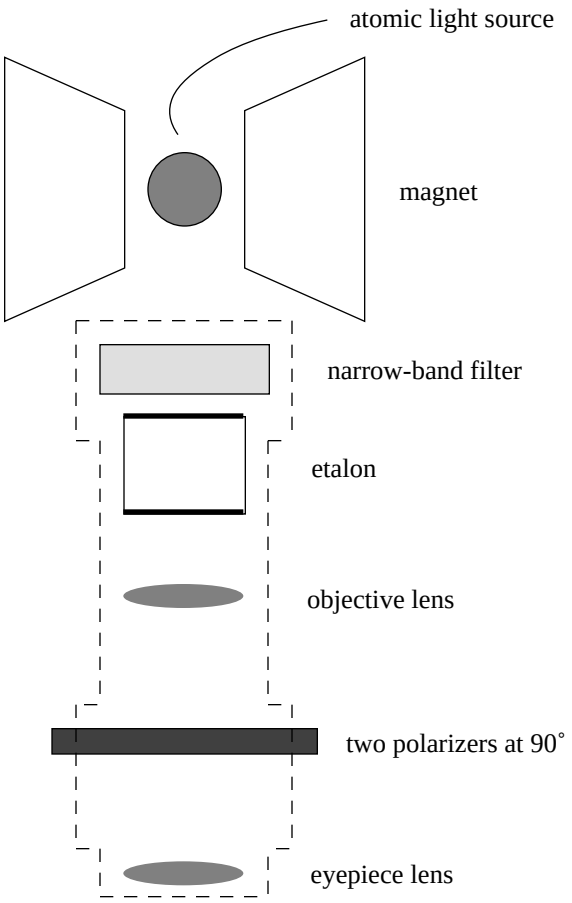

Fig. 6 Top view of optical system.