APPLIED PHYSICS-II

For Second Semester Diploma Students

As per AICTE Curriculum for Diploma Students

Dr. Prajapati Palaria

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By

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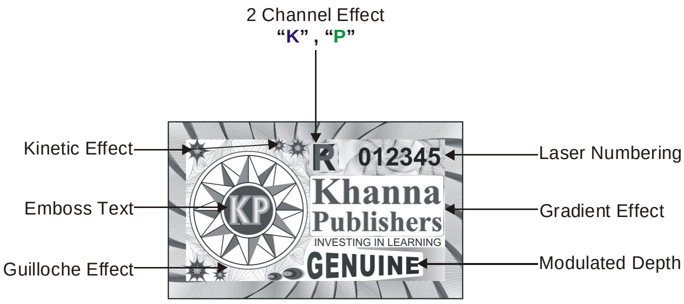

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Preface

This book Applied Physics—II has been written as per AICTE Curriculum for the Diploma students, for their second semester course. The aim of writing this book is to be provided the students a clear understanding of the basic concepts and principles.

The subject matter has been developed in steps for easy understanding. Throughout the book, the stress has been given on the topics through figures and solved examples.

The book is divided into **Six Chapters** including Practical work.

Exercises, True/False statements and fill in the blanks with their answers also hints are provided at the end of each unit.

Although, every attempt has been taken to make this edition error-free. However, some mistakes may crept in, so, if the reader bring to such mistakes; I would be highly thankful to them. I shall do my level best to rectify them in the next edition. At the same time, feedback and valuable suggestions regarding the improvement of the book—Applied Physics-II, will be gratefully acknowledged.

—Prajapati Palaria

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CHAPTER 1

Structure of Atom and Origin of Spectra

Although the thousands year ago the philosopher like Democritus proposed that matter is made of tiny particles, but the actual contribution to percept the atom structure is started from 19th century.

Before the discovery of subatomic particles, John Dalton (in 1803) gave the Dalton's atomic model where he suggested that atoms are indivisible particles, and compounds are formed by a combination of two or more atoms. His atomic model is known as Dalton's Billiard Ball Model.

1.1 THOMSON'S MODEL

After the discovery of electron J.J. Thomson in 1904 proposed his atomic model. It provided the base for several other atomic structure models. He proposed that an atom is shaped like a sphere with a radius of approximately 10^{-10} metre. Where the positive charge is uniformly distributed the negatively charged electrons are embedded in this sphere. The atom has no charge as whole and it is electrically neutral. Thomson's model resembles a spherical plum pudding as well as a watermelon with seeds inside.

The phenomenon of thermoionic emission, photoelectric emission and ionization were explained on the basis of this model

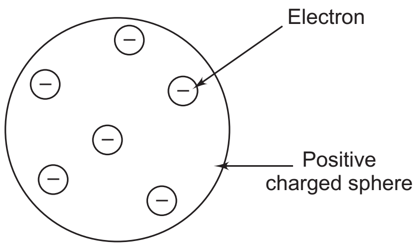

Fig 1.1: Thomson's Watermelon Model; where redpart is +ve charged and seeds are –ve charged.

Thomson model failed to explain how the positive charge holds the electrons inside the atom. It also failed to explain an atom's stability. The model was unable to explain the spectrum of hydrogen atom. The theory did not mention anything about the nucleus of an atom.

Rutherford's Model

Rutherford and his student, Heiger and Marsden performed an experiment where they bombarded very thin gold foil of about 10 nm thickness with α-particles. A circular type fluorescent zinc suphide screen was placed around the gold foil.

In the experiment most of the α-particles passed undeflected through the foil. A small number of α-particles were deflected by small angles and very few were bounced back.

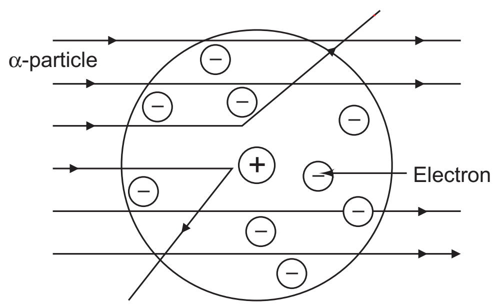

Fig. 1.2: Rutherford Model

Based on the result (Fig. 1.2) Rutherford made the conclusion (year 1911) that most of the space in the atom is empty. There must be some positive charged particle to deflect the α-particle and the volume of the positive charge has to be concentrated in a very small volume. This is called nucleus whose size is about 10^{-5} times the atom.

Rutherford's model was unable to explain the certain things.

Maxwell electromagnetic theory says that revolving electrons have acceleration and accelerated charged particles emit radiation, hence continuously losses the energy. Therefore the orbit of electrons will gradually shrink and finally the electrons collapse in the nucleus. Thus the model unable to explain the stability of an atom.

- Model did not mention anything about the arrangement of electrons in the orbit.
- Rutherford model could not explain the line spectrum.

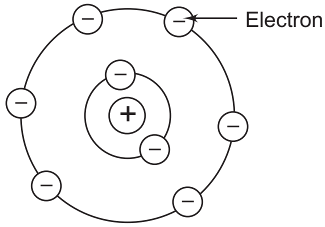

Fig. 1.3: Bohr Model

Bohr's model

Rutherford basically explained a nucleus of an atom whereas Bohr took the model one step ahead.

In 1913, Bohr proposed his quantized shell model of atom and modified the Rutherford theory by requiring that the electron move in the orbits of fixed size and energy (Fig 1.3). Some main postulates of Bohr atomic model are,

- Electron revolve around the nucleus in a fixed circular path termed as orbit or shell or energy level.
- Every orbit has a certain amount of fixed energy. Electrons revolve only in those orbits in which their angular momentum is an integral multiple of $\frac{h}{2\pi}$, where h is plank's constant.

  If m is the mass of electron, v is its orbital velocity and radius of orbit is r, then its angular momentum = mvr

  $$\therefore \qquad mvr = n\frac{h}{2\pi} \qquad ...(1.1)$$

  where n = 1, 2, 3..., is the integer values of orbits or energy levels and it is called quantum number.
- Electronic distribution of electron in various levels are given by the formula $2n^2$. Thus the maximum number of electrons in I^{st} orbit = 2.
- Change in energy ΔE occurs when the electrons jumps from one energy level E_1 to other E_2 ($\Delta E = E_1 \sim E_2$). It emits radiation when jumps from higher level to lower.

However Bohr could not satisfactorily explain the zeeman effect, uncertainity principle and spectra of larger atom but these drawbacks are overcame by introducing some other atomic modes like, sommerfield, scrodinger etc.

1.2 EXCITATION OF ATOM

An atom is said to be in the ground state when its energy is least. An atom can emit spectral radiation, when the electron has to raise to a higher orbits. This process is called excitation of the atom. Discharge tube, electrical energy are used to excite the atom. If the excitation is so intense that an electron is completely knocked out of the atom, the atom is said to be ionised and the electron is known as free electron.

Excitation Potential

The energy (eV) required to raise an atom from the ground state into an excited state is called excitation potential of the state.

For example, the ground state energy for hydrogen atom is $E_1 = -13.6$ eV and energy of the second orbit is $E_2 = -3.4$ eV. This means to excite hydrogen atom, the energy required to be given to it is $E_2 - E_1 = -3.4 - (-13.6) = +10.2$ eV. Hence, 10.2 eV is the first excitation energy of the hydrogen atom. Similarly the IInd excitation potential energy is $E_3 - E_1$.

Ionisation Potential

Energy required to remove an electron from a given orbit to an infinity from the nucleus. It E_1 and E_∞ represent the energy of the atom when it is in the ground state and in the infinite state respectively, than the ionization energy of the atom is given by $E_\infty - E_1 = 0 - (-13.6) = +13.6$ eV. Actually the ionisation potential is the energy needed in electron volt to remove an electron from the influence of the nucleus.

In case of hydrogen atom, there are only are ionization potential whereas there are several excitation potential. In other atom the energy required for the removal of the outermost valence electron, which is least attracted by the nucleus is called first ionization potential. Now relatively increase of the positive charge the second ionization potential will be higher than the first ionization potential and so on.

1.3 ENERGY BAND

Bohr model discovered that in each atom there are different energy levels. Solids are formed by a large number of atoms. There are millions of electrons related to a particular energy levels of atoms. The difference in a particular energy levels is very small, therefore these energy levels combine to from a strip type structure. There strips are called band. Thus in a solid levels having same energy combines to from a band. The first levels from first energy band, similarly second, third levels (orbits) from the respective bands.

1.4 LINE SPECTRUM

When an atomic gas or vapour is excited, the emitted radiation has a spectrum which contains certain specific wavelengths only. Each of there wavelength components is called a spectral line and the whole family of lines is called a line spectrum. Study of emission line spectra shows that every atom has its own characteristic spectrum. The spectrum of atomic hydrogen as shown by a spectrometer is given in Fig. 1.4.

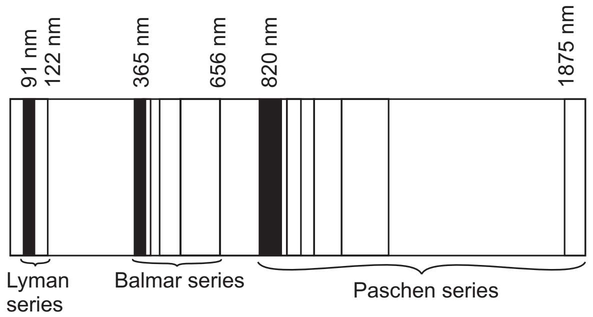

Fig. 1.4: Emission lines in the spectrum of hydrogen

Spectral lines

The spectrum of hydrogen atom is observed a series of lines whose separation and intensity decreases in a perfectly regular manner towards shorter wavelengths.

The first series was observed by Jack of Balamer in the visible reign. The line with longest wavelength is 656 nm called H_α line. Similarly next line is called H_β and so on.

The formula for wavelength is found to be

$$\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{n^2}\right); n = 3, 4, 5,...$$

where R is Rydberg constant having value $1.097 \times 10^7 \text{ m}^{-1}$, n is integral values; 3, 4, 5 ...... The spectral lies in the ultraviolet region form the Lyman series which is given by,

$$\frac{1}{\lambda} = R\left(\frac{1}{1^2} - \frac{1}{n^2}\right); n = 2,3,4,...$$

The spectral series in infrared region are;

$$\frac{1}{\lambda} = R\left(\frac{1}{3^2} - \frac{1}{n^2}\right); n = 4,5,6,... \quad \text{(Paschen)}$$

$$\frac{1}{\lambda} = R\left(\frac{1}{4^2} - \frac{1}{n^2}\right); n = 5,6,7,... \quad \text{(Brackett)}$$

$$\frac{1}{\lambda} = R\left(\frac{1}{5^2} - \frac{1}{n^2}\right); n = 6,7,8,... \quad \text{(P fund)}$$

1.5 BAND SPECTRUM

Band spectrum is the name given to groups of lines so closely spaced that each group appears to be a band. Band spectrum are obtained from molecules. It is the characteristics of the molecule. Example nitrogen spectrum.

Example 1. Find the shortest wavelength in Balmer series transition

Solution. For shortest wavelength atomic transition will be $n = 2$ to $n = \infty$

$$\therefore \quad \frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{\infty^2}\right)$$

$$\therefore \quad \frac{1}{\lambda} = 1.097 \times 10^7 \times \text{m}^{-1} \times \left(\frac{1}{4}\right)$$

$$\Rightarrow \quad \lambda = 3.65 \times 10^{-7} \text{ m} = 365 \text{ nm}.$$

Example. 2. Atom makes a transition from $n = 4$ to $n = r$ level. Find the frequency of emitted photon.

Solution. Initial orbit of electron, $n_i = 4$

Final orbit of electron, $n_f = 2$

$$\because \quad \Delta E = -13.6\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

$$= -13.6\left(\frac{1}{2^2} - \frac{1}{4^2}\right)$$

$$= -13.6 \times \frac{3}{16} = 2.25 \text{ eV}$$

We know, $\Delta E = h\nu$

where h is Planck's constant and ν is frequency of emitted photon.

$$h = 6.63 \times 10^{-34} \text{ Js and 1eV} = 1.6 \times 10^{-19} \text{ J}$$

$$\nu = \frac{\Delta E}{h} = \frac{2.25 \times 1.6 \times 10^{-19}}{6.63 \times 10^{-34}}$$

$$= 6.15 \times 10^{14} \text{ Hz}$$

1.6 OPTICS

You know that in the absence of an obstacle the light rays advance in straight lines without changing direction. When it meets a surface separating two media; reflection and refraction occur and the light rays bend.

Reflection

According to the Fig. 1.5, light ray *AP* entering at a point *P* on plane surface is reflected through *PB*. The angle between *AP* and normal *PN* (a line drawn perpendicular to plane surface) is called angle of incidence (i) and the angle between the reflected ray *PB* and the normal is called the angle of reflection (r).

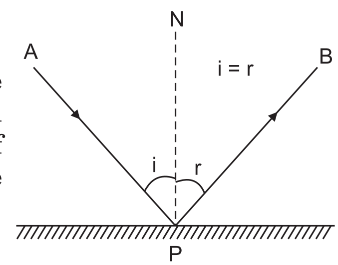

Fig. 1.5

Experiments show that in the case of reflection:

(i) the angle of incidence is equal to the angle of reflection.

(ii) the incident ray, the reflected ray and the normal at the point of incidence all lie in the plane. These are called the two laws of reflection.

Refraction

In a homogeneous medium light ray travels in straight line. Whenever a ray of light passes from one transparent medium to another it deviates from the original path† (Fig. 1.6).

Thus, the bending of light when it travels from one medium to another is called refraction. Refraction of light takes place according to the following two laws :

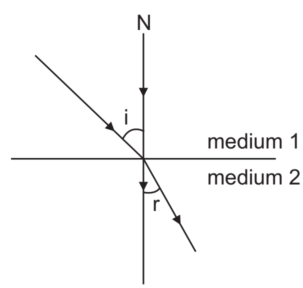

Fig. 1.6

1. The incident ray, the refracted ray and the normal at the incident point, all lie in the same plane.

† **Statement shall not follow if the ray of light is incident normally on the surface**

2. For any two media and for light of a given wavelength, the ratio of the sine of the angle of incidence i to the sine of the angle of refraction r is a constant.

$$\frac{\sin i}{\sin r} = \text{constant}$$

This is also called the 'Snell's law'. If n_1 and n_2 are the refractive indices of the first and second medium respectively, then the above equation is rewritten as

$$\frac{\sin i}{\sin r} = \frac{n_2}{n_1} = {}_1n_2 \qquad \text{...(1.2)}$$

If the path of the light be reversed then the equation will be

$$\frac{\sin r}{\sin i} = {}_2n_1 \qquad \text{...(1.3)}$$

$$\therefore \qquad {}_1n_2 \times {}_2n_1 = 1$$

If first medium is air and second medium is water then

$$ {}_an_w \times {}_wn_a = 1 \qquad \text{...(1.4)}$$

Now focusing again on Eq. (1.2) there are two conditions.

(*i*) If $n_2 > n_1$; first medium is rarer, and second is denser,

In that condition

$$\frac{\sin i}{\sin r} > 1 \qquad \left[\because \frac{n_2}{n_1} > 1\right]$$

$$\therefore \qquad \sin i > \sin r$$

$$\text{or} \qquad i > r \qquad (\text{or } r < i)$$

So, angle of incidence will be greater than the angle of refraction and light bends towards the normal (see Fig. 1.7*a*)

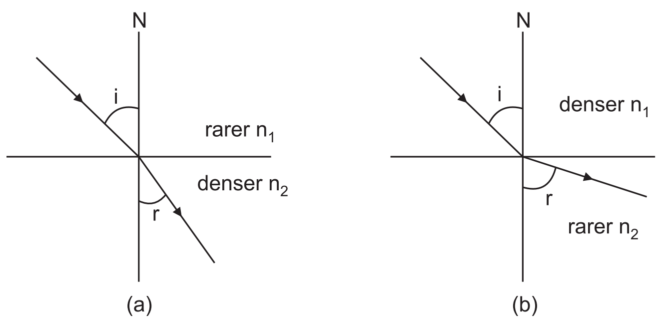

Fig.1.7

(*ii*) If $n_1 > n_2$, *i.e.*, first medium is denser then second.

In this condition

$$\frac{\sin i}{\sin r} < 1$$

$$\sin i < \sin r \qquad \left[\because \frac{n_2}{n_1} < 1\right]$$

$$\text{or} \qquad i < r \qquad (\text{or } r > i)$$

Angle of incidence is smaller than angle of refraction or angle of refraction will be greater than angle of incidence and light bends away from the normal [Fig. 1.7*b*].

It is clear that when light ray travels from rarer to denser medium, it bends towards the normal (Fig. 1.7*a*) and when it travels from denser to rarer medium the ray bends away from the normal (Fig. 1.7*b*).

Now concentrate upon Fig. 1.8. According to the figure, it is clear that when the angle of incidence i in the denser medium is increased then corresponding angle of refraction r in the rarer medium is also increased. At an angle i_c the angle of refraction becomes 90° (ray 2). Beyond this angle (ray 3) the angle of refraction becomes (> 90°) or in other words ray totally reflected back into the same medium.

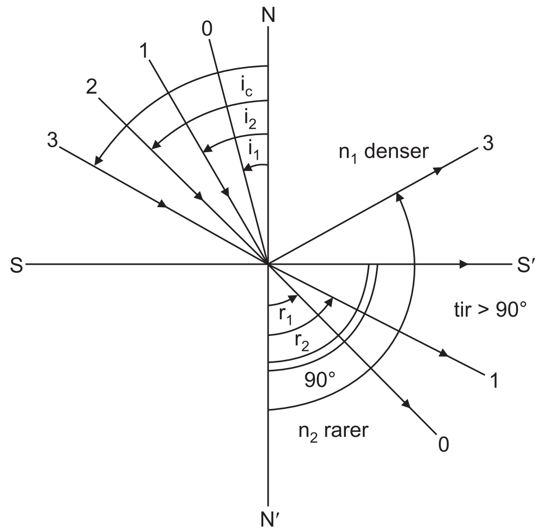

Fig. 1.8

The angle of incidence in the denser medium for which the angle of refraction is 90° is called critical angle. It is denoted by i_c or C. If the incident angle is greater than the critical angle than the light is completely reflected back into the same medium. This phenomenon is known as total internal reflection (tir).

The following condition must be satisfied for total internal reflection,

(1) The incident light should be in the optically denser medium,

(2) The angle of incidence should be greater than the critical angle.

It should be clear that the critical angle means it is the critical condition for just commencing the total internal reflection.

1.7 SOME OBSERVED PHENOMENON BASED ON REFRACTION

1. **Deep water appears shallow** Due to the refraction a deep water appears shallow. To explain it consider a point O at the bottom of a vessel containing water as in Fig. 1.9. The rays originating from O are refracted at water-air boundary and bent. Both refracted rays of light appear to come from a point O'. Thus, the depth of the water, as seen by the observer is AO' white the actual depth is AO. This explain why water pond appears shallow.

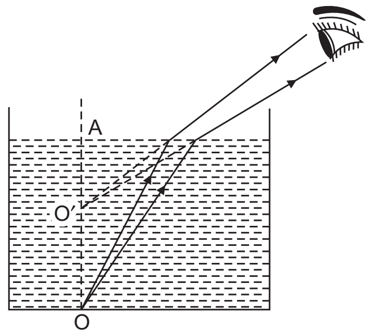

Fig. 1.9

2. **Sun is visible before sunrise and also after sun set** The sun is visible before the actual sunrise and also after actual sun set. To explain it consider an observer *O* on the earth and *S* is the actual position of sun (Fig. 1.10). Light from the sun reaches *O* after refraction through the earth's atmosphere. The light appears to come from S′ is the apparent position of the sun which is above horizon for the observer.

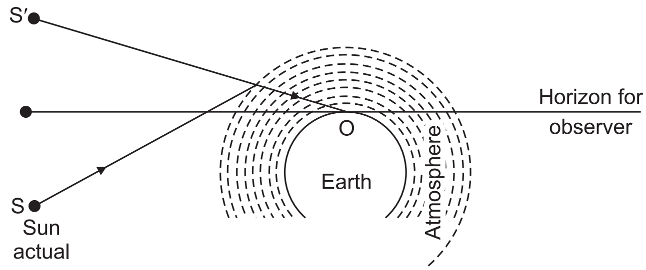

Fig. 1.10

3. **Coin hanging in air** Put a coin at the bottom of a glass tumbler containing some water. (Fig. 1.11). When the tumbler is tilted and viewed at a suitable angle, the coin appears to flow out in air. This is because the light coming from the coin suffers total internal reflection.

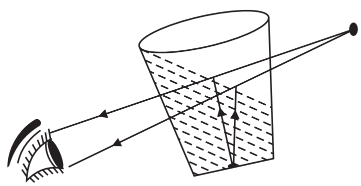

Fig.1.11

4. **Diamond Sparkle with great brilliance** The brilliance of diamond is due to total internal reflection. Diamond has a high refractive index of 2.42 and therefore a small critical angle of about 24°. Thus light entering a diamond suffers total internal reflection at nearly all the surfaces.
5. The optical illusion that water is present at some distant place is called inferior mirage (or generally mirage) in which one can see the inverted images of distant objects. This generally occurs on very hot days or in desert places. Except it phenomenon of looming or superior mirage happens in cold regions. In which the objects appear floating in air. These both phenomenon are observed due to total internal reflection of light in air.

1.8 REFRACTIVE INDEX

The velocity of a monochromatic beam of light in material medium is different from that in vacuum. If c and v are the velocities of light rays in free space and in a medium respectively, the ratio c/v is defined as the refractive index n of the medium

$$n = \frac{c}{v}$$

Also $c = f\lambda$ where f is the frequency of the vibration, where light is propagated from one medium to another medium, the frequency remains unchanged. Hence, wavelength is different in different medium.

If λ and λ_m are the wavelength in vacuum (free space) and in the medium, then

$$n = \frac{\lambda}{\lambda_m}$$

As $v = f\lambda$ (or $v \propto \lambda$, $\because f$ = constant)

Hence, velocity of ray varies in different medium. Thus the variation of velocity in different medium gives rise to the phenomenon of refraction.

Example. 3. Refractive index of water with respect to air is $\frac{4}{3}$. What is the refractive index of air with respect to water?

Solution. Given,

$$_a n_\omega = \frac{4}{3}$$

$$\because \quad _\omega n_a = ?$$

$$\therefore \quad _a n_\omega \times {_\omega n_a} = 1$$

$$_\omega n_a = \frac{1}{4/3} = \frac{3}{4}$$

Example. 4. A pool of water $\left(\text{refractive index } = \frac{3}{4}\right)$ is 300 cm deep. Find its apparent depth when viewed vertically through air.

Solution.

$$_a n_\omega = \frac{\text{Real depth}}{\text{apparent depth}}$$

$$\therefore \quad \frac{4}{3} = \frac{300}{h(\text{say})}$$

$$\text{or} \quad h = \frac{300 \times 3}{4} = 225 \text{ cm}$$

EXERCISE

1. Describe Rutherford α-particle scattering experiment and its outcome.
2. Differentiate between Rutherford model and Bohr model
3. Define Rutherford's atomic model and its limitations.

4. What is ionization and excitation energy for hydrogen atom? Why the second ionization is more than first in other atoms ?
5. What are the parts of an atom. What was J. Thomson contribution to the atomic theory ?
6. What are the successes and shortcomings of Bohr theory?
7. Using the Rydberg constant, calculate the wavelength of first two spectral lines in the Lyman series.

   [Ans. λ_{21} = 1216A°, λ_{31} = 1025 A°]
8. Using Snell's low explain the phenomenon of refraction.
9. What is total internal reflection? How is critical angle related to refractive index ?

True/False statements

1. Rutherford discovered nucleus.
2. Electron needed to fill the first energy level is 2.
3. Band spectrum can also formed by atom.
4. The minimum angular momentum of electron in hydrogen atom is h/π.
5. The minimum energy level of a hydrogen atom is –10.2 eV.
6. Refraction of light occur because the speed of light is different in different media.
7. Total internal reflection can occurs only when incident light should be in optically denser medium.
8. Electronic distribution is given by the formula $2\pi n^2$.

ANSWERS

1. T
2. T
3. T
4. (F, $h/2\pi$)
5. (F, –13.6 eV)
6. T
7. T
8. (F, $2n^2$)

Fill in the blanks

1. Plum pudding model is developed by _____.
2. Electron needed to fill the first energy level is _____ (18, 4, 2).
3. The value of Rydberg constant is _____
4. Radius of an atom is in the order of _____ metre.
5. Energy of fourth level in hydrogen atom is _____.

6. Low of reflection says, angle of incident is equal to _____.
7. When a ray incident from _____ to _____ medium it bands towards the normal.
8. Shortest wavelength corresponds to _____ energy difference between energy levels. (largest smallest)

ANSWERS

1. J.J. Thomson
2. 2
3. 1.097×10^7 metre^{-1}
4. 10^{-10}
5. $\left(E_n = -\frac{13.6}{n^2}, -0.85\,\text{eV}\right)$
6. angle of reflection.
7. rarer, denser.
8. largest

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