B.Sc. (Sem. - 4) Physics

Course: US04CPHY21

Electromagnetic Theory and Spectroscopy

UNIT-3 Lecture 4

Dr. A. R. Jivani, Physics Department, VPM

Atomic Spectra

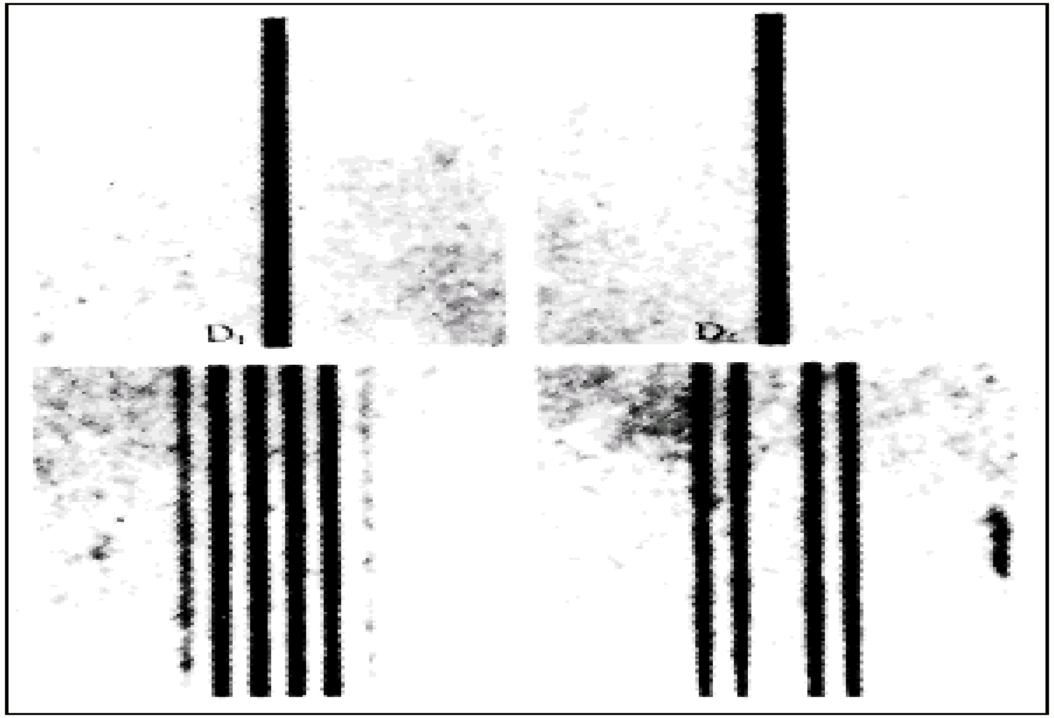
Dr. A. R. Jivani, Physics Department, VPM

UNIT - III Atomic Spectra-Topics

- **ZEEMAN EFFECT**
- **PASCHEN-BACK EFFECT**
- **STARK EFFECT**

What is Zeeman effect?

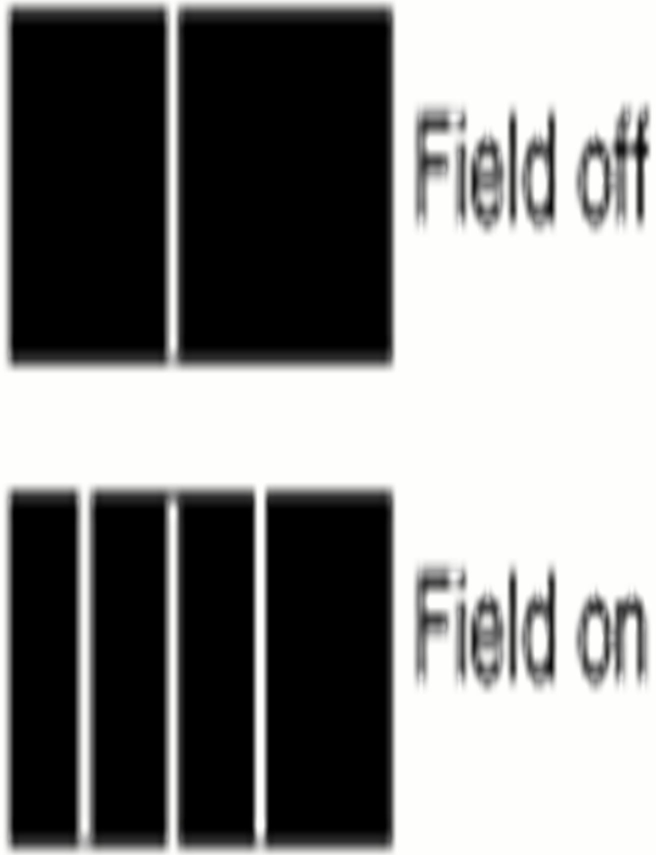
The splitting of a spectral line into several components in the presence of a ***static magnetic field.***



Zeeman effect: The **effect of magnetic field** on the spectrum lines.

What is Zeeman effect?

- A single spectral line splits up into **three** components.
- One line has larger frequency.
- One line has lower frequency.
- One line has the frequency of original line.



Introduction:

- According to **classical concept**, **light is emitted due to periodic motion of charge particles within the atoms**.

- Now when these charge particles are subjected to external magnetic or electric fields, then definitely they will show variations in the frequencies of radiations emitted.

What is Stark effect?

The shifting and splitting of spectral lines of atoms and molecules due to the presence of an ***external static electric field.***

Experimental Study of Zeeman effect

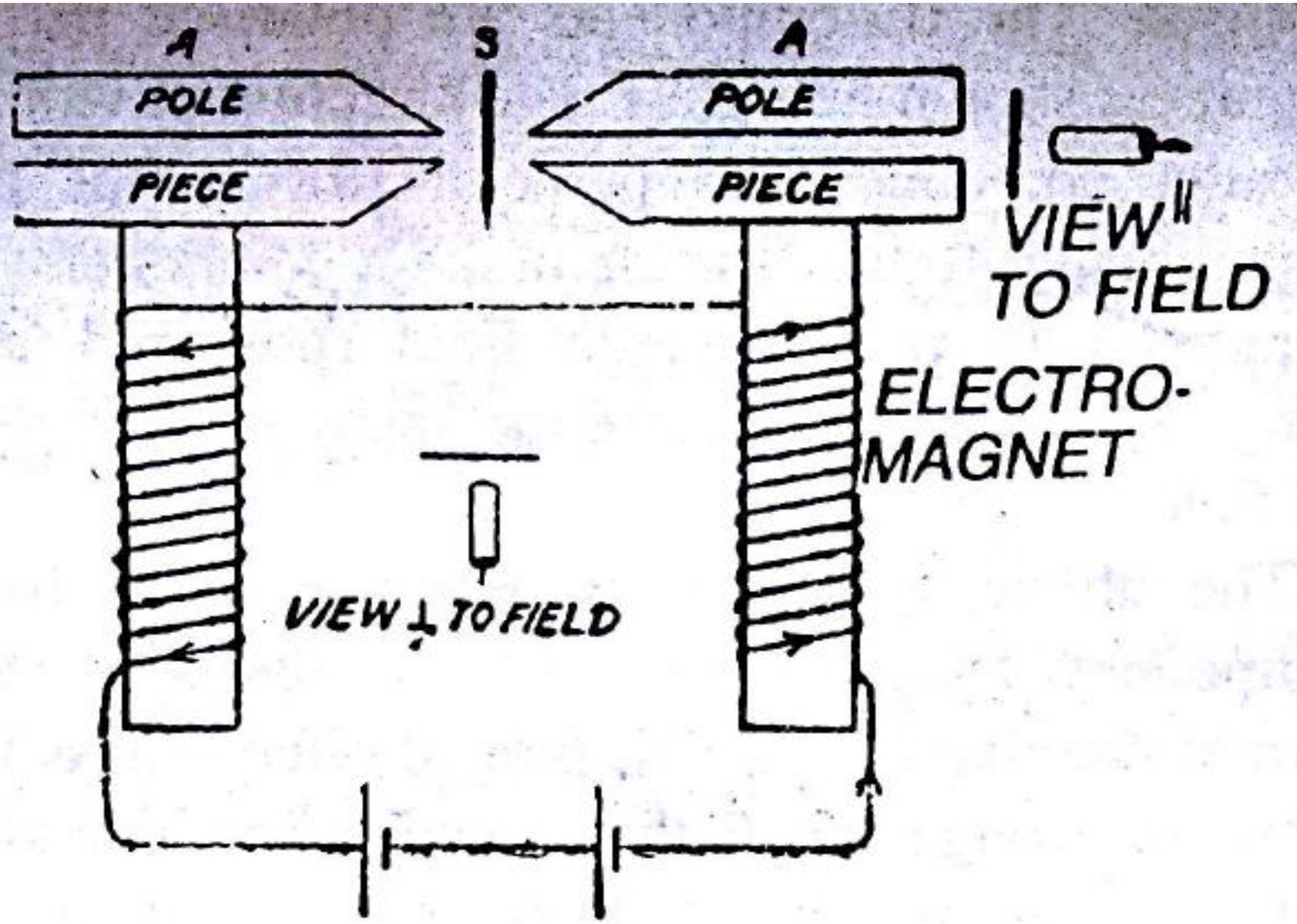


Fig. 1. Experimental arrangement of studying Zeeman effect.

Experimental Study of Zeeman effect

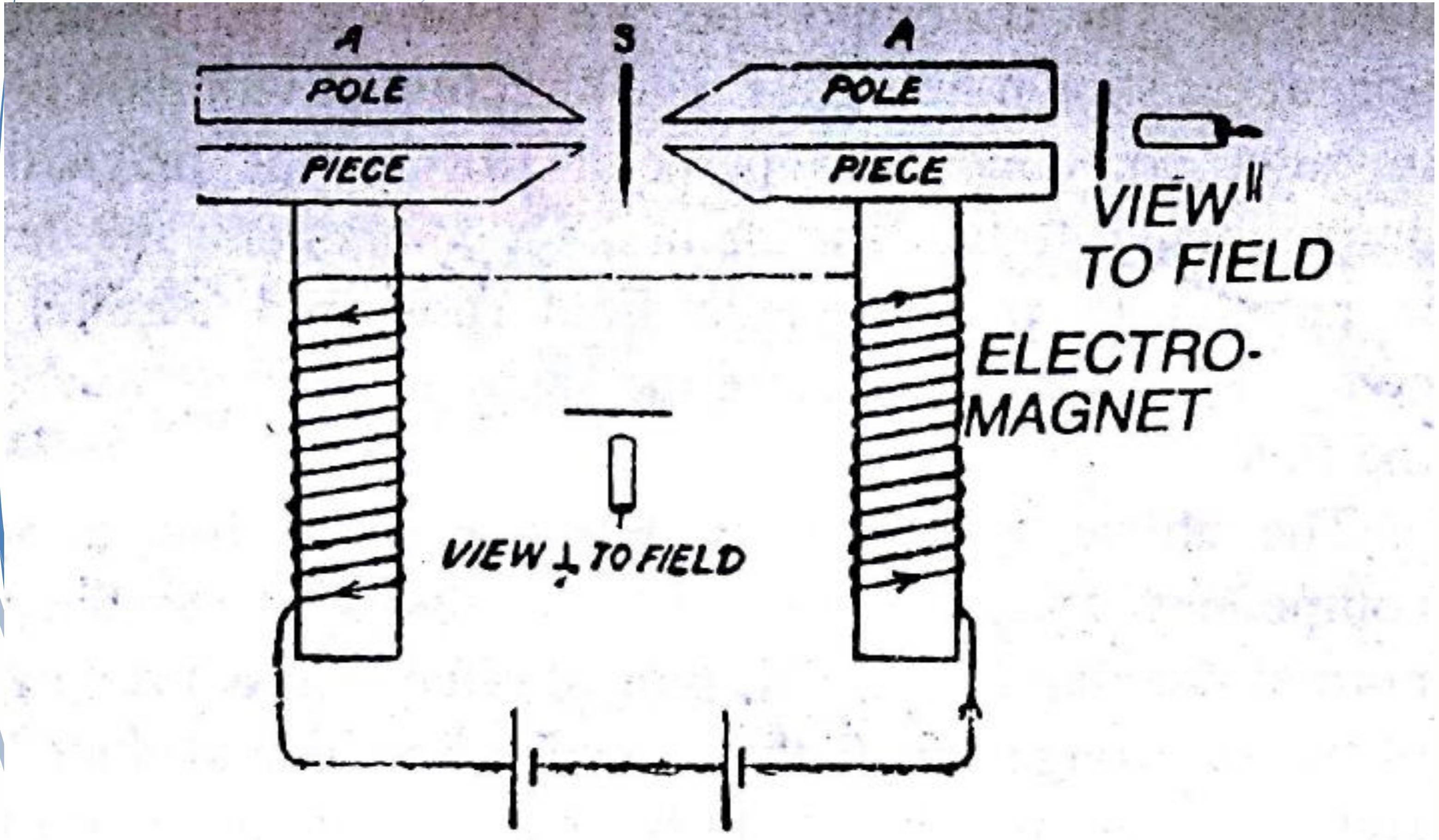


Fig. 1. Experimental arrangement of studying Zeeman effect.

- S is source of light

- e.g.
- Na Lamp
- Hg arc
- etc

Experimental Study of Zeeman effect

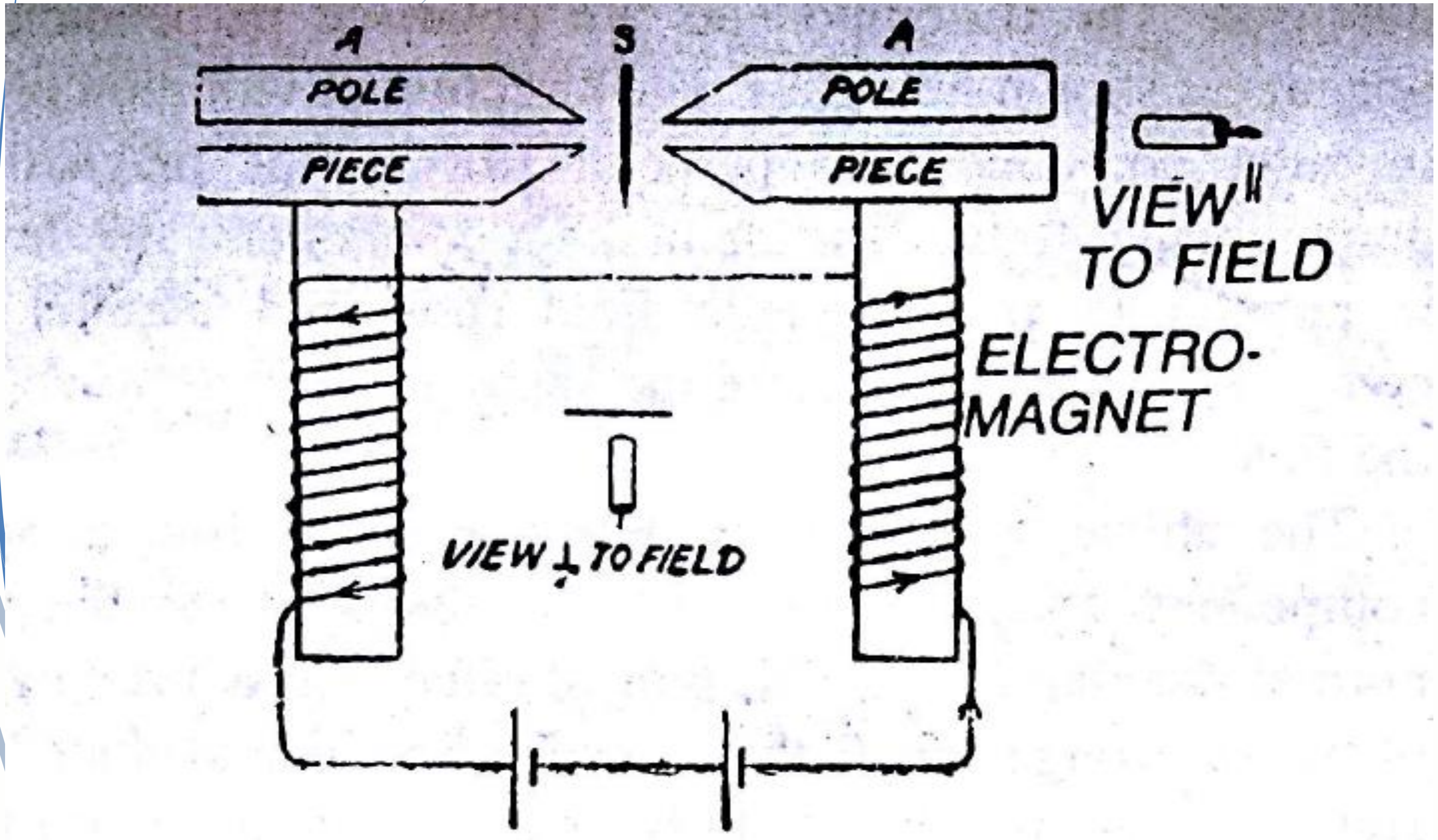


Fig. 1. Experimental arrangement of studying Zeeman effect.

- AA are two pole pieces of a strong electromagnet

Experimental Study of Zeeman effect

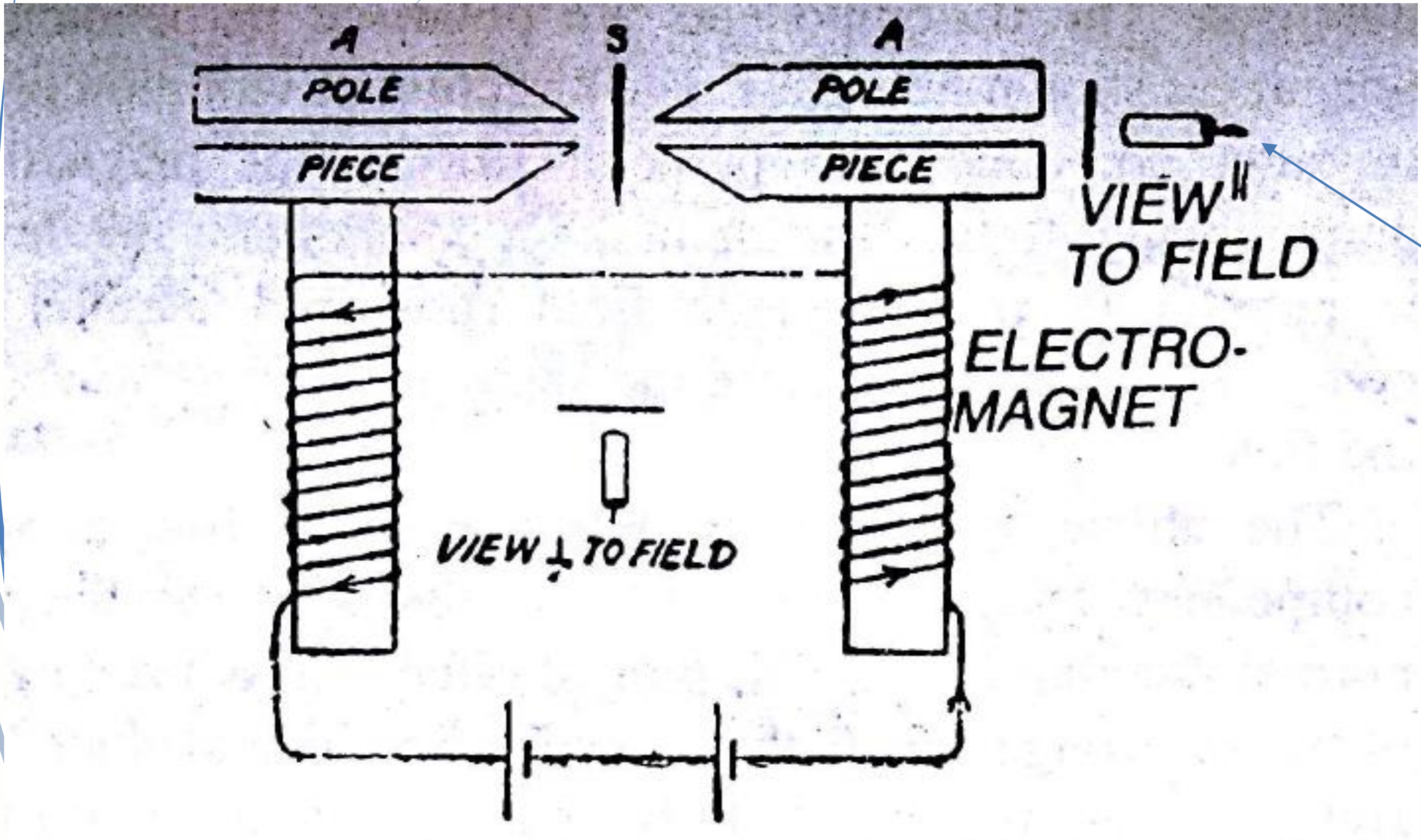


Fig. 1. Experimental arrangement of studying Zeeman effect.

- The light coming from the source is observed with the help of high resolving power instruments (Lummer plate and a spectroscope) and is analyzed with the help of Nicol prism.

Experimental Study of Zeeman effect

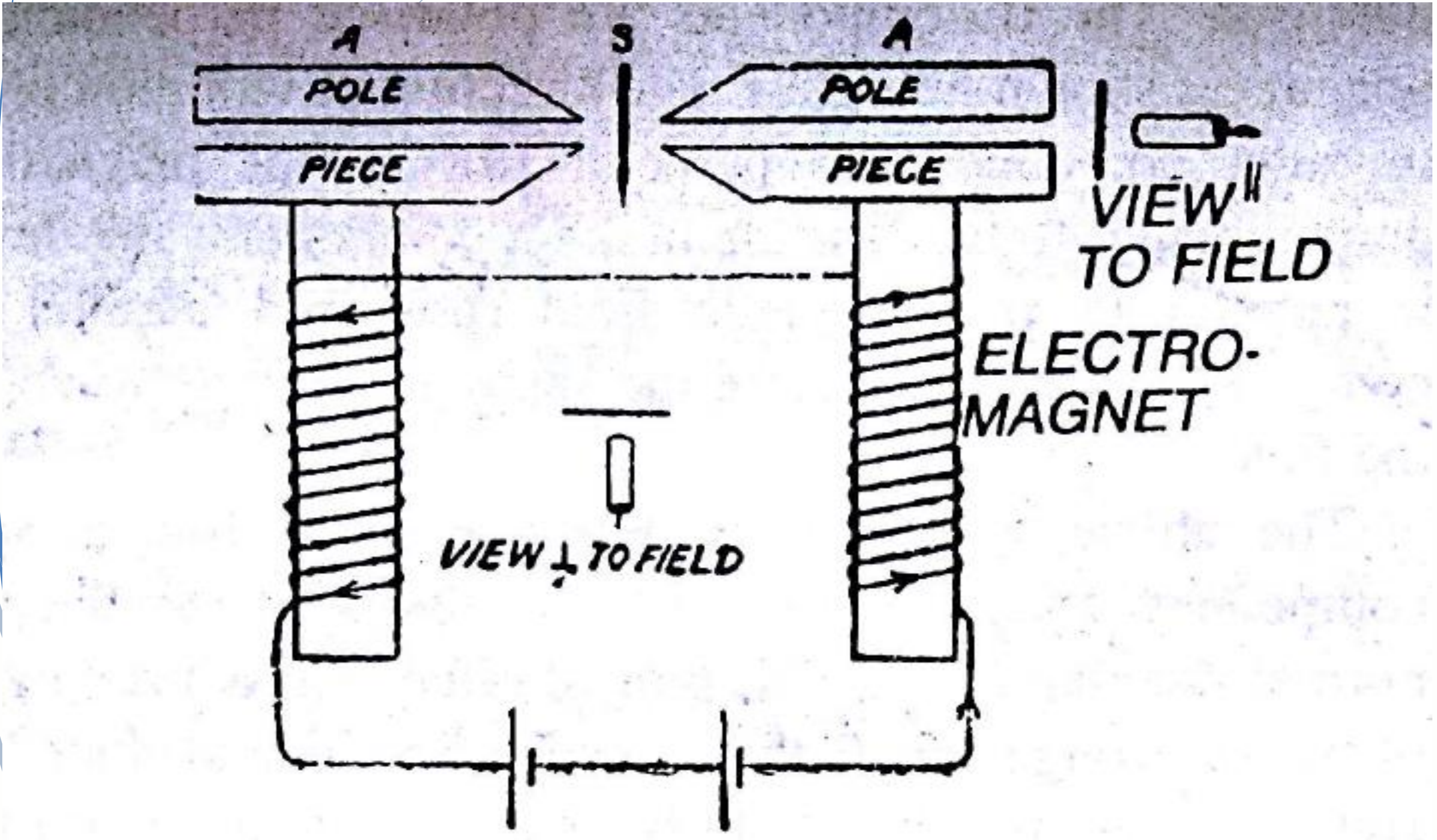


Fig. 1. Experimental arrangement of studying Zeeman effect.

- The light can be viewed perpendicular to the field and parallel to the field.

Experimental Study of Zeeman effect

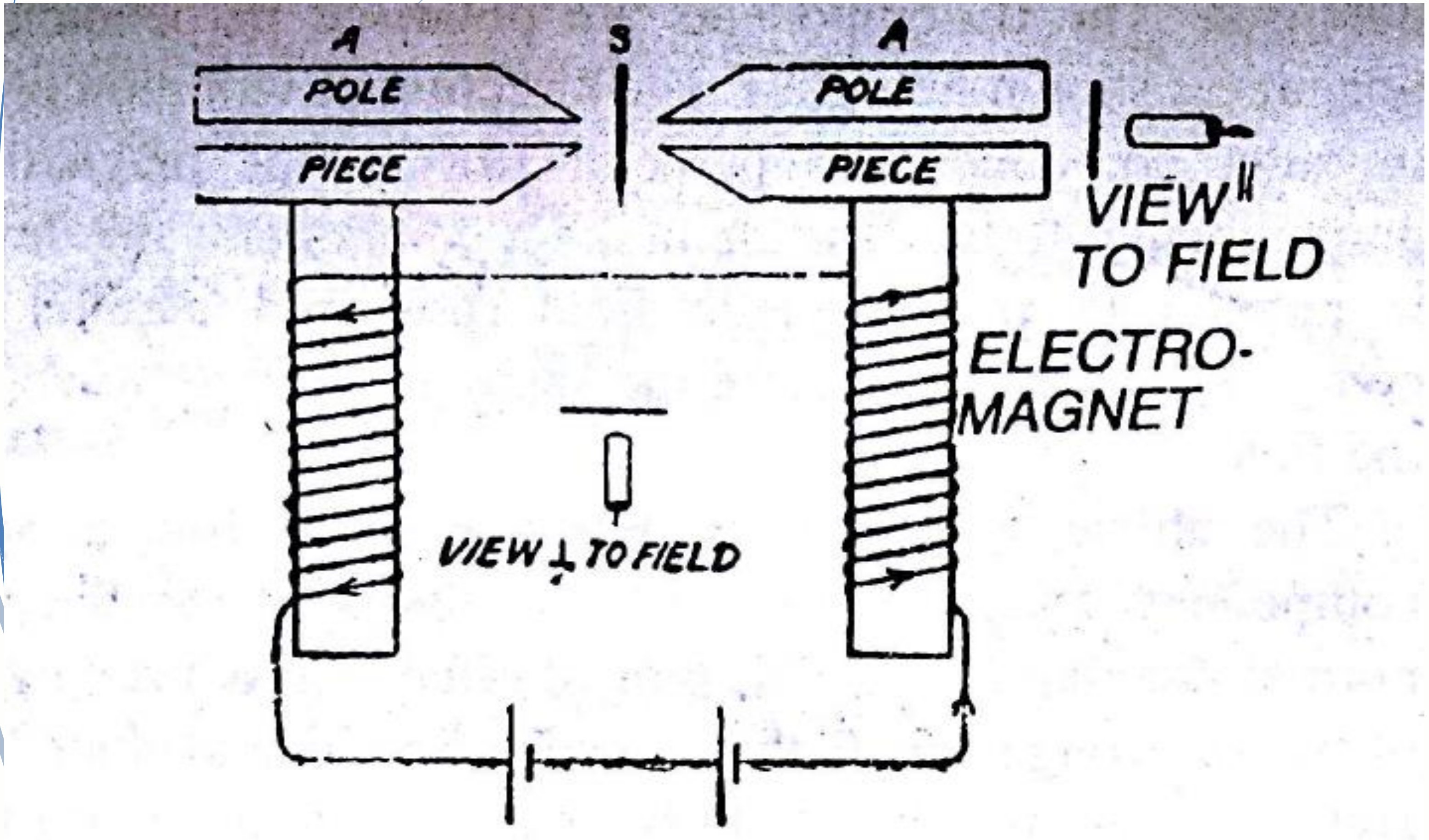
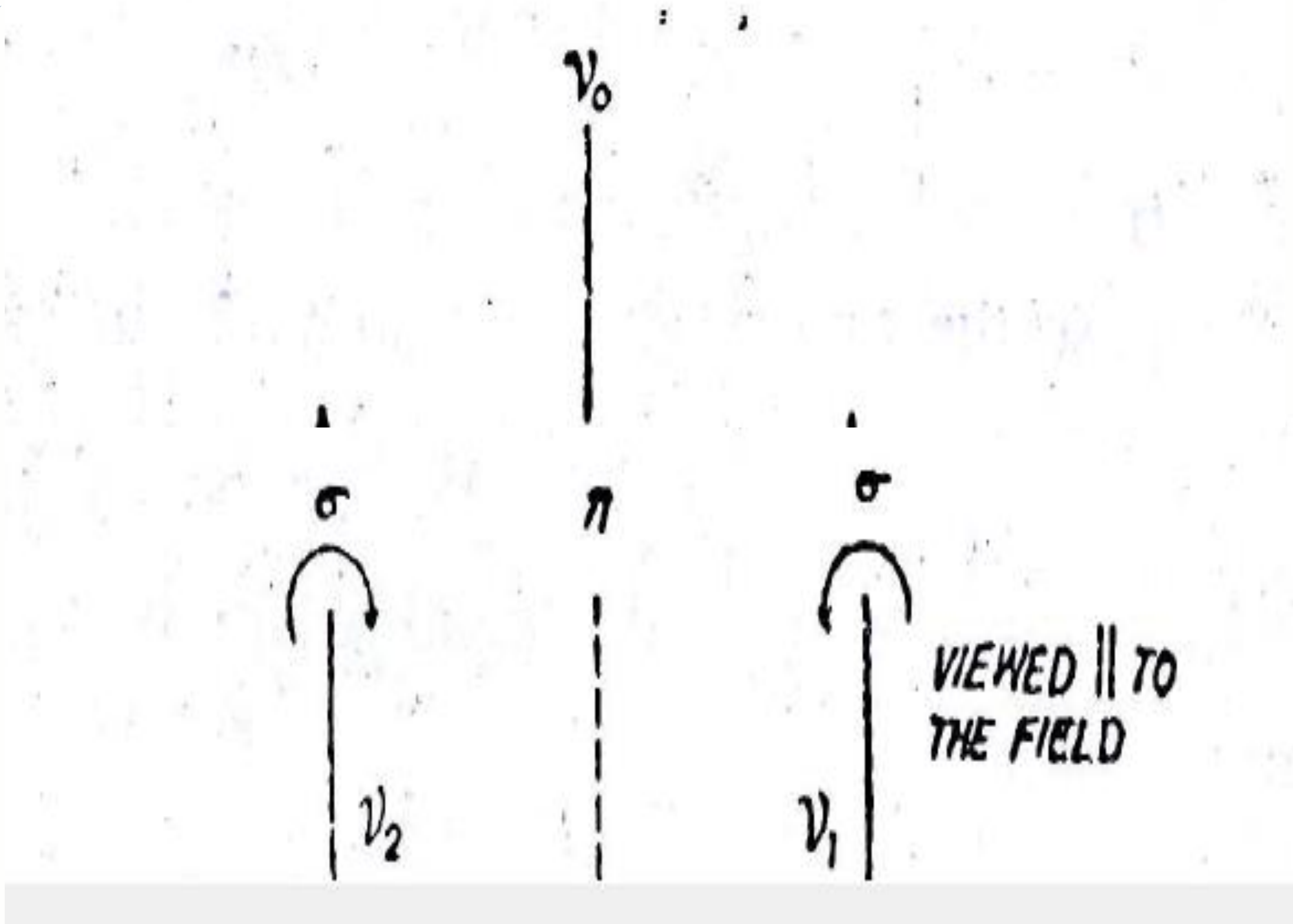


Fig. 1. Experimental arrangement of studying Zeeman effect.

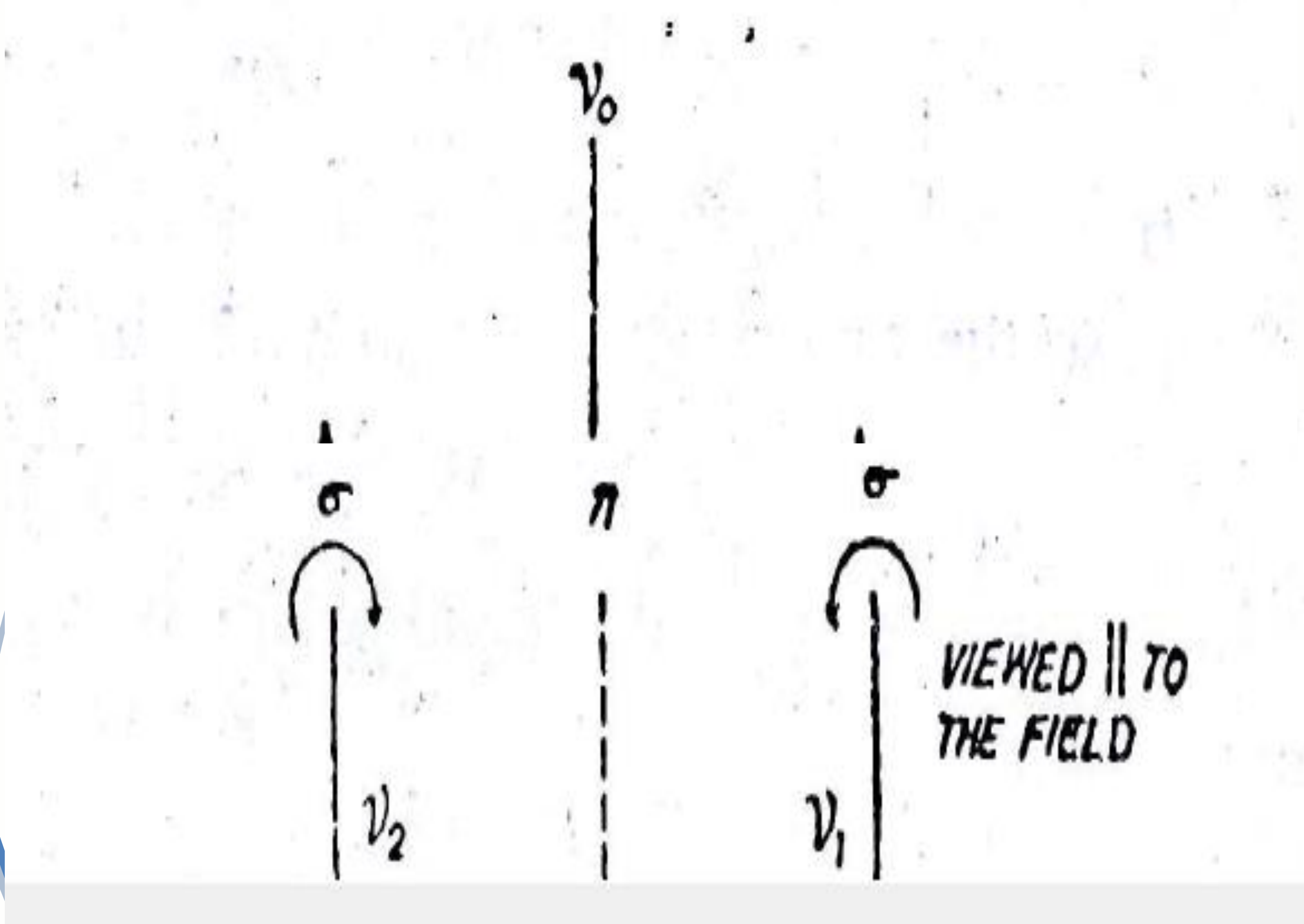
- To observe the emitted light **parallel** to the field, a hole is drilled in the pole pieces of the electromagnet.

View parallel to the magnetic field



Two components are plane polarized. **[Normal Zeeman Effect]**

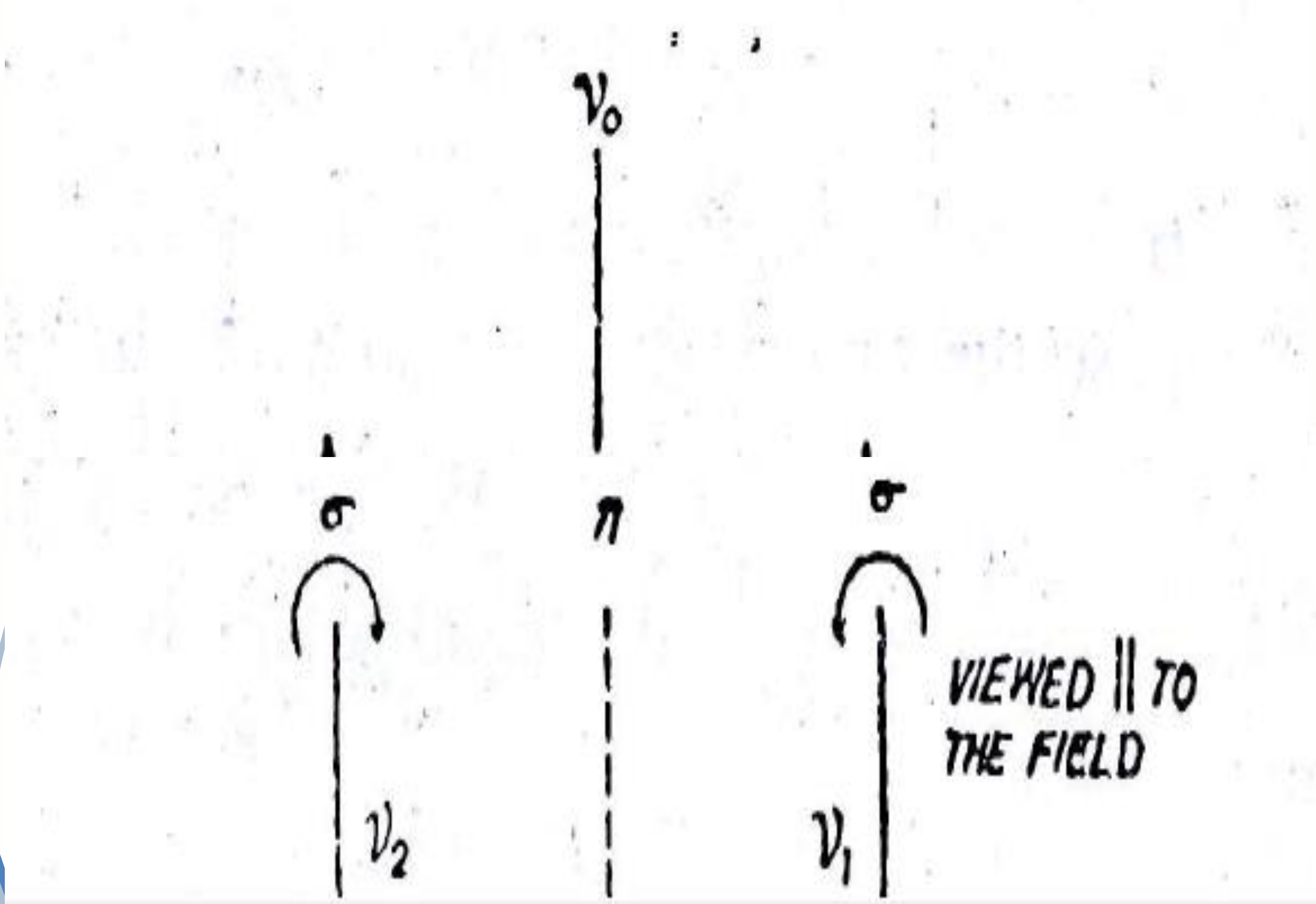
View parallel to the magnetic field



- One component has a **higher frequency than the original line** and the other **lower**.
- **The original line is not observed.**

Two components are plane polarized. **[Normal Zeeman Effect]**

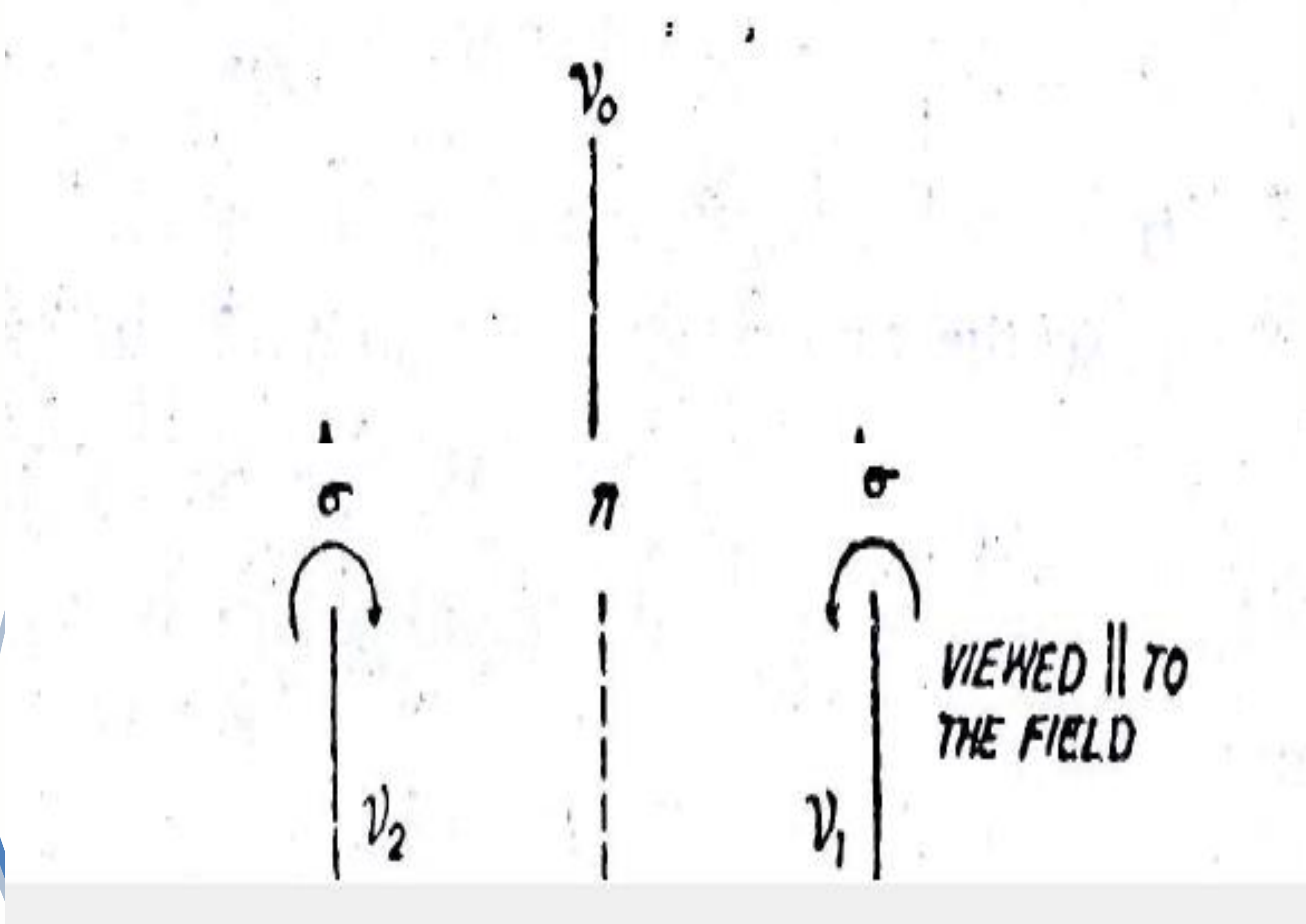
View parallel to the magnetic field



- Although the original line is unpolarized but the component lines are found to be polarized.

Two components are plane polarized. **[Normal Zeeman Effect]**

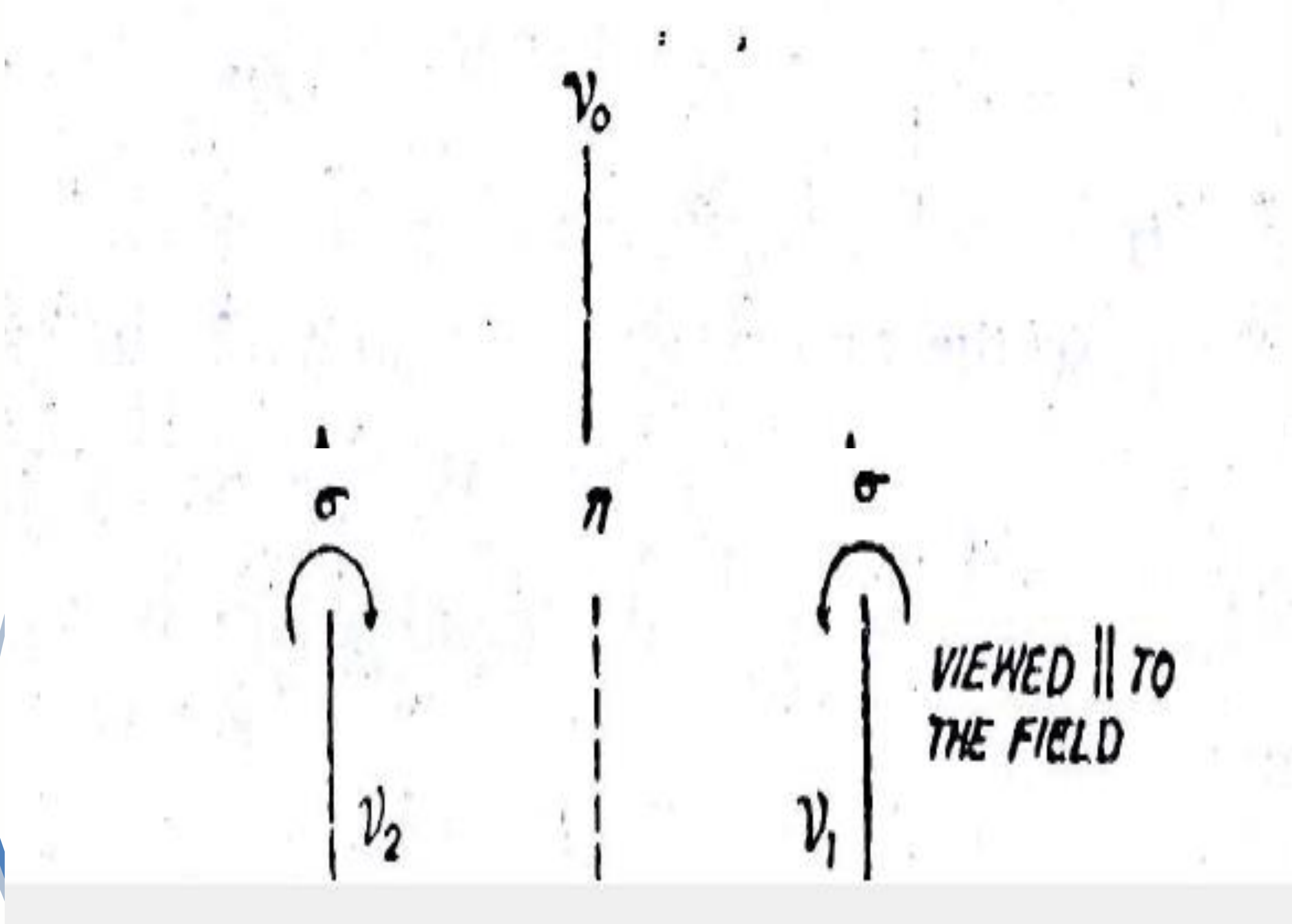
View parallel to the magnetic field



- The outer components are circularly polarized in opposite directions.

Two components are plane polarized. **[Normal Zeeman Effect]**

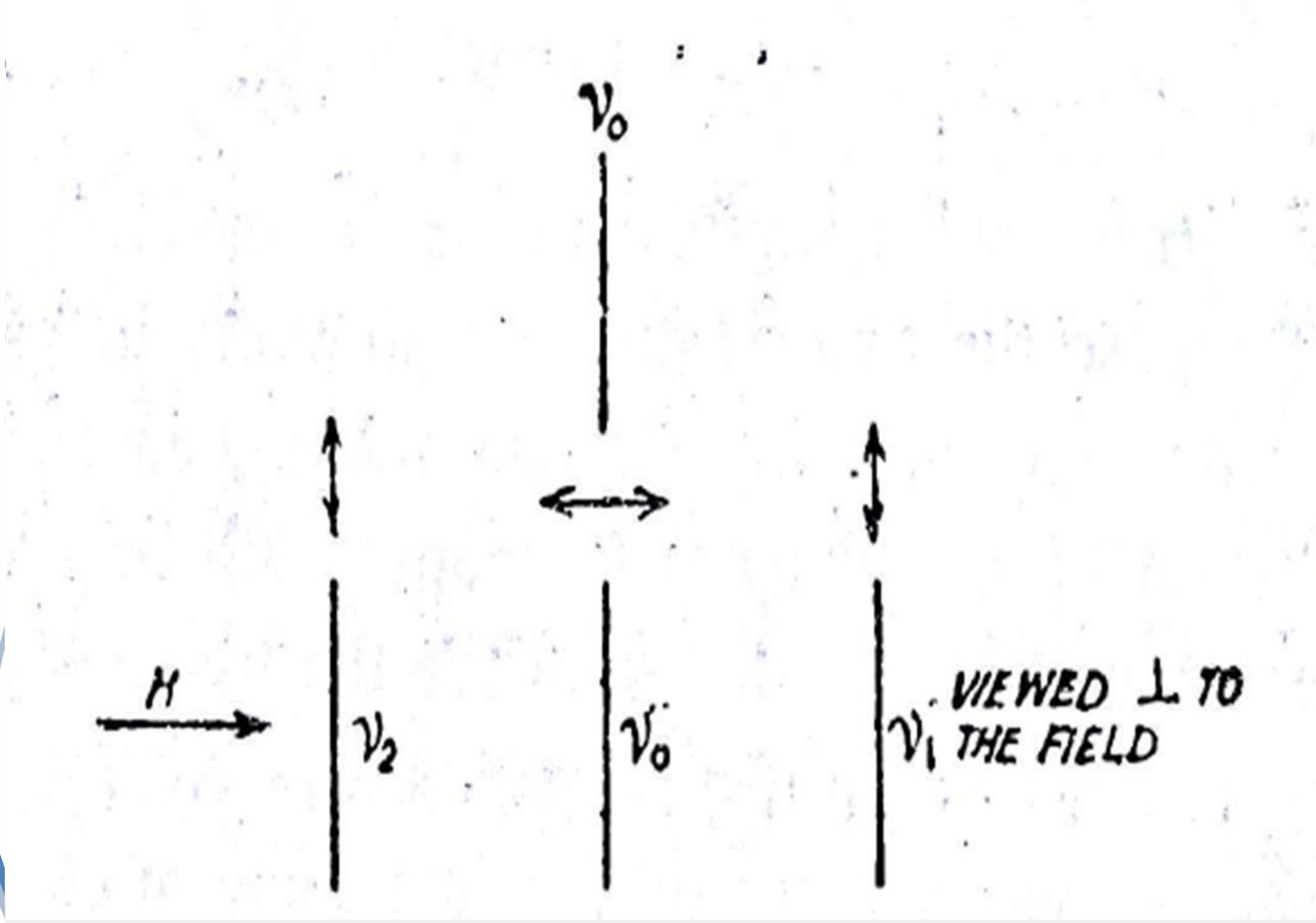
View parallel to the magnetic field



- The **outer components** are known as **σ components** and
- the **middle component** is known as **π component.**

Two components are plane polarized. **[Normal Zeeman Effect]**

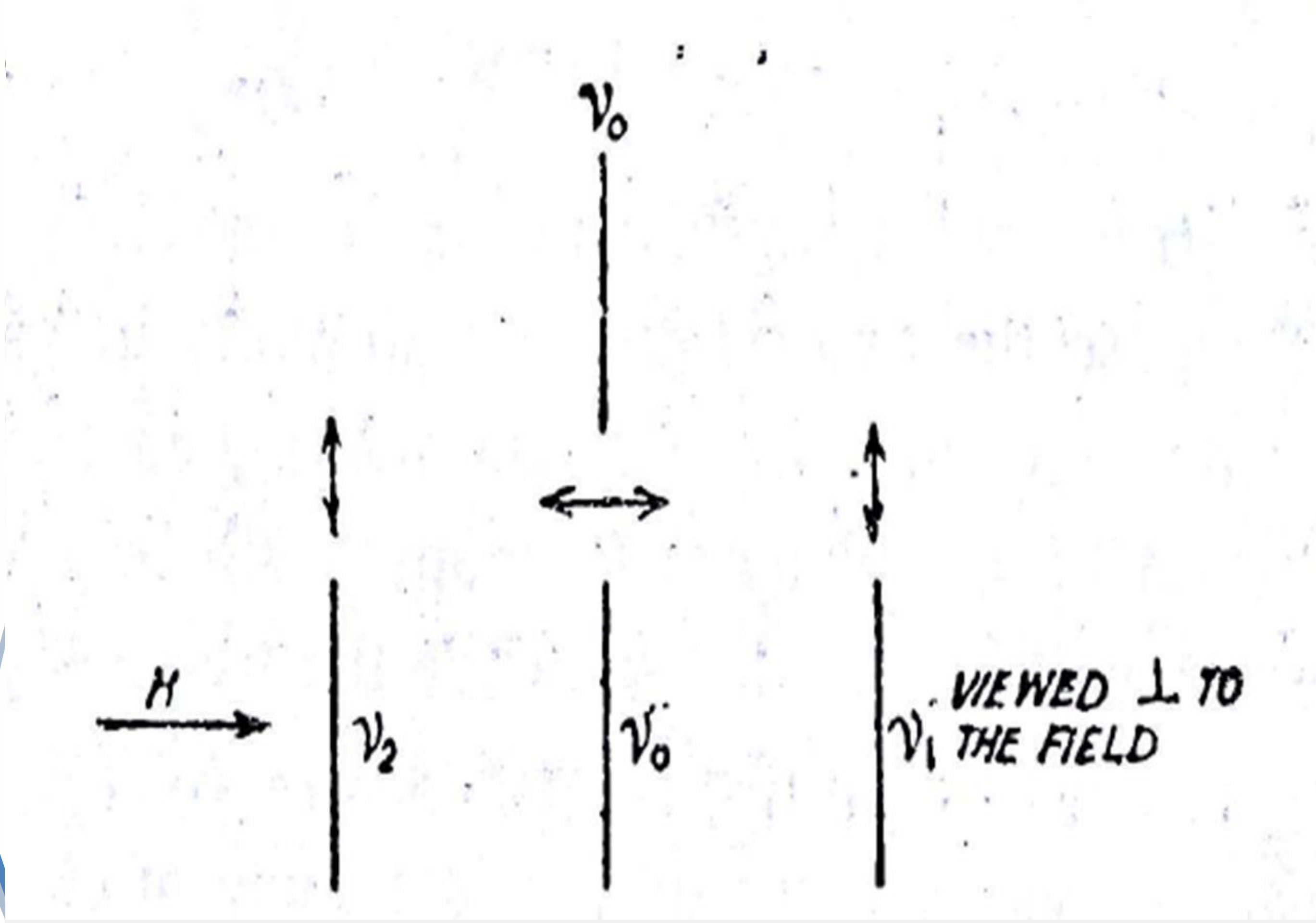
View perpendicular to magnetic field



- When light is observed perpendicular to the magnetic field, **three component lines** are seen.

Three components are plane polarized. **[Normal Zeeman Effect]**

View perpendicular to magnetic field



- One component line is in the same position as the **original line** and the other two components—one on either side of this line-are **separated by equal amounts**.

Normal Zeeman effect

The splitting of a spectral line into three components in the presence of a **strong static magnetic field.**

Anomalous Zeeman effect

The splitting of a spectral line into several components in the presence of a **weak static magnetic field.**

Differences between Normal Zeeman effect and Anomalous Zeeman Effect

Normal Zeeman effect

- Rarely Observed
- It is called Normal due to simplicity and due to its explanation by classical theory

Anomalous Zeeman Effect

- Generally Observed
- It does not explain on the basis of classical theory

Classical Interpretation of *Normal Zeeman effect*

- The basis of interpretation is **Lorentz classical theory** according to which if a source of light is placed in a magnetic field, **the frequency of motion of electrons** moving in a **circular orbit** would be modified.

- It can be shown that the **magnitude of change in frequency** is given by $\Delta \upsilon = \dfrac{e\,B}{4\,\pi\,m_0}$

- where **B** is field strength, **e** and m_0 are the charge and mass of the electron.

Classical Interpretation of *Normal Zeeman effect*

- Suppose the **field is directed normally upwards** from the book paper, then the frequency of electrons moving in an orbit in **counterclockwise** direction (in the plane of the paper) will become $\boldsymbol{v_0} + \Delta\ \boldsymbol{v}$, i.e., motion of electron will be **speeded up.**

Classical Interpretation of *Normal Zeeman effect*

- The frequency of electron moving in an orbit in **clockwise direction** will be $\upsilon_0 - \Delta\ \upsilon$, i.e., motion of electron will be **slowed down**.

- υ_0 is the orbital frequency of electron motion without field.

- The change in frequency $\Delta\ \upsilon$, can be calculated as follows:

Classical Interpretation of *Normal Zeeman effect*

- For the revolution of electron, the equilibrium is maintained according to the equation,

$$m_0\,\omega^2\,r = F, \tag{2}$$

- where $\boldsymbol{\omega}$ is the **angular frequency** and **F** represents **electrostatic force of attraction** that provides necessary centripetal force $m\,\omega^2\,r$.

Classical Interpretation of *Normal Zeeman effect*

- For the electron moving in **counterclockwise** direction and in the presence and in the presence of magnetic field **B** acting normally upwards form the book paper, the Lorentz force ***B e v*** will also act in the direction of **F** in addition to F.

- This additional force changes the angular frequency of the revolution of electron. The governing equations becomes

$$m_0\,(\omega + \Delta\omega)^2\, r = F + B\, e\, v \qquad (3)$$

Classical Interpretation of *Normal Zeeman effect*

$$m_0\,(\,\omega + \,\Delta\omega)^2\, r = F + B\, e\, v \qquad (3)$$

- $m_0\,(\omega^2 + 2\omega\,\Delta\omega + [\Delta\omega]^2)r = F + B\,e\,v$

- Neglecting the term $(\,\Delta\omega)^2$, we have

$$m_0\,(\omega^2 + 2\omega\,\Delta\omega)r = F + B\,e\,v$$

$$\cancel{m_0\omega^2\,r} + \,2m_0\,r\,\omega\,\Delta\omega = \cancel{F} + B\,e\,v$$

$$2\,m_0\,\omega\,\Delta\omega\,\;r = B\,e\,v$$

Classical Interpretation of *Normal Zeeman effect*

$$2\, m_0\, \omega\, \Delta\omega\;\; r = B\; e\; \omega r$$

$$\because\ \omega r = \text{v}$$

- Hence $\Delta\omega = \dfrac{B\, e}{2\, m_0}$
- Therefore, change in frequency $\Delta \upsilon = \dfrac{B\, e}{4\, \pi\, m_0}$

Classical Interpretation of *Normal Zeeman effect*

- For the electron, moving in **clockwise direction**, the Lorentz force will be acting opposite to F.

- This gives $\Delta\upsilon = -\dfrac{B\,e}{4\,\pi\,m_0}$

- Hence in the presence of magnetic field the frequencies of two directions of motion will be $\upsilon_0 + \Delta\,\upsilon$ (for **anti-clockwise** motion) and $\upsilon_0 - \Delta\,\upsilon$ (for **clockwise** motion)

Classical Interpretation of Noraml Zeeman effect

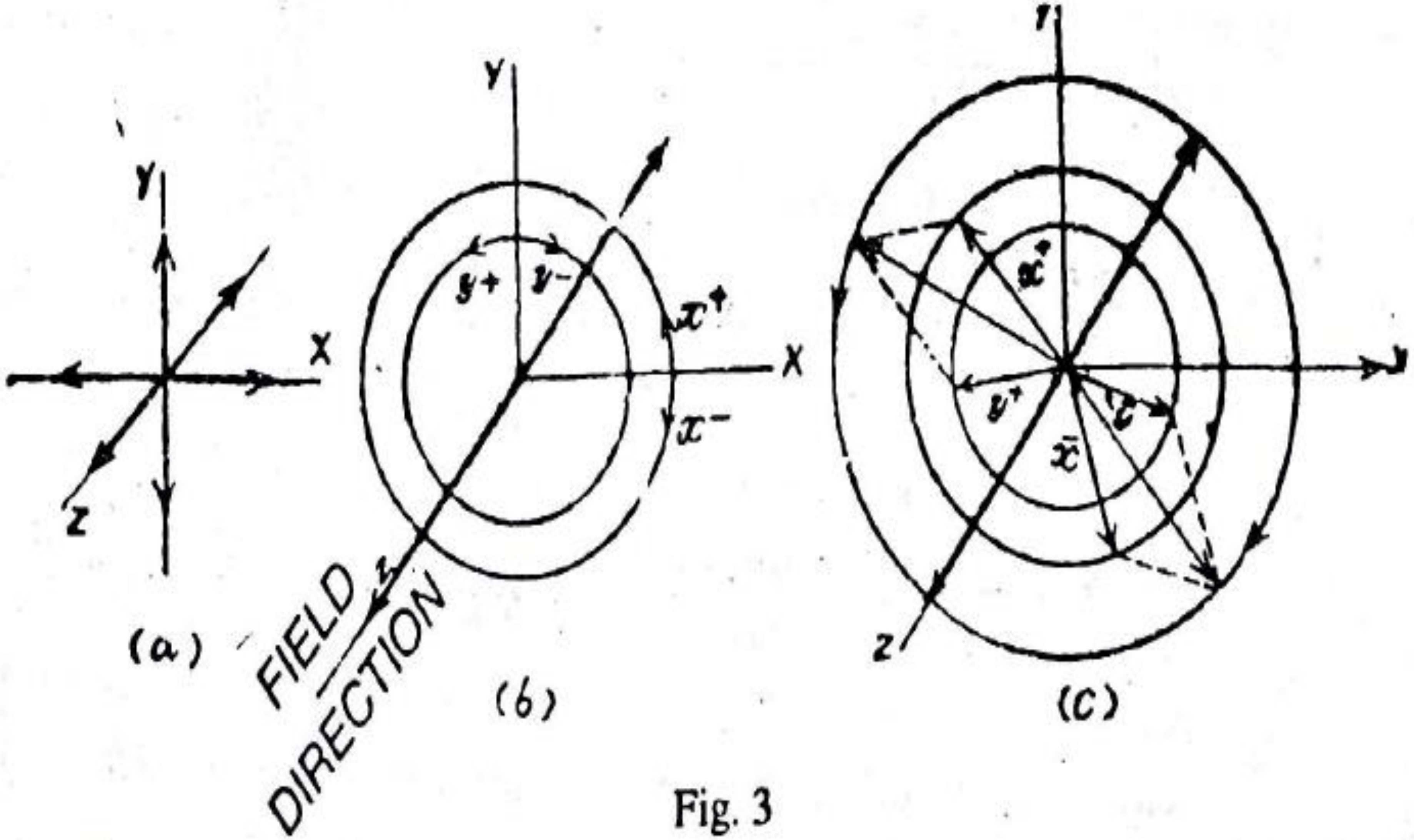


Fig. 3

View Along the Field Direction:

υ_0 is the unchangred frequency of electron motion along field direction i.e., along z-axis.

When the **source is viewed along the direction of field** then because of the transverse character of the light, the unchanged component of motion along z-axis (υ_0 frequency) will not be visible

but only two circularly polarised components in x and y-directions (of frequency $\upsilon_0 + \Delta\, \upsilon$ and $\upsilon_0 - \Delta\, \upsilon$) will be observed.

View Perpendicular to the Field Direction:

The view consists of **three plane polarized components**

When the source is viewed perpendicular to the field direction then the **z-component of motion will also become visible** (the electric vector vibrates parallel to the field).
The frequency of this component, as explained earlier, remains unchanged and is denoted by υ_0.

View Perpendicular to the Field Direction:

In addition to this component, motions in x and y directions, which were **circularly polarized** when seen along **field direction**, will also be visible in this direction but only their **edges**.

Thus, circular motion in x and y directions are observed as two plane polarised components equally displaced on either side of z-motion for this direction of observation.

View Perpendicular to the Field Direction:

Thus it explains that the view will consist of three plane polarised components-one unshifted line at the centre and two other lines on both sides of this unshifted line at equal distances.

9.3. VECTOR MODEL AND NORMAL ZEEMAN EFFECT

9.3. VECTOR MODEL AND NORMAL ZEEMAN EFFECT

If we leave the **spin motion of the electron**, then the **angular momentum** possessed by the electron is given by

$$p_l = \frac{l\,h}{2\,\pi}$$

and magnetic moment

$$\mu_l = e\,\frac{l\,h}{4\,\pi\,m_0} = \frac{e}{2\,m_0}\,p_l$$

9.3. VECTOR MODEL AND NORMAL ZEEMAN EFFECT

In the presence of external magnetic field, the vector *l* precesses around the field direction.

The frequency of this precession is given by

$$\omega_l = B\,\frac{\mu_l}{p_l} = \frac{e}{2\ m_0}\,B$$

$$\because \mu_l = \frac{e}{2\ m_0}\,p_l$$

9.3. VECTOR MODEL AND NORMAL ZEEMAN EFFECT

The **additional energy of the electron** due to this motion is given by

$\Delta E = \omega_L$ x projection of mechanical momentum on the field direction

$$\Delta E = \frac{e}{2\ m_0}\ B\, p_l \cos\theta \quad \text{or} \quad \Delta E = \frac{e\,B}{2\ m_0}\ \frac{l\,h}{2\,\pi} \cos\theta \quad \text{Or}$$

$$\Delta E = \frac{e\,B}{2\ \pi\, m_0}\ m_l \qquad \text{since } l \cos\theta = m_l$$

9.3. VECTOR MODEL AND NORMAL ZEEMAN EFFECT

$$\Delta E = \frac{e\,B}{2\,\pi\, m_0}\; m_l$$

m_l can have **(2*l* + 1)** values right from +*l* to -*l*.

Therefore, **the effect of magnetic field is to split up each energy level into (2 *l* + 1) levels** and

The magnitude of separation is proportional to the strength of the magnetic field.

9.3. VECTOR MODEL AND NORMAL ZEEMAN EFFECT

Now we suppose that E_1 and E_2 are the **energies of the two levels in the presence of magnetic field** and $E^{(1)}$ and $E^{(2)}$ in the **absence of the field** with the two values m_l as m_{l_1} and m_{l_2}

Then we have

$$E_1 = E^{(1)} + \Delta E_1 = E^{(1)} + \frac{e\,h\,B}{4\,\pi\,m_0}\,m_{l_1}$$

$$E_2 = E^{(2)} + \Delta E_2 = E^{(2)} + \frac{e\,h\,B}{4\,\pi\,m_0}\,m_{l_2}$$

9.3. VECTOR MODEL AND NORMAL ZEEMAN EFFECT

The **quantity of energy radiated in the presence of magnetic field** is

$$E_1 - E_2 = E^{(1)} - E^{(2)} + \frac{e\,h\,B}{4\,\pi\,m_0}\,(m_{l_1} - m_{l_2})$$

$$h\,\nu - h\,\nu_0 = \frac{e\,h\,B}{4\,\pi\,m_0}\,\Delta\,m_l$$

$$\nu - \nu_0 = \frac{e\,B}{4\,\pi\,m_0}\,\Delta\,m_l$$

$$\nu = \nu_0 + \frac{e\,B}{4\,\pi\,m_0}\,\Delta\,m_l$$

9.3. VECTOR MODEL AND NORMAL ZEEMAN EFFECT

The **quantity of energy radiated in the presence of magnetic field** is

$$E_1 - E_2 = E^{(1)} - E^{(2)} + \frac{e\,h\,B}{4\,\pi\,m_0}\,(m_{l_1} - m_{l_2})$$

$$\cancel{h}\,\nu - \cancel{h}\,\nu_0 = \frac{e\,\cancel{h}\,B}{4\,\pi\,m_0}\,\Delta\,m_l$$

$$\nu - \nu_0 = \frac{e\,B}{4\,\pi\,m_0}\,\Delta\,m_l$$

$$\nu = \nu_0 + \frac{e\,B}{4\,\pi\,m_0}\,\Delta\,m_l$$

9.3. VECTOR MODEL AND NORMAL ZEEMAN EFFECT

The **quantity of energy radiated in the presence of magnetic field** is

$$E_1 - E_2 = E^{(1)} - E^{(2)} + \frac{e\,h\,B}{4\;\pi\,m_0}\,(m_{l_1} - m_{l_2})$$

$$h\,\nu - h\,\nu_0 = \frac{e\,h\,B}{4\;\pi\,m_0}\,\Delta\,m_l$$

$$\nu - \nu_0 = \frac{e\,B}{4\;\pi\,m_0}\,\Delta\,m_l$$

9.3. VECTOR MODEL AND NORMAL ZEEMAN EFFECT

$$\nu = \nu_0 + \frac{e\,B}{4\,\pi\,m_0}\,\Delta\,m_l$$

ν_0 is the **frequency of the line in the absence of the field**,

$\Delta\,m_l$ is subjected to the **selection rule**;

$$\Delta\,m_l = 0\ or\ \pm 1$$

9.3. VECTOR MODEL AND NORMAL ZEEMAN EFFECT

$$\nu = \nu_0 + \frac{e\,B}{4\,\pi\,m_0}\,\Delta\,m_l$$

Three possible lines,

$$\nu_1 = \nu_0$$

$$\nu_2 = \nu_0 + \frac{e\,B}{4\,\pi\,m_0}$$

$$\nu_3 = \nu_0 - \frac{e\,B}{4\,\pi\,m_0}$$

It is to be noted that the change in the frequency is by the amount $\frac{e\,B}{4\,\pi\,m_0}$ is known as **Lorentz unit.**

9.3. VECTOR MODEL AND NORMAL ZEEMAN EFFECT

Three possible lines

$$\nu_1 = \nu_0$$

$$\nu_2 = \nu_0 + \frac{e\,B}{4\,\pi\, m_0}$$

$$\nu_3 = \nu_0 - \frac{e\,B}{4\,\pi\, m_0}$$

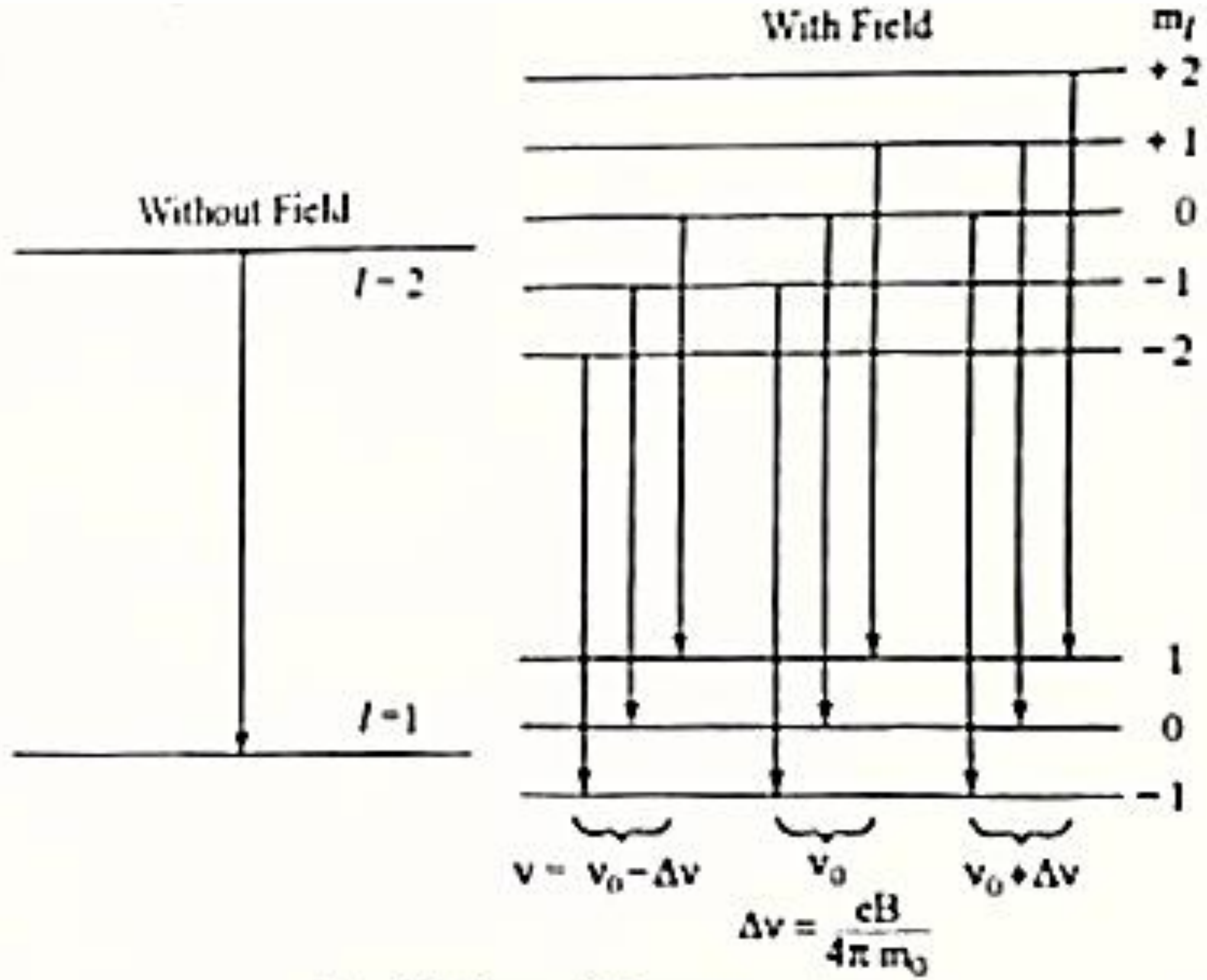
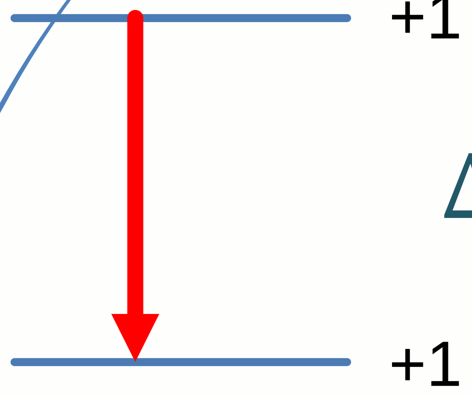


Fig. 9.4. Normal Zeeman effect.

9.3. VECTOR MODEL AND NORMAL ZEEMAN EFFECT

$$\nu_1 = \nu_0$$



$$\Delta m_l = 0$$

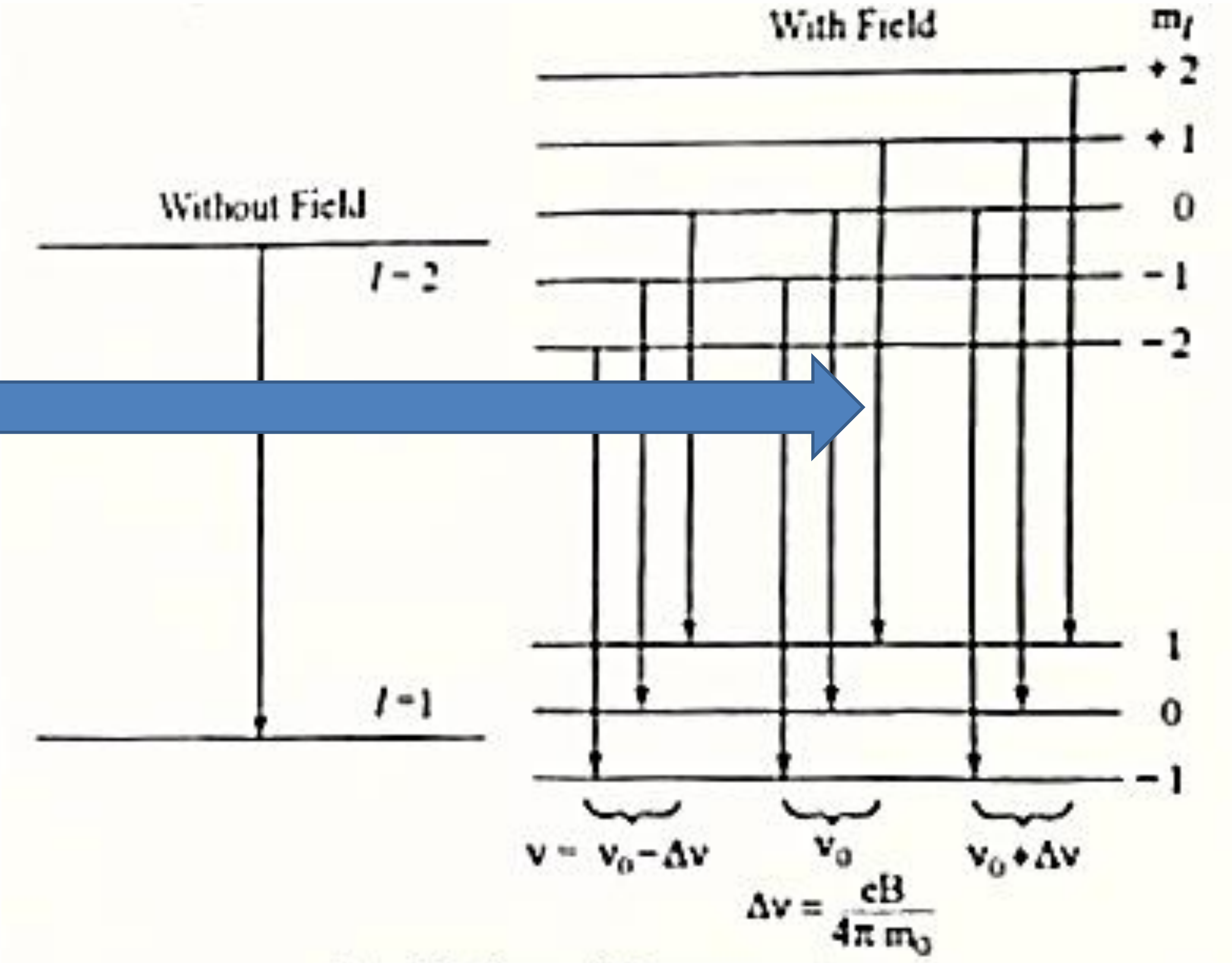
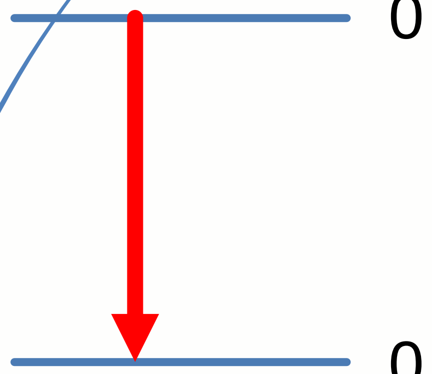


Fig. 9.4. Normal Zeeman effect.

9.3. VECTOR MODEL AND NORMAL ZEEMAN EFFECT

$$\nu_1 = \nu_0$$



$$\Delta m_l = 0$$

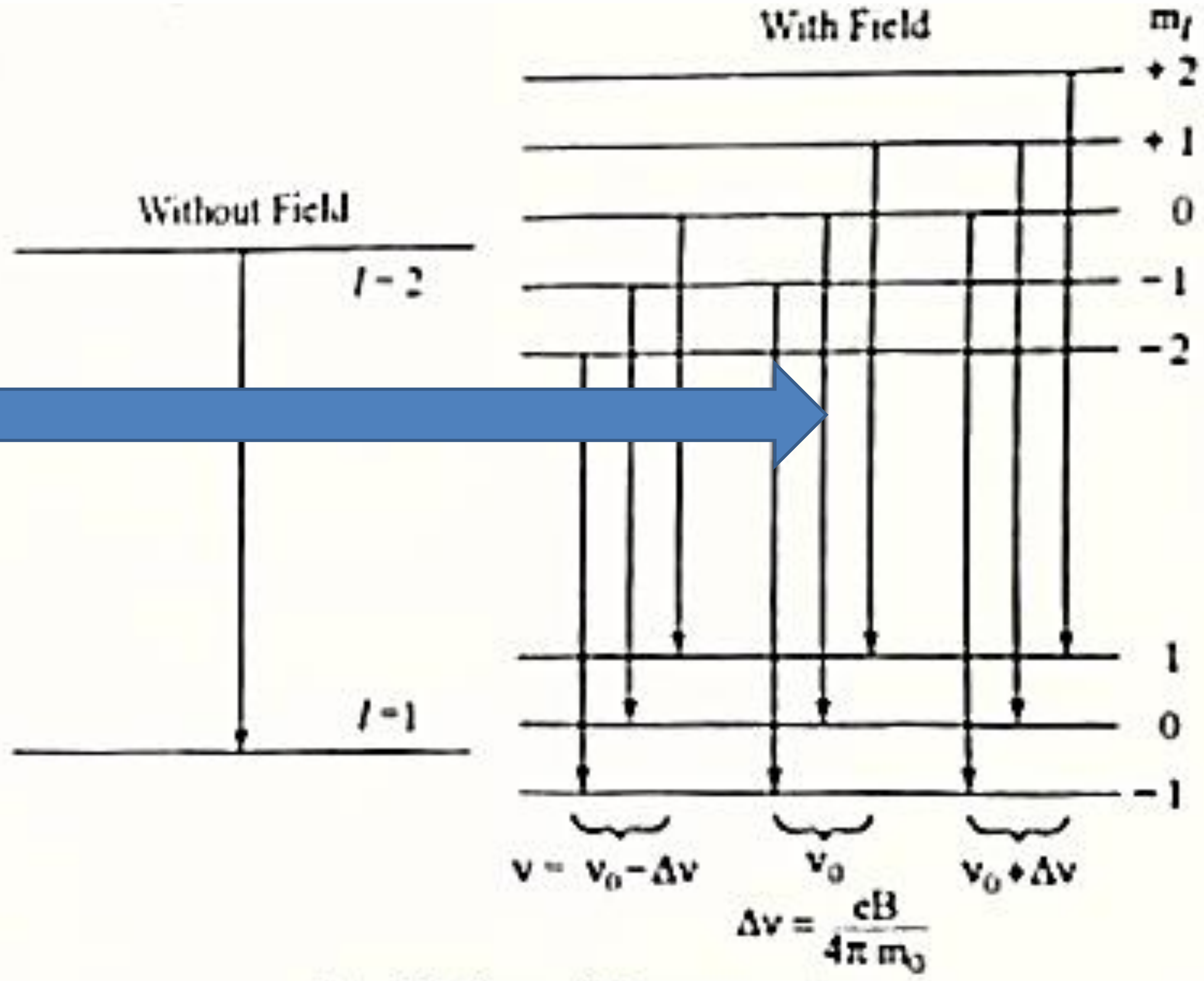
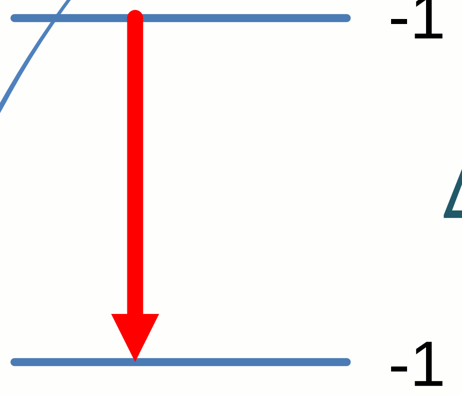


Fig. 9.4. Normal Zeeman effect.

9.3. VECTOR MODEL AND NORMAL ZEEMAN EFFECT

$$\nu_1 = \nu_0$$



$$\Delta m_l = 0$$

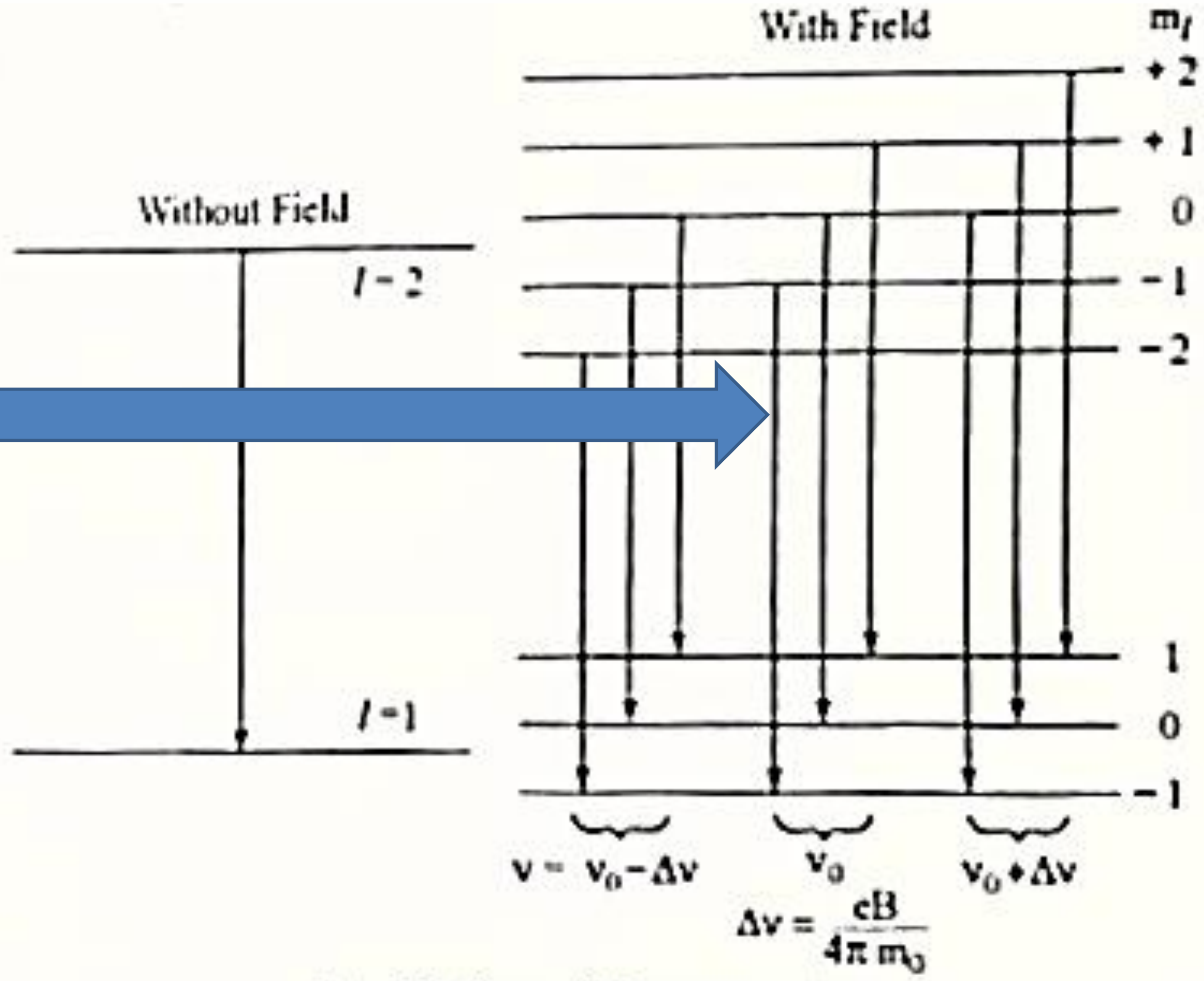
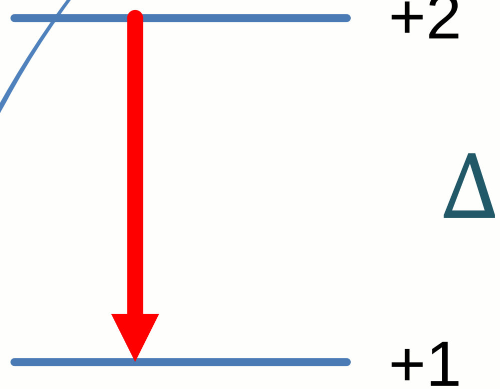


Fig. 9.4. Normal Zeeman effect.

9.3. VECTOR MODEL AND NORMAL ZEEMAN EFFECT

$$\nu_2 = \nu_0 + \frac{e\,B}{4\,\pi\,m_0}$$



$$\Delta\, m_l = 1$$

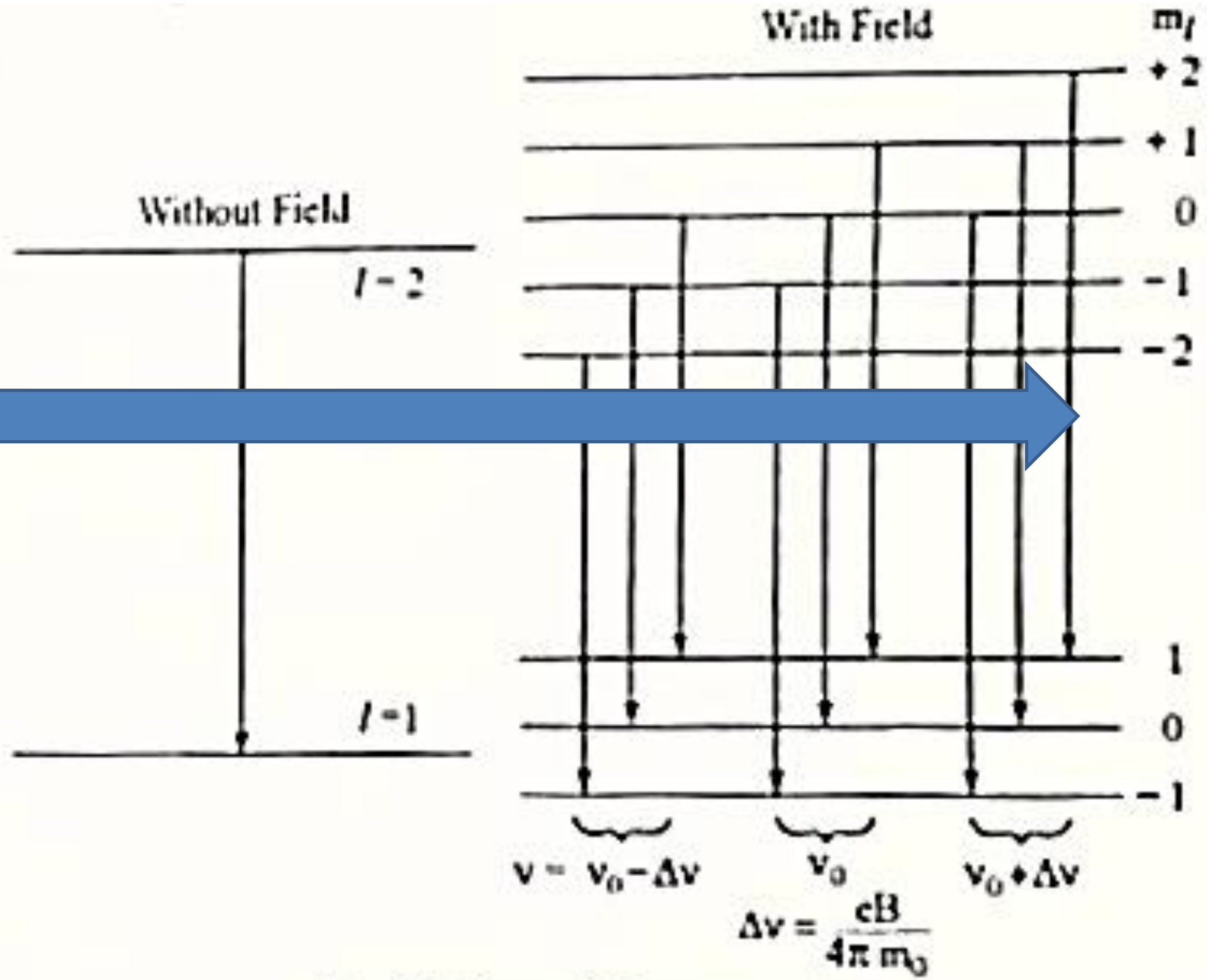
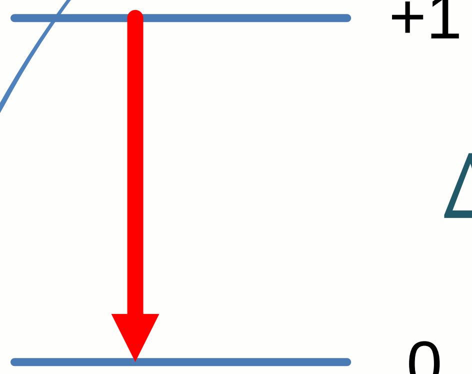


Fig. 9.4. Normal Zeeman effect.

9.3. VECTOR MODEL AND NORMAL ZEEMAN EFFECT

$$\nu_2 = \nu_0 + \frac{e\,B}{4\,\pi\,m_0}$$



$$\Delta\, m_l = 1$$

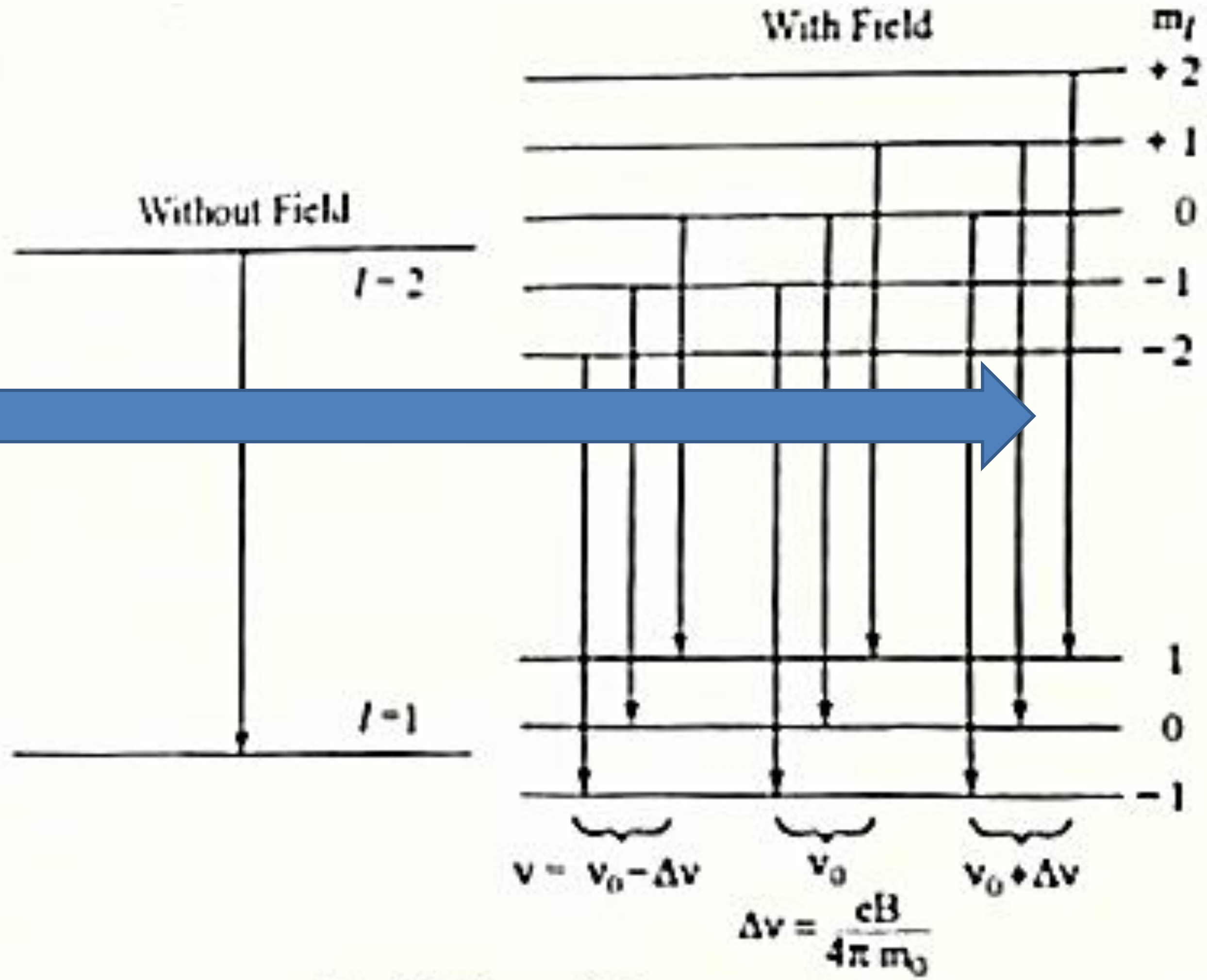
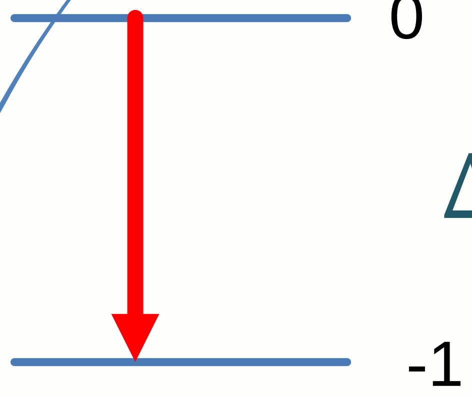


Fig. 9.4. Normal Zeeman effect.

9.3. VECTOR MODEL AND NORMAL ZEEMAN EFFECT

$$\nu_2 = \nu_0 + \frac{e\,B}{4\,\pi\,m_0}$$



$$\Delta\, m_l = 1$$

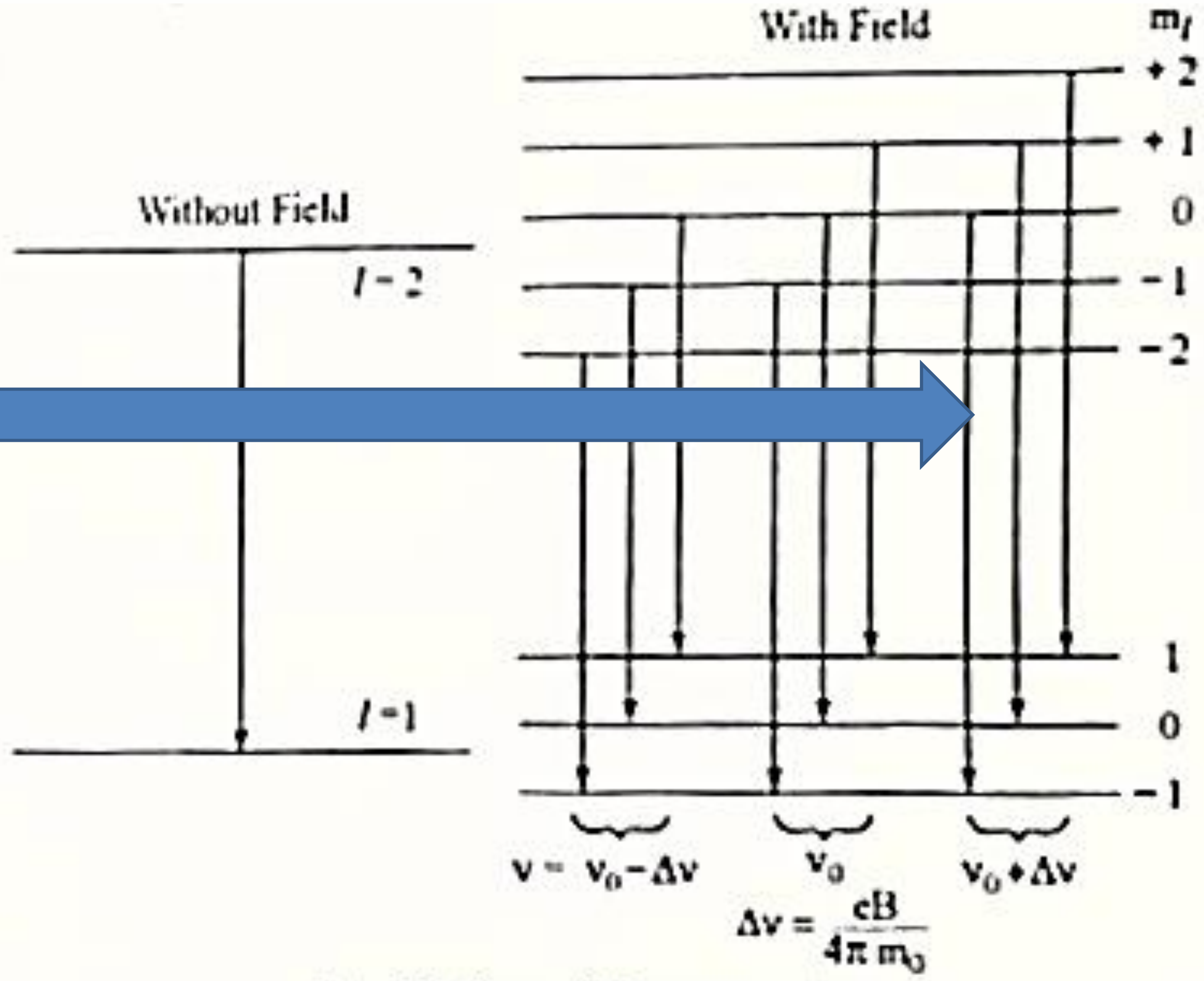
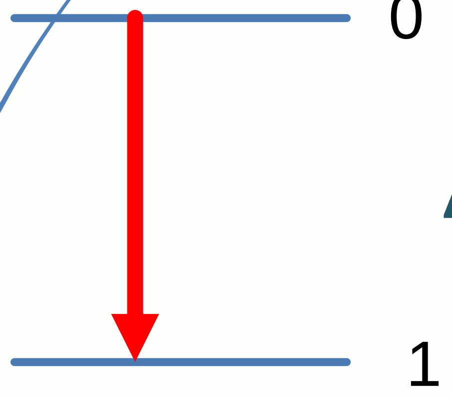


Fig. 9.4. Normal Zeeman effect.

9.3. VECTOR MODEL AND NORMAL ZEEMAN EFFECT

$$\nu_2 = \nu_0 - \frac{e\,B}{4\,\pi\,m_0}$$



$\Delta\, m_l$ = -1

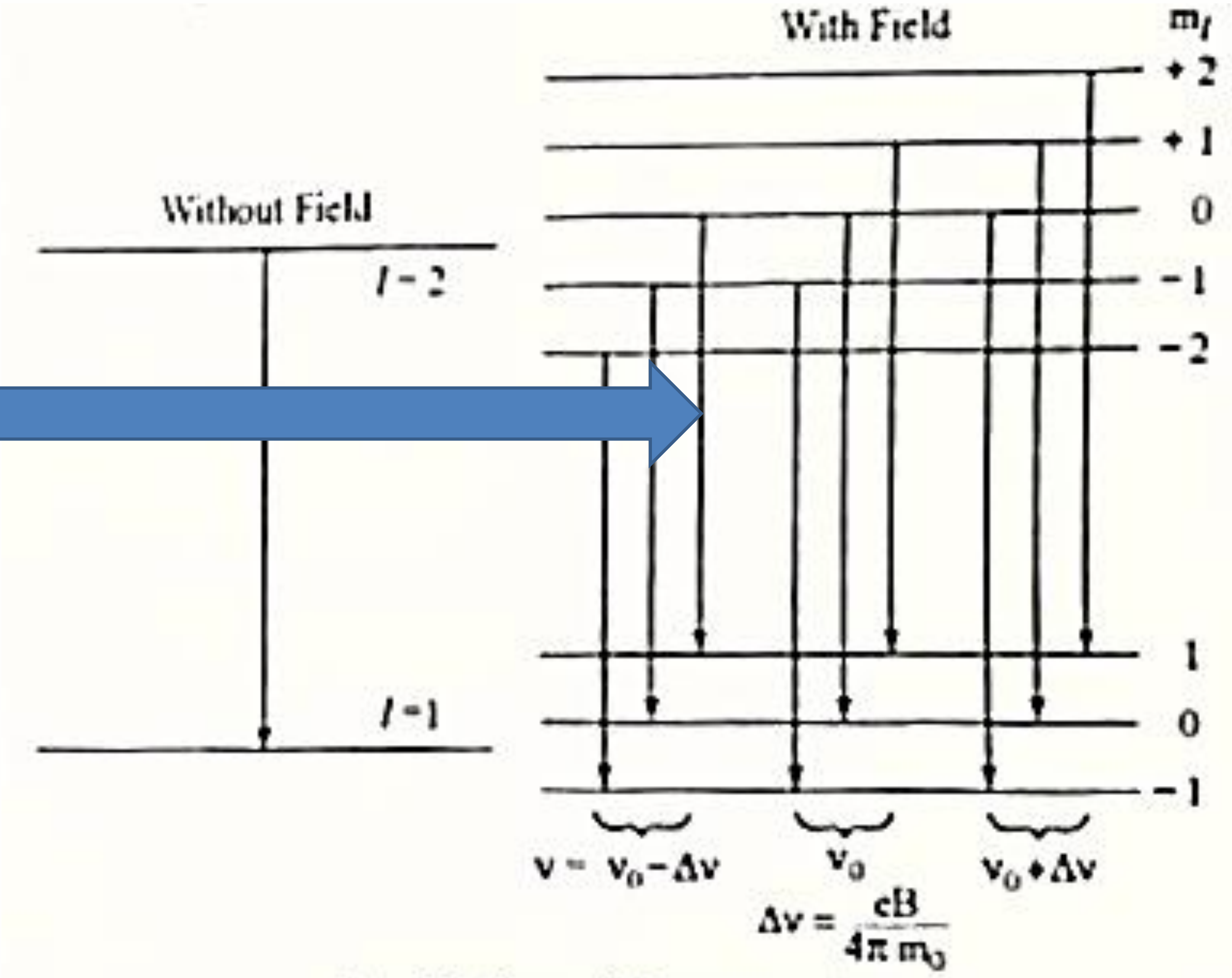
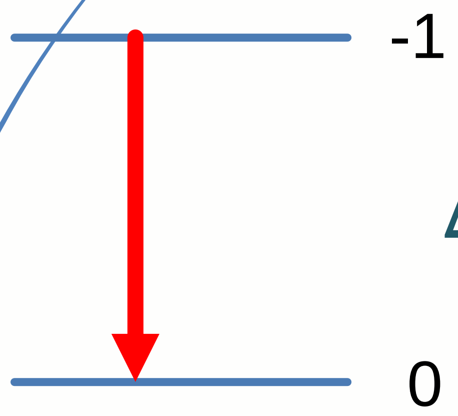


Fig. 9.4. Normal Zeeman effect.

9.3. VECTOR MODEL AND NORMAL ZEEMAN EFFECT

$$\nu_2 = \nu_0 - \frac{e\,B}{4\,\pi\,m_0}$$



$\Delta\, m_l$ = -1

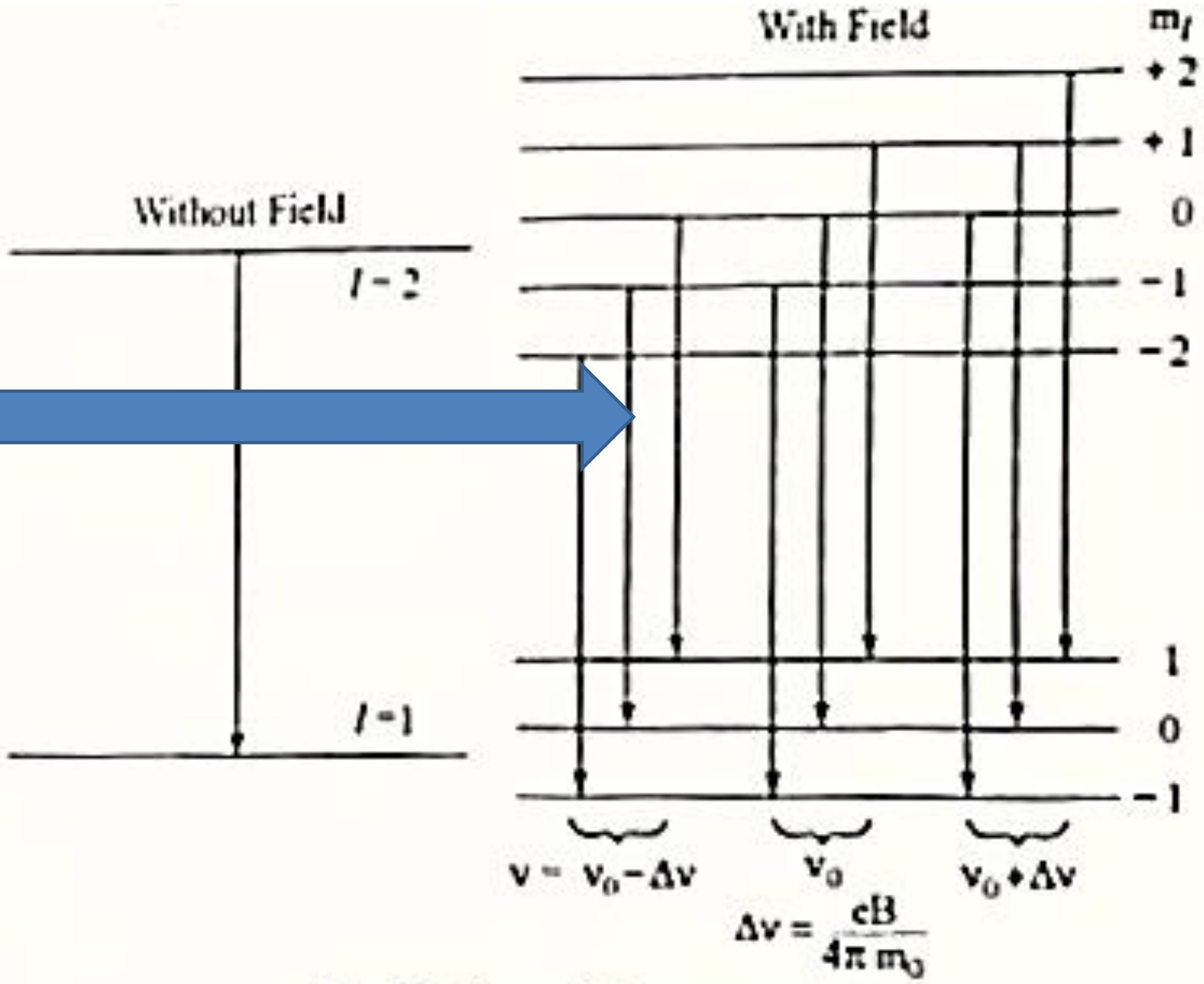
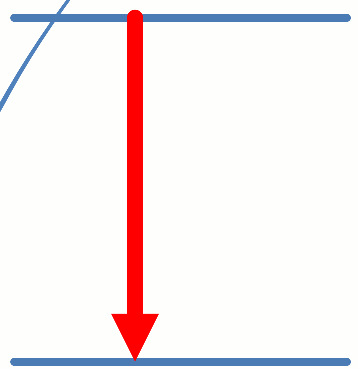


Fig. 9.4. Normal Zeeman effect.

9.3. VECTOR MODEL AND NORMAL ZEEMAN EFFECT

$$\nu_2 = \nu_0 - \frac{e\,B}{4\,\pi\,m_0}$$



$\Delta\, m_l$ = -1

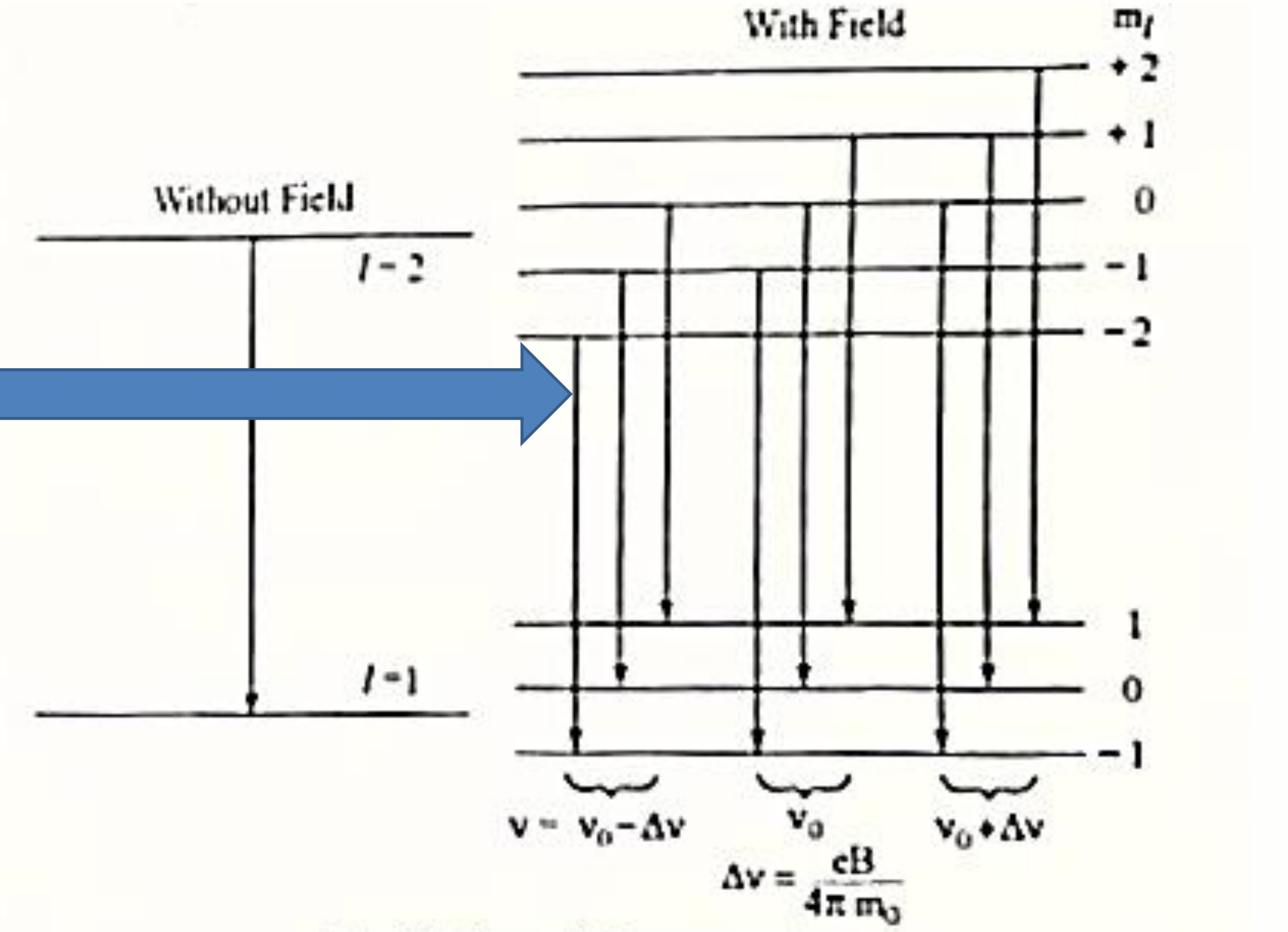


Fig. 9.4. Normal Zeeman effect.

9.3. VECTOR MODEL AND NORMAL ZEEMAN EFFECT

Three possible lines,

$$\nu_1 = \nu_0$$

$$\nu_2 = \nu_0 + \frac{e\,B}{4\;\pi\,m_0}$$

$$\nu_3 = \nu_0 - \frac{e\,B}{4\;\pi\,m_0}$$

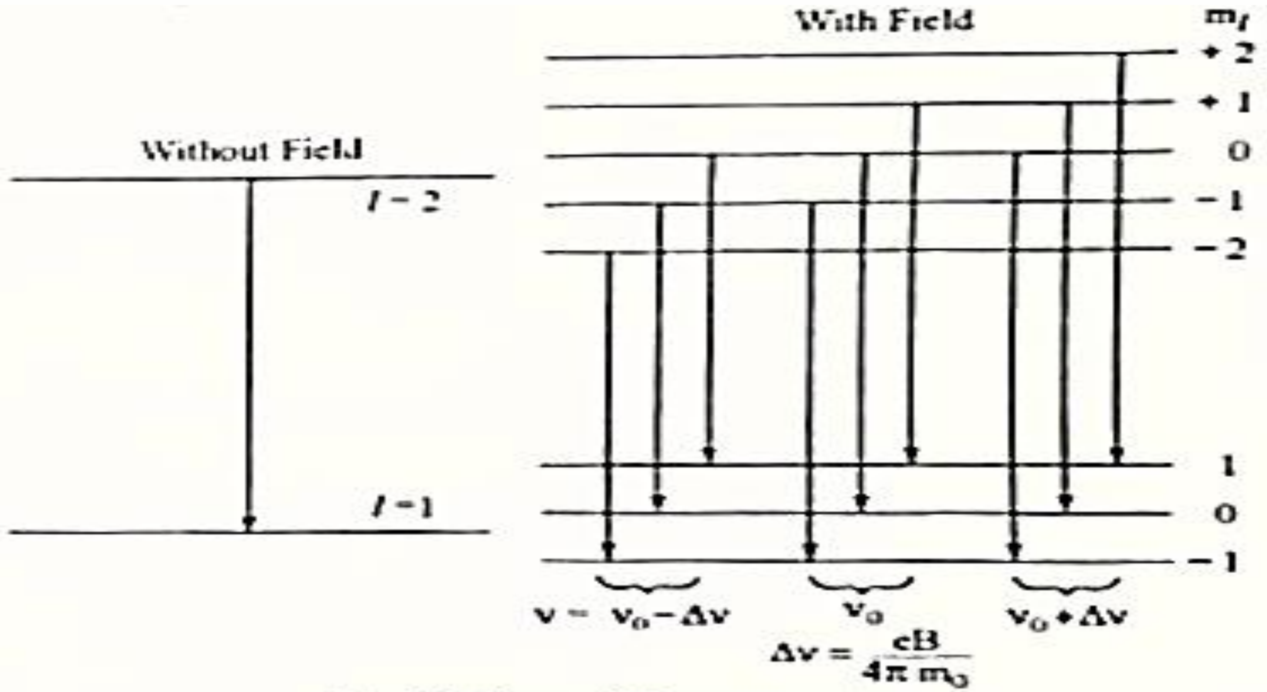


Fig. 9.4. Normal Zeeman effect.

For three transitions in a bracket change in the value of $\Delta\, m_l$ is the same and hence they represent **same change of energy** and a **single line**.

9.5 PASCHEN-BACK EFFECT

9.5 PASCHEN-BACK EFFECT:

- *In the Paschen-Back effect, when the external magnetic field is* ***stronger*** *than the fine structure's level (= spin-orbital interaction level), the orbital and spin angular momenta become "****quantized****" in the direction of the magnetic field (B)*

9.5 PASCHEN-BACK EFFECT:

- In the explanation of Zeman effect, we assume that the **external magnetic field** is **weak** compared with the **internal magnetic field** due to spin and orbital motions of the valence electron.

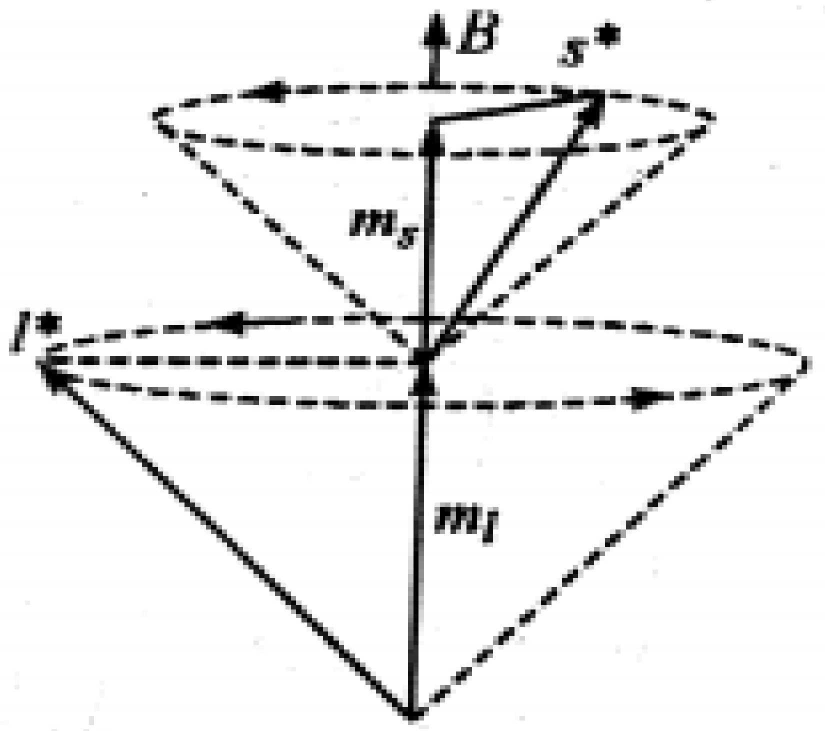
- In this case the precession of l^* and s^* vector around j^* much **faster than** that of j^* around B making thereby **no perturbation due to the motion** of l^* and s^* into other motions.

9.5 PASCHEN-BACK EFFECT:

•But when the **external magnetic field is increased in its strength**, the **coupling** between $l^*$and s^* **breaks down** and j^* loses its significance.

•l^* and s^* are **quantized separately** and precess more or less independently around B as shown in Fig 9.

This is known as Paschen-Back effect.



9.5 PASCHEN-BACK EFFECT:

- Further, when the motion of l^* and s^* become separately quantized, the **perpendicular component of magnetic moment does not average out to zero** and continues to total magnetic moment, i.e., now **total magnetic moment is not equal to m_j.**

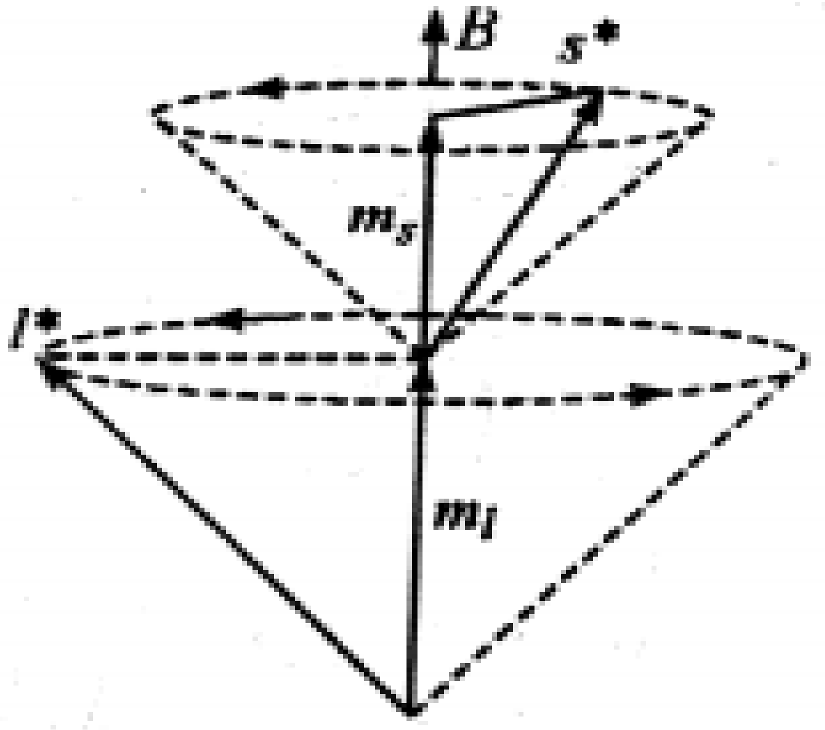
- Due to this **sort of splitting**, whatever be the **anomalous Zeeman pattern in the weak magnetic field it is converted into normal pattern in the strong magnetic field.**

9.5 PASCHEN-BACK EFFECT:

- The **angular velocities of two precessions** are

$$\omega_l = B\,\frac{e}{2\ m_0}$$ and

$$\omega_s = B\,\frac{e}{2\ m_0}\,2$$



9.5 PASCHEN-BACK EFFECT:

- Therefore, the **change in interaction energy due to these two motions** is the sum of two changes i.e.

$$\Delta E = \Delta E_{lB} + \Delta E_{sB}$$

where

$$\Delta E_{lB} = B \frac{e}{2 \ m_0} \ l^* \ \frac{h}{2\pi} \cos(l^* \ B)$$

$$\Delta E_{sB} = B \frac{\mathbf{2} \ e}{2 \ m_0} \ s^* \ \frac{h}{2\pi} \cos(s^* \ B)$$

9.5 PASCHEN-BACK EFFECT:

$$\Delta E_{lB} = B\,\frac{e}{2\,m_0}\,l^*\,\frac{h}{2\,\pi}\cos(l^*\,B) \Rightarrow \Delta E_{lB} = \frac{e\,h}{4\,\pi\,m_0}\,B\,m_l$$

$$\Delta E_{sB} = B\,\frac{2\,e}{2\,m_0}\,s^*\,\frac{h}{2\,\pi}\cos(s^*\,B) \Rightarrow \Delta E_{sB} = \frac{e\,h}{4\,\pi\,m_0}\,B\,2\,m_s$$

Therefore, $\Delta E = (m_l + 2\,m_s)\,B\,\frac{e\,h}{4\,\pi\,m_0}$

- The quantity, $(m_l + 2\,m_s)$ is known as **strong field quantum number**.

9.5 PASCHEN-BACK EFFECT:

- In terms of the **frequency change**

$$\Delta\,\nu = \Delta(m_l \;\pm 2\,m_s)\;\frac{e\,B}{4\;\pi\,m_0}$$

- and in terms of **wave number**.

$$\Delta\,\bar{\nu} = \Delta(m_l \;\pm 2\,m_s)\;\frac{e\,B}{4\;\pi\,m_0\,c}$$

$\Delta\,\bar{\nu} = \Delta(m_l \;\pm 2\,m_s)$, in Lorentz unit.

9.5 PASCHEN-BACK EFFECT:

- Now, since
- $\Delta\, m_l = 0 \; or \; \pm 1$, and
- $\Delta\, m_s = 0$ so

$$\Delta(m_l \pm 2\, m_s) = 0 \; or \; \pm 1$$

9.5 PASCHEN-BACK EFFECT:

- Now, since $\Delta\, m_l = 0\ or\ \pm 1$, and $\Delta\, m_s = 0$ so

$$\Delta(m_l \pm 2\, m_s) = 0\ or\ \pm 1$$

- We get **three different frequencies**. It means that the result is **normal Zeman triplet** as said before.
- As a specific example, we consider a **principal series doublet**,

$$(\ {}^2P_{3/2} \rightarrow {}^2S_{1/2}\ )\ \text{and}\ (\ {}^2P_{1/2} \rightarrow {}^2S_{\frac{1}{2}})$$

9.5 PASCHEN-BACK EFFECT:

$$\left({}^{2}P_{3/2} \rightarrow {}^{2}S_{1/2} \right)$$

and

$$\left({}^{2}P_{1/2} \rightarrow {}^{2}S_{\frac{1}{2}} \right)$$

Term
${}^{2}P_{3/2}$
${}^{2}P_{1/2}$
${}^{2}S_{1/2}$

9.5 PASCHEN-BACK EFFECT:

- In the **strong** field **P level** is split up into **six levels.**

- For a particular value of *l*, m_l has $(2\,l + 1)$ values (here 1, 0, -1) and for each value of m_l.

Table 9.1.

Term	l	s	m_l
$^2P_{3/2}$	1	$+\frac{1}{2}$	1
	1	$+\frac{1}{2}$	0
	1	$+\frac{1}{2}$	–1
$^2P_{1/2}$	1	$+\frac{1}{2}$	1
	1	$+\frac{1}{2}$	0
	1	$+\frac{1}{2}$	–1
$^2S_{1/2}$	0	$+\frac{1}{2}$	0
	0	$+\frac{1}{2}$	0

9.5 PASCHEN-BACK EFFECT:

- m_s has two values ($+\frac{1}{2}$ and $-\frac{1}{2}$) and levels with same value of $(m_l + 2\,m_s)$ coincide.

Table 9.1.

Term	l	s	m_l	m_s
$^2P_{3/2}$	1	$+\frac{1}{2}$	1	$+\frac{1}{2}$
	1	$+\frac{1}{2}$	0	$+\frac{1}{2}$
	1	$+\frac{1}{2}$	-1	$+\frac{1}{2}$
$^2P_{1/2}$	1	$+\frac{1}{2}$	1	$-\frac{1}{2}$
	1	$+\frac{1}{2}$	0	$-\frac{1}{2}$
	1	$+\frac{1}{2}$	-1	$-\frac{1}{2}$
$^2S_{1/2}$	0	$+\frac{1}{2}$	0	$+\frac{1}{2}$
	0	$+\frac{1}{2}$	0	$-\frac{1}{2}$

9.5 PASCHEN-BACK EFFECT:

- Levels with same value of $(m_l + 2\,m_s)$ coincide.

- So, on the whole we have **five sub-levels** of ***P* level** and ***two sublevels*** of ***S level***.

Table 9.1.

Term	l	s	m_l	m_s	$m_l + 2m_s$
	1	$+\frac{1}{2}$	1	$+\frac{1}{2}$	2
$^2P_{3/2}$	1	$+\frac{1}{2}$	0	$+\frac{1}{2}$	1
	1	$+\frac{1}{2}$	-1	$+\frac{1}{2}$	0
	1	$+\frac{1}{2}$	1	$-\frac{1}{2}$	0
$^2P_{1/2}$	1	$+\frac{1}{2}$	0	$-\frac{1}{2}$	-1
	1	$+\frac{1}{2}$	-1	$-\frac{1}{2}$	-2
$^2S_{1/2}$	0	$+\frac{1}{2}$	0	$+\frac{1}{2}$	+1
	0	$+\frac{1}{2}$	0	$-\frac{1}{2}$	-1

9.5 PASCHEN-BACK EFFECT:

The values of the different quantum numbers are given in Table 9.1.

Table 9.1.

Term	l	s	m_l	m_s	$m_l + 2m_s$	$a m_l m_s$
$^2P_{3/2}$	1	$+\frac{1}{2}$	1	$+\frac{1}{2}$	2	$\frac{a}{2}$
	1	$+\frac{1}{2}$	0	$+\frac{1}{2}$	1	0
	1	$+\frac{1}{2}$	–1	$+\frac{1}{2}$	0	$-\frac{a}{2}$
$^2P_{1/2}$	1	$+\frac{1}{2}$	1	$-\frac{1}{2}$	0	$-\frac{a}{2}$
	1	$+\frac{1}{2}$	0	$-\frac{1}{2}$	–1	0
	1	$+\frac{1}{2}$	–1	$-\frac{1}{2}$	–2	$\frac{a}{2}$
$^2S_{1/2}$	0	$+\frac{1}{2}$	0	$+\frac{1}{2}$	+1	0
	0	$+\frac{1}{2}$	0	$-\frac{1}{2}$	–1	0

9.5 PASCHEN-BACK EFFECT:

- The allowed transitions are shown in Fig. 9.9, with the coincidence of the transitions having the same value $\Delta(m_l + 2m_s)$.

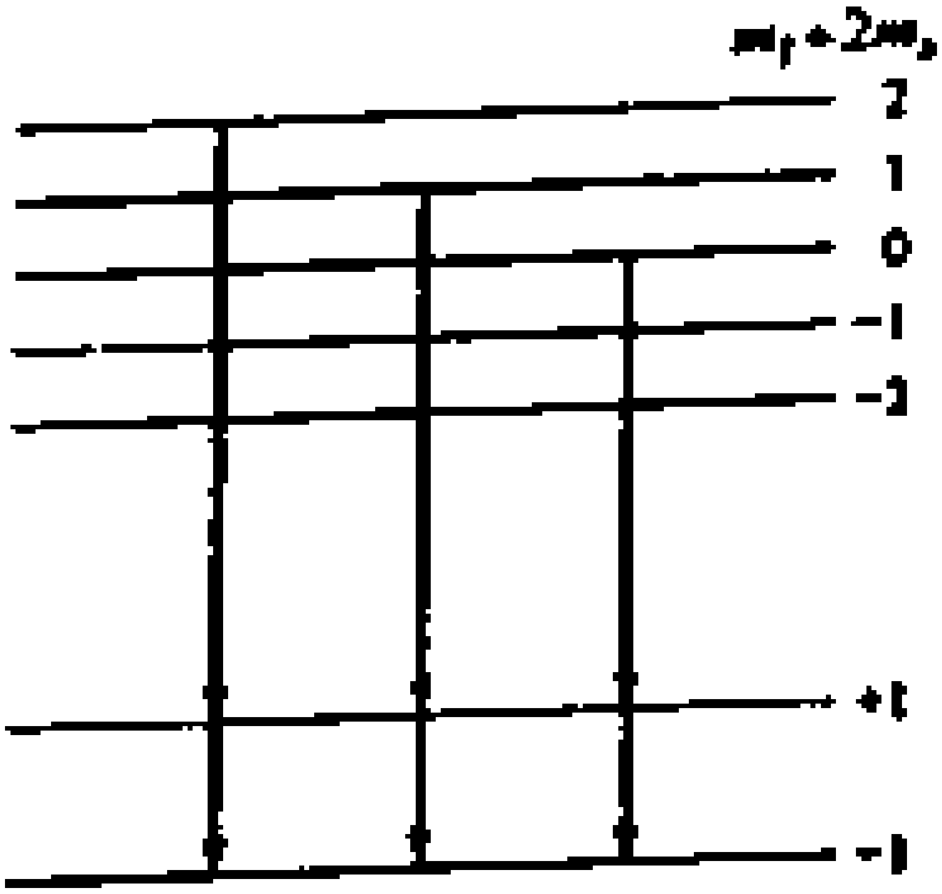
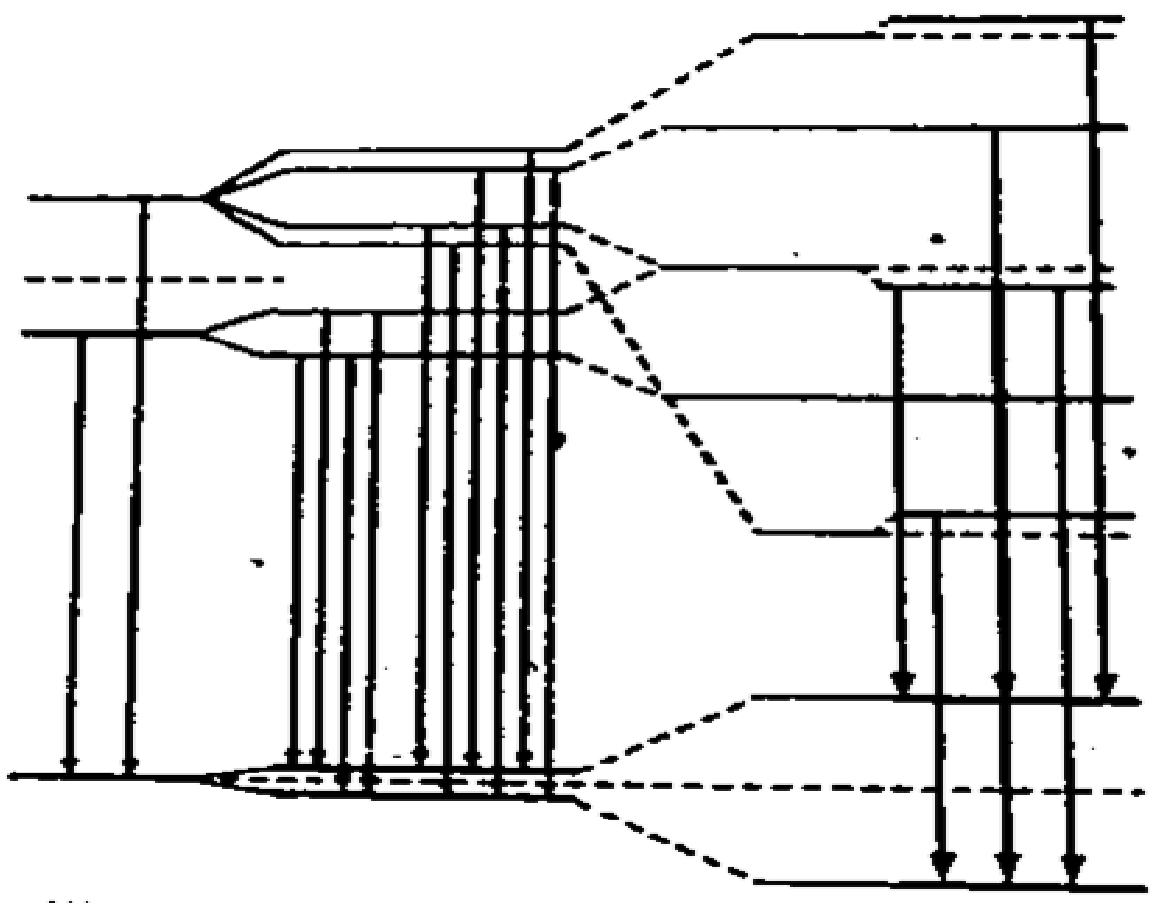


Fig. 9.9. Paschen-Back Effect

9.5 PASCHEN-BACK EFFECT:

Fig. 9.10. Transition from weak field to strong field.



9.5 PASCHEN-BACK EFFECT:

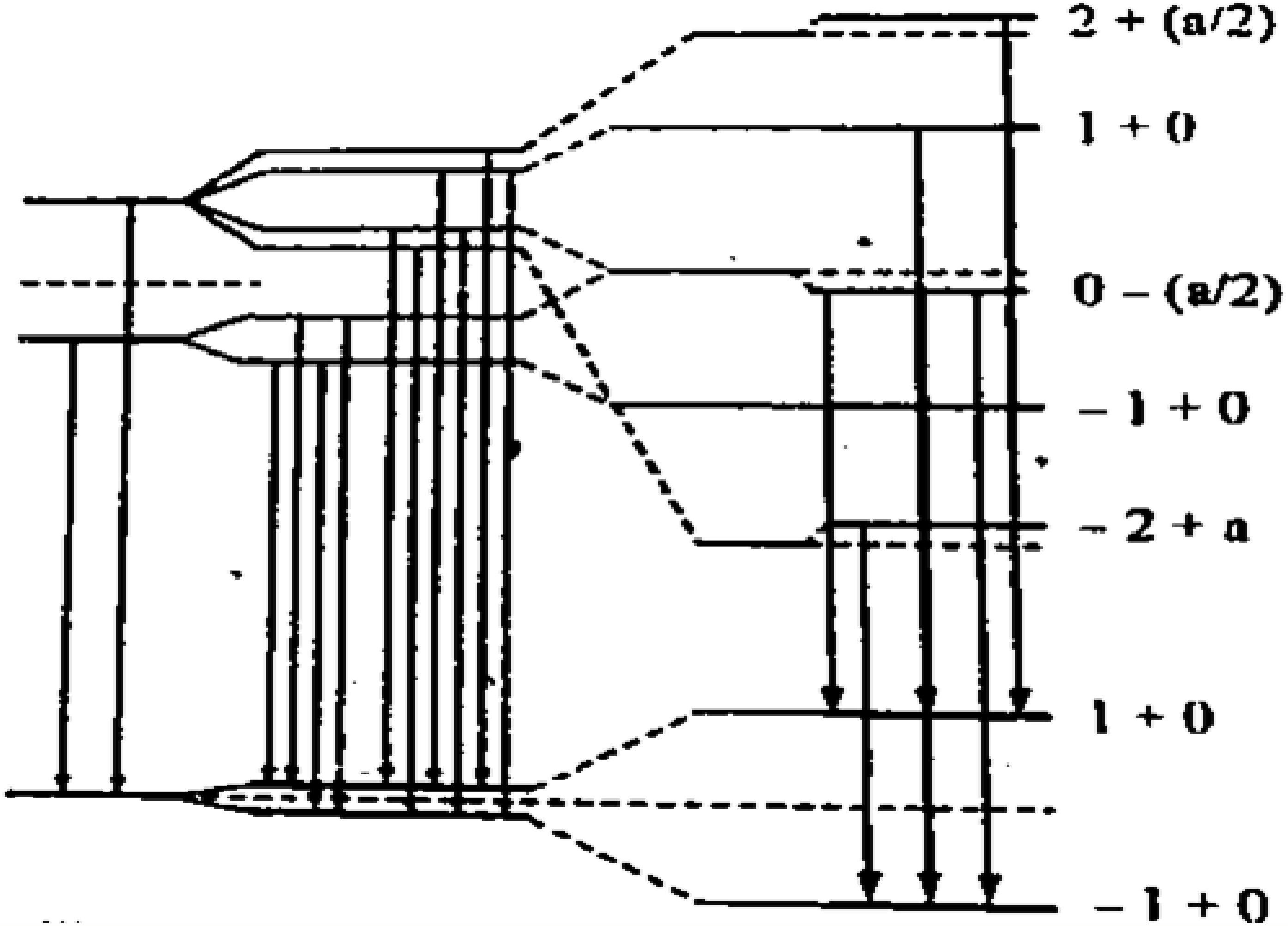
- If we add to the effect of external magnetic field, the change in term value due to spin orbit interaction, then the **term value of a magnetic level** is written as

$$T_m = T_0 - \ (m_l + 2\,m_s)O - a\,m_l\,m_s$$

- where T_0 is the hypothetical centre the levels in the absence of field, O is Lorentz unit and 'a' is a constant concerning spin orbit interaction. The spin orbit correction has been listed in Table 9.1.

9.5 PASCHEN-BACK EFFECT:

- The net splitting is shown in Fig. 9.10. The splitting of transition lines shows that we get a normal triplet; each σ component of triplet contains 2 fine lines.



9.12 STARK EFFECT

9.12 STARK EFFECT

Zeeman effect	1896
Stark Effect	1913

After 17 years

Main practical difficulties designing of a tube to study electric effect.

9.12 STARK EFFECT - Experimental Set up

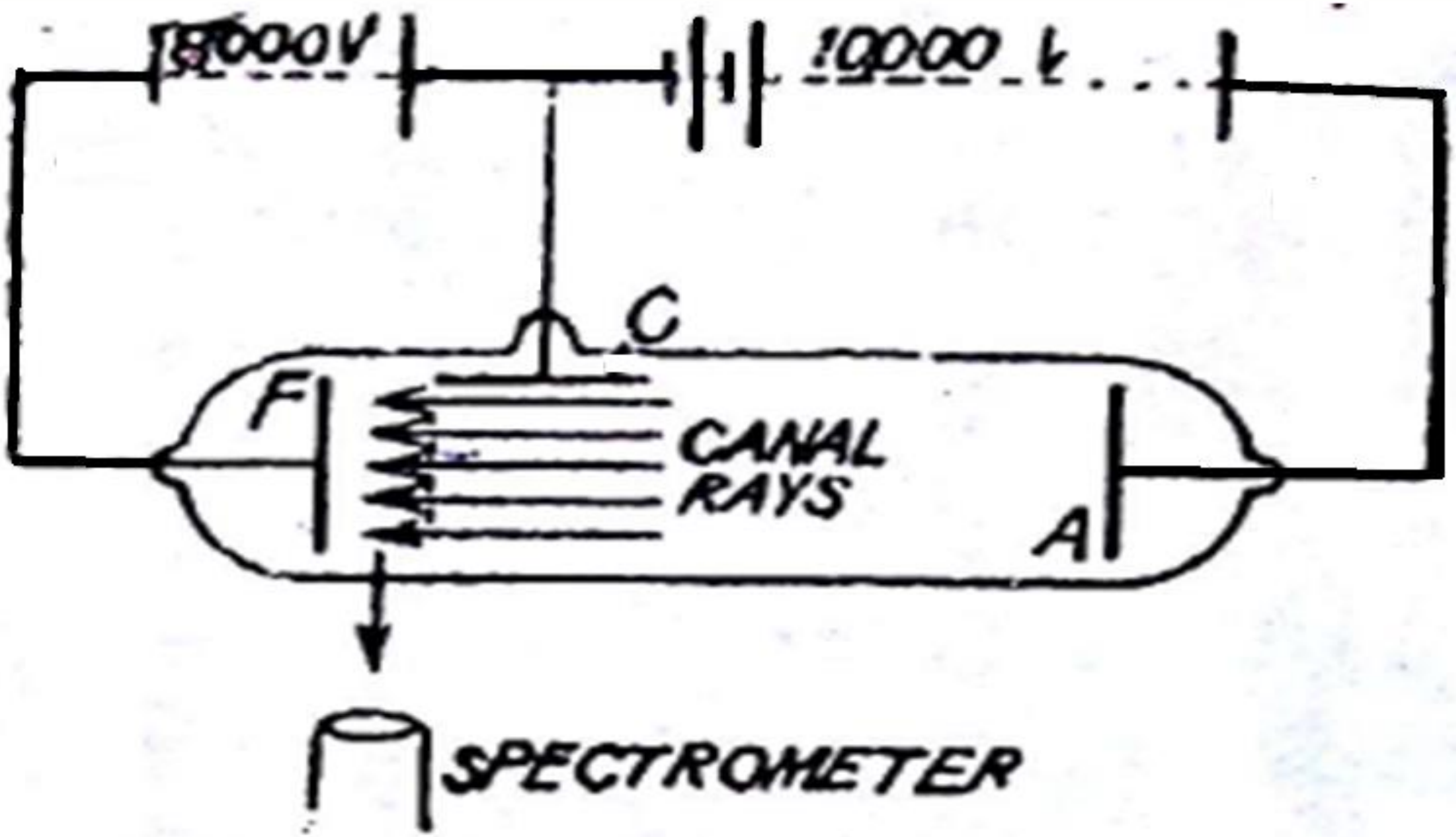
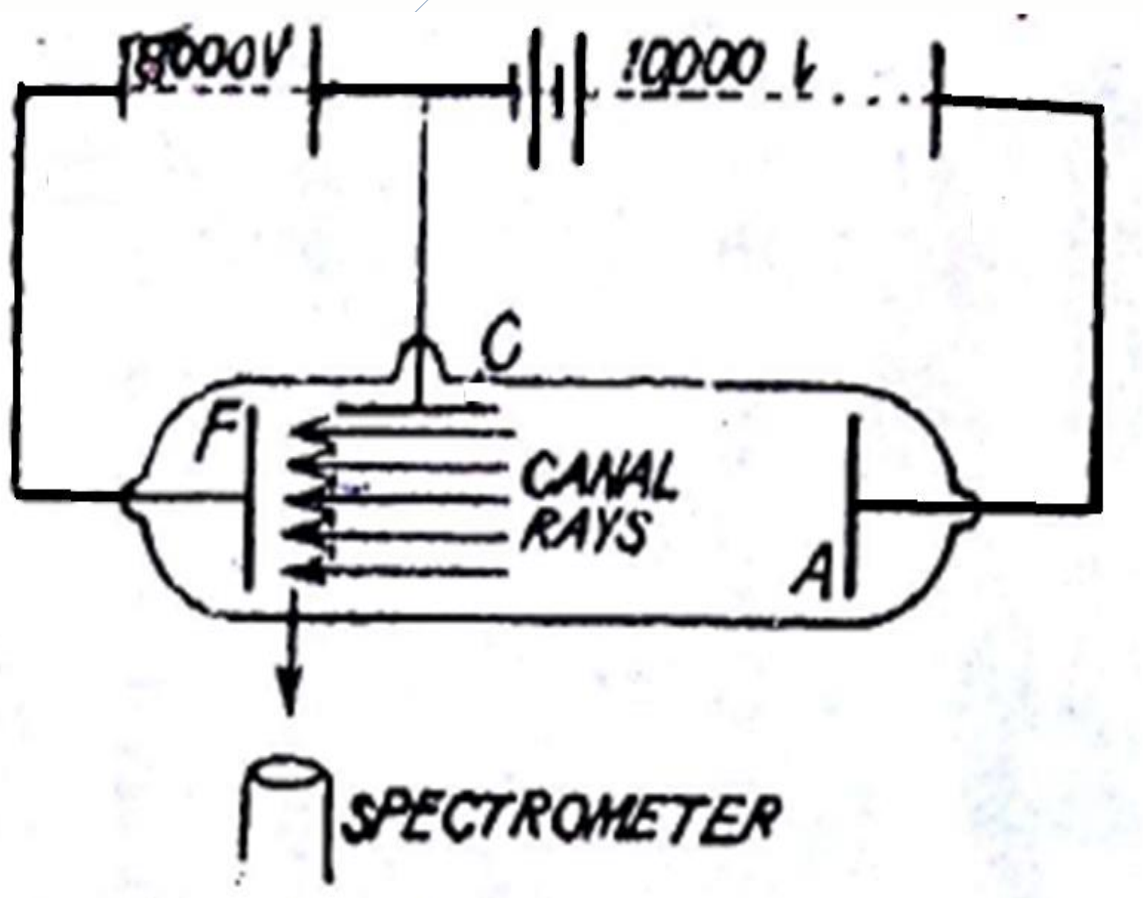


Fig. 20. Stark's Apparatus.

9.12 STARK EFFECT - Experimental Set up

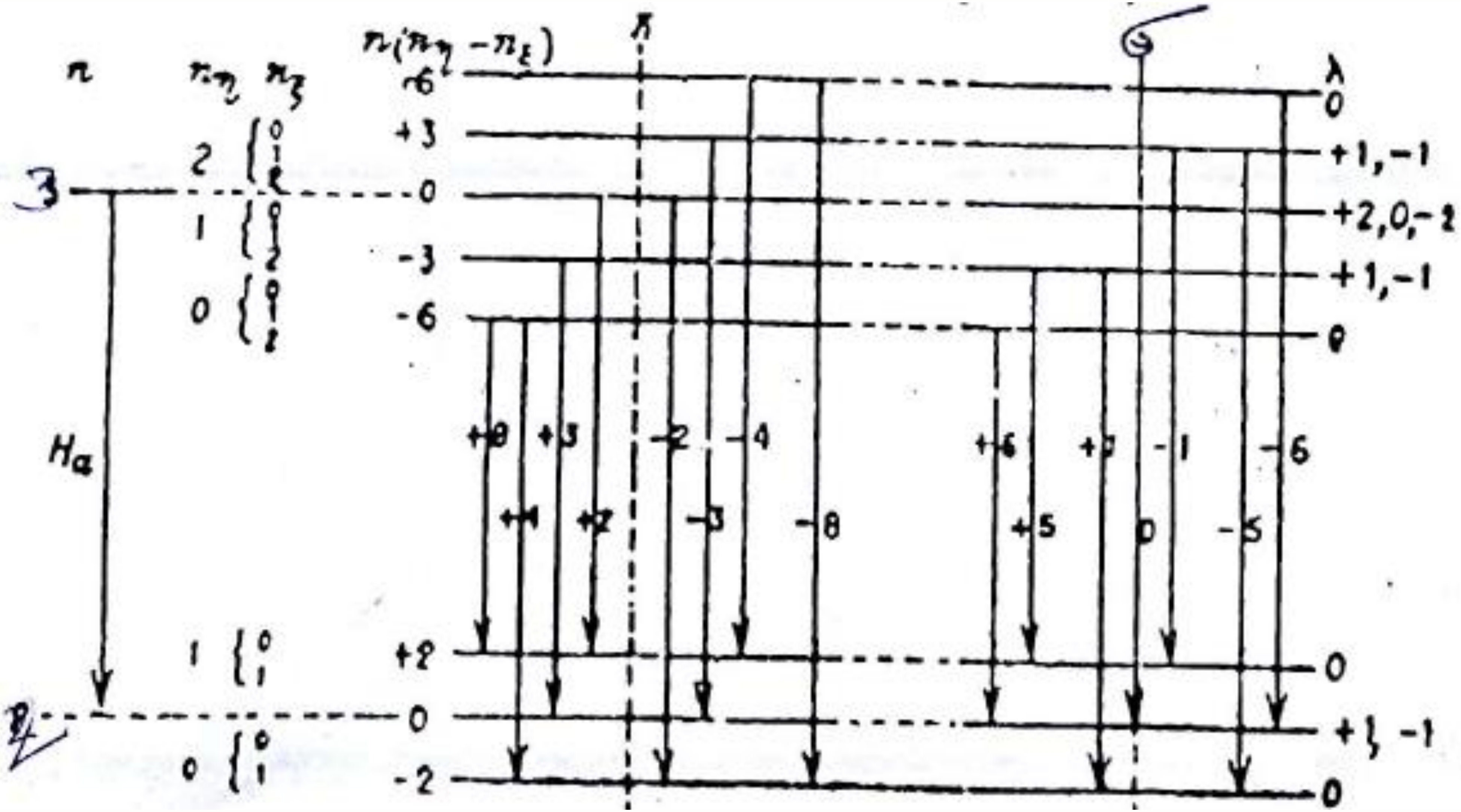


F is auxiliary electrode

C is Cathode

Cannal ray

9.12 STARK Pattern of Hα line



9.12 STARK Pattern – Main features

Points (1):

All hydrogen lines form **symmetrical patterns**, but the **Patten depends markedly on the quantum number n** of the term involved,

- The **number of lines** and the **total width of the pattern increases with n**.

9.12 STARK Pattern – Main features

Points (1):

- The **number of lines** and the **total width of the pattern increases with n**.
- Thus
- the number of components of H_β lines is greater than those of the $H\alpha$ line similarly,
- the number of components of **$H\gamma$** is greater than those of **H_β**.

9.12 STARK Pattern – Main features

Points (2)

The **wave number differences are integral multiples of a unit which is proportional to the field strength F** and is the **same** for all hydrogen lines.

9.12 STARK Pattern – Main features

Points (3)

Observation perpendicular to the direction of the electric field show that the components are polarised in part **parallel to the field** (π components)
and,

in part, **perpendicular to the field** (σ components).

9.12 STARK Pattern – Main features

Points (4)

Upto the field of about **100000 volts per cm**, the resolution increases in proportional to the field strength.

In this region, we have the **linear stark effect**.

9.12 STARK Pattern – Main features

Points (5)

In the case of more intense field, more complicated effects, so called **quadratic stark effect**.