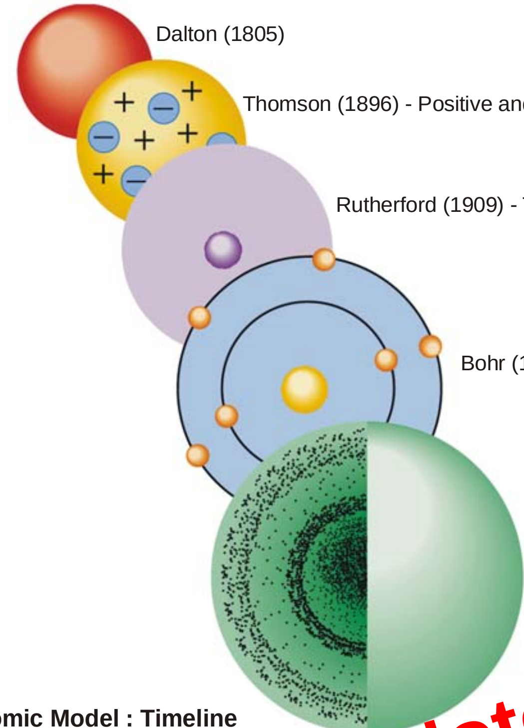
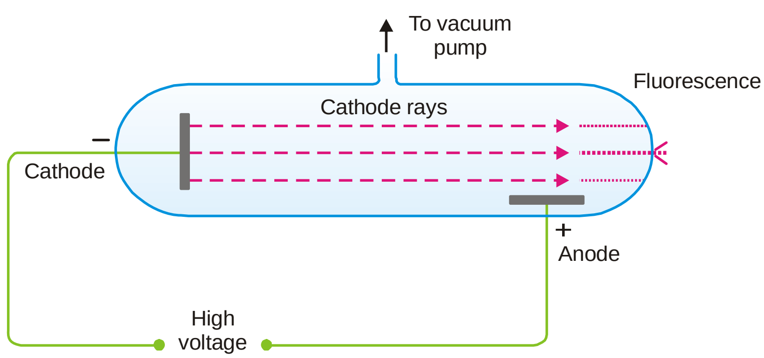


■ **Atomic Model : Timeline**

CATHODE RAYS – THE DISCOVERY OF ELECTRON

The knowledge about the electron was derived as a result of the study of the electric discharge in the **discharge tube** (J.J. Thomson, 1896). The discharge tube consists of a glass tube with metal electrodes fused in the walls (Fig. 1.1). Through a glass side-arm air can be drawn with a pump. The electrodes are connected to a source of high voltage (10,000 Volts) and the air partially evacuated. The electric discharge passes between the electrodes and the residual gas in the tube begins to glow. If virtually all the gas is evacuated from within the tube, the glow is replaced by faintly luminous 'rays' which produce fluorescence on the glass at the end far from the cathode. **The rays which proceed from the cathode and move away from it at right angles in straight lines are called Cathode Rays.**



■ **Figure 1.1**
Production of cathode rays.

SOLVED PROBLEM. The wavelength of a violet light is 400 nm. Calculate its frequency and wave number.

SOLUTION. We know that

$$\text{frequency, } \nu = \frac{c}{\lambda}$$

Here $c = 3.0 \times 10^8$ m sec^{-1}; $\lambda = 400$ nm $= 400 \times 10^{-9}$ m

$$\nu = \frac{c}{\lambda} = \frac{3.0 \times 10^8 \text{ m sec}^{-1}}{400 \times 10^{-9} \text{ m}}$$

$$= \frac{3}{400} \times 10^{17} \text{ sec}^{-1}$$

$$= \frac{3000}{400} \times 10^{14} \text{ sec}^{-1}$$

$$= \mathbf{7.5 \times 10^{14}\ sec^{-1}}$$

Also, wave number $\bar{\nu} = \dfrac{1}{\lambda}$

$$\bar{\nu} = \frac{1}{400 \times 10^{-9} \text{ m}}$$

$$= \mathbf{25 \times 10^5\ m^{-1}}$$

SOLVED PROBLEM. The frequency of strong yellow line in the spectrum of sodium is 5.09×10^{14} sec^{-1}. Calculate the wavelength of the light in nanometers.

SOLUTION. We know that wavelength, $\lambda = \dfrac{c}{\nu}$

Here $c = 3.0 \times 10^8$ m sec^{-1}

$\nu = 5.09 \times 10^{14}$ sec^{-1} (given)

Wavelength $\lambda = \dfrac{3.0 \times 10^8 \text{ m sec}^{-1}}{5.09 \times 10^{14} \text{ sec}^{-1}}$

$$= \frac{3000}{5.09} \times 10^{-9} \text{ m}$$

$$= 589 \times 10^{-9} \text{ m}$$

$$= \mathbf{589\ nm} \qquad [\because\ 1 \text{ nm} = 10^{-9} \text{ m}]$$

SPECTRA

A spectrum is an array of waves or particles spread out according to the increasing or decreasing of some property. An increase in frequency or a decrease in wavelength represent an increase in energy.

THE ELECTROMAGNETIC SPECTRUM

Electromagnetic radiations include a range of wavelengths and this array of wavelengths is referred to as the *Electromagnetic radiation spectrum* or simply *Electromagnetic spectrum*. The electromagnetic spectrum with marked wavelengths is shown in Fig. 1.14.

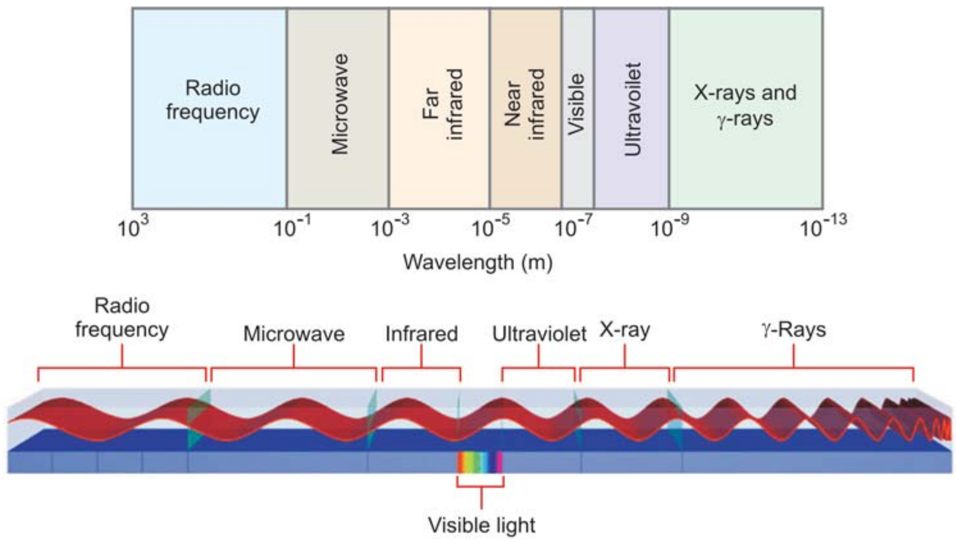


Figure 1.14
Electromagnetic spectrum. Wavelength boundaries of each region are approximate.

CONTINUOUS SPECTRUM

White light is radiant energy coming from the sun or from incandescent lamps. It is composed of light waves in the range 4000-8000 Å. Each wave has a characteristic colour. When a beam of white light is passed through a prism, different wavelengths are refracted (or bent) through different angles. When received on a screen, these form a continuous series of colour bands : violet, indigo, blue, green, yellow, orange and red (VIBGYOR). **This series of bands that form a continuous rainbow of colours, is called a Continuous Spectrum.**

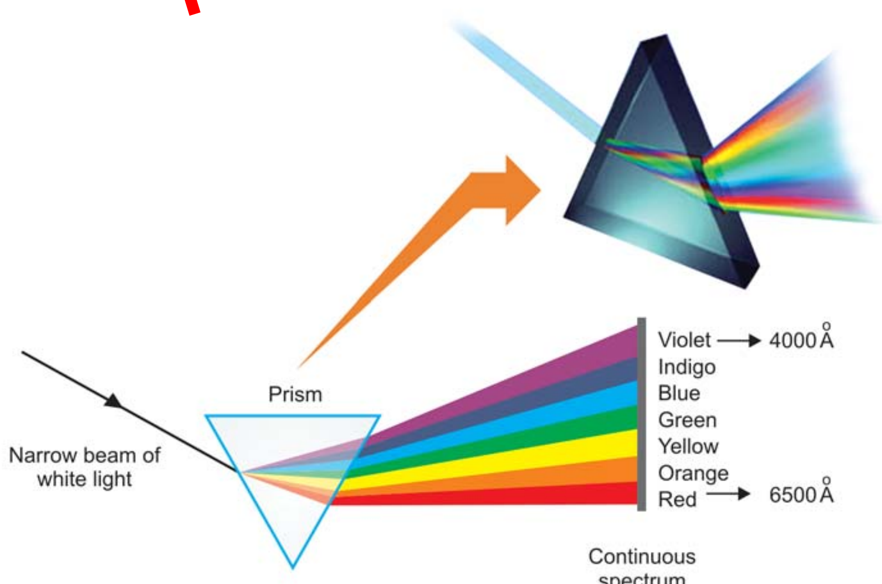


Figure 1.15
The continuous spectrum of white light.

Name	Region where located
(1) Lyman Series	Ultraviolet
(2) Balmer Series	Visible
(3) Paschen Series	Infrared
(4) Brackett Series	Infrared
(5) Pfund Series	Infrared

Balmer equation had no theoretical basis at all. Nobody had any idea how it worked so accurately in finding the wavelengths of the spectral lines of hydrogen atom. However, in 1913 Bohr put forward his theory which immediately explained the observed hydrogen atom spectrum. Before we can understand Bohr theory of the atomic structure, it is necessary to acquaint ourselves with the quantum theory of energy.

QUANTUM THEORY OF RADIATION

The wave theory of transmission of radiant energy appeared to imply that energy was emitted (or absorbed) in continuous waves. In 1900 Max Planck studied the spectral lines obtained from hot-body radiations at different temperatures. According to him, light radiation was produced discontinuously by the molecules of the hot body, each of which was vibrating with a specific frequency which increased with temperature. Thus Planck proposed a new theory that a hot body radiates energy not in continuous waves but in small units of waves. The 'unit wave' or 'pulse of energy' is called **Quantum** (plural, *quanta*). In 1905 Albert Einstein showed that light radiations emitted by 'excited' atoms or molecules were also transmitted as particles or quanta of energy. These light quanta are called **photons.**

The general **Quantum Theory of Electromagnetic Radiation** in its present form may be stated as :

(1) **When atoms or molecules absorb or emit radiant energy, they do so in separate 'units of waves' called quanta or photons.** Thus light radiations obtained from energised or 'excited atoms' consist of a stream of photons and not continuous waves.

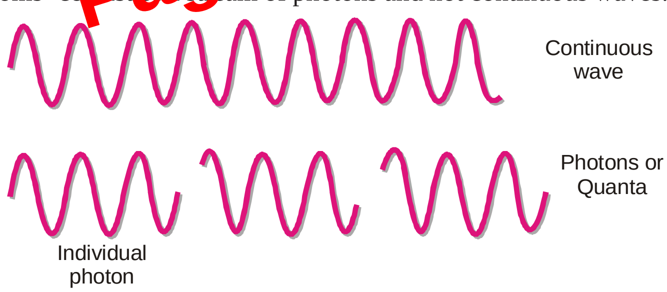


Figure 1.20
A continuous wave and photons.

(2) **The energy, *E*, of a quantum or photon is given by the relation**

$$E = h\nu \qquad ...(1)$$

where ν is the frequency of the emitted radiation, and h the **Planck's Constant.** The value of $h = 6.62 \times 10^{-27}$ erg sec. or 6.62×10^{-34} J sec.

We know that c, the velocity of radiation, is given by the equation

$$c = \lambda\nu \qquad ...(2)$$

Substituting the value of ν from (2) in (1), we can write

Significance of Negative Value of Energy

The energy of an electron at infinity is arbitrarily assumed to be zero. This state is called *zero-energy* state. When an electron moves and comes under the influence of nucleus, it does some work and spends its energy in this process. Thus the energy of the electron decreases and it becomes less than zero *i.e.* it acquires a negative value.

Bohr's Explanation of Hydrogen Spectrum

The solitary electron in hydrogen atom at ordinary temperature resides in the first orbit (n = 1) and is in the lowest energy state (ground state). When energy is supplied to hydrogen gas in the *discharge tube*, the electron moves to higher energy levels *viz.*, 2, 3, 4, 5, 6, 7, etc., depending on the quantity of energy absorbed. From these high energy levels, the electron returns by jumps to one or other lower energy level. In doing so the electron emits the excess energy as a photon. This gives an excellent explanation of the various spectral series of hydrogen.

Lyman series is obtained when the electron returns to the ground state *i.e.*, n = 1 from higher energy levels (n_2 = 2, 3, 4, 5, etc.). Similarly, Balmer, Paschen, Brackett and Pfund series are produced when the electron returns to the second, third, fourth and fifth energy levels respectively as shown in Fig. 1.28.

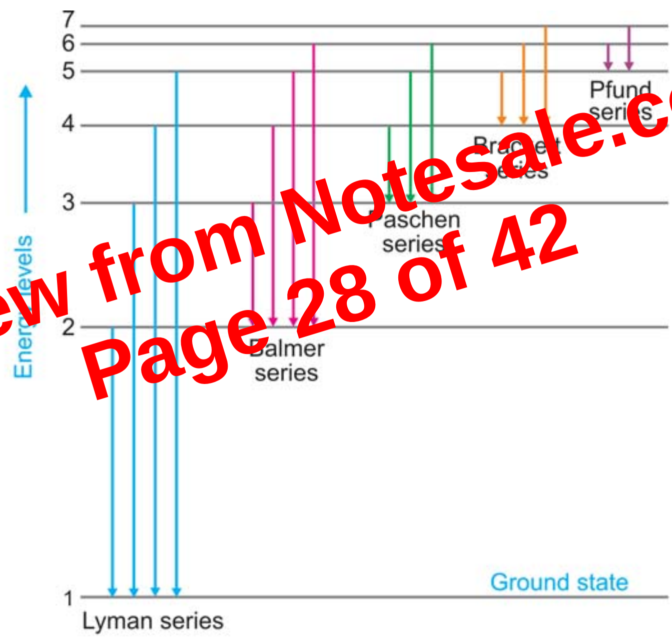


Figure 1.28
Hydrogen spectral series on a Bohr atom energy diagram.

TABLE 1.3. SPECTRAL SERIES OF HYDROGEN

Series	n_1	n_2	Region	Wavelength λ (Å)
Lyman	1	2, 3, 4, 5, etc.	ultraviolet	920-1200
Balmer	2	3, 4, 5, 6, etc.	visible	4000-6500
Paschen	3	4, 5, 6, 7, etc.	infrared	9500-18750
Brackett	4	5, 6, 7	infrared	19450-40500
Pfund	5	6, 7	infrared	37800-75000

29. In hydrogen atom the energy of the electron in first Bohr's orbit is -1312×10^5 J mol^{-1}. What is the energy required for the excitation of second Bohr's orbit ? (*Burdwan BSc, 2005*)

Answer. 9.84×10^5 J mol^{-1}

30. Calculate the wavelength in Å of the photon that is emitted when an electron in Bohr orbit $n = 2$ returns to the orbit $n = 1$ in the hydrogen atom. The ionisation potential in the ground state of hydrogen atom is 2.17×10^{-11} erg per atom. (*Kalayani BSc, 2005*)

Answer. 1220 Å

31. A line at 434 nm in Balmer series of spectrum corresponds to a transition of an electron from the *n*th to 2nd Bohr orbit. What is the value of *n* ? (*Gulbarga BSc, 2006*)

Answer. $n = 5$

32. The energy transition in hydrogen atom occurs from $n = 3$ to $n = 2$ energy level. ($R = 1.097 \times 10^7$ m^{-1}). (i) Calculate the wavelength of the emitted electron (ii) Will this electron be visible ? (iii) Which spectrum series does this photon belong to ? (*Vikram BSc, 2006*)

Answer. 6564 Å ; Yes ; Balmer series

33. The energy of the electron in the second and third Bohr orbits of the hydrogen atom is -5.42×10^{-12} erg and -2.41×10^{-12} erg respectively. Calculate the wavelength of the emitted radiation when the electron drops from third to second orbit. (*Calicut BSc, 2006*)

Answer. 6600 Å

MULTIPLE CHOICE QUESTIONS

1. Cathode rays are deflected by

(*a*) electric field only (*b*) magnetic field only

(*c*) electric and magnetic field (*d*) none of these

Answer. (*c*)

2. The *e*/*m* value for the particles constituting cathode rays is the same regardless of

(*a*) the gas present in cathode rays tube (*b*) the metal of which cathode was made

(*c*) both of these (*d*) none of these

Answer. (*c*)

3. The charge to mass ratio (*e*/*m*) of positive particles

(*a*) varies with the nature of gas in discharge tube

(*b*) is independent of the gas in discharge tube

(*c*) is constant

(*d*) none of the above

Answer. (*a*)

4. A sub atomic particle which has one unit mass and one unit positive charge is known as

(*a*) hydrogen atom (*b*) neutron

(*c*) electron (*d*) proton

Answer. (*d*)

5. Atomic number of an element is equal to the number of _______ in the nucleus of the atom.

(*a*) neutrons (*b*) protons

(*c*) both the neutrons and protons (*d*) electrons

Answer. (*b*)

6. The mass number of an atom is equal to the number of _______ in the nucleus of an atom

(*a*) protons (*b*) neutrons

17. In photoelectric effect, the kinetic energy of the photoelectrons increases linearly with the

(*a*) wavelength of the incident light (*b*) frequency of the incident light

(*c*) velocity of the incident light (*d*) none of these

Answer. (*b*)

18. The kinetic energy of the photoelectrons emitted from the metal surface is given by the relation (v_o is the threshold frequency and v is the frequency of incident light)

(*a*) $\frac{1}{2} m v^2 = hv - hv_o$ (*b*) $\frac{1}{2} mv^2 = hv + hv_o$

(*c*) $\frac{1}{2} mv^2 = hv$ (*d*) $\frac{1}{2} mv^2 = hv_o$

Answer. (*a*)

19. In Bohr's model of atom, the angular momentum of an electron orbiting around the nucleus is given by the relation

(*a*) $m\, v\, r = \dfrac{h}{2\,\pi}$ (*b*) $m\, v\, r = \dfrac{n\, h}{2\,\pi}$

(*c*) $m\, v\, r = \dfrac{n^2\, h^2}{4\,\pi}$ (*d*) $m\, v\, r = \dfrac{n\, h}{4\,\pi}$

Answer. (*b*)

20. The radius of first orbit in hydrogen atom according to Bohr's Model is given by the relation

(*a*) $r = \dfrac{h^2}{4\,\pi^2\, m\, e^2}$ (*b*) $r = \dfrac{h}{4\,\pi^2\, m\, e^2}$

(*c*) $r = \dfrac{h^2}{4\,\pi\, m\, e^2}$ (*d*) $r = \dfrac{h^2}{4\,\pi\, m\, e^4}$

Answer. (*a*)

21. The radius of first orbit in hydrogen atom is 0.529 Å. The radius of second orbit is given by

(*a*) ½ × 0.529 Å (*b*) 2 × 0.529 Å

(*c*) 4 × 0.529 Å (*d*) 8 × 0.529 Å

Answer. (*c*)

22. The energy of an electron in the first orbit in hydrogen atom is $-313.6/n^2$ kcal mol^{-1}. The energy of the electron in third orbit is given by the relation

(*a*) $E_3 = \dfrac{-313.6}{3}$ kcal mol^{-1} (*b*) $E_3 = \dfrac{-313.6}{2}$ kcal mol^{-1}

(*c*) $E_3 = \dfrac{-313.6}{9}$ kcal mol^{-1} (*d*) $E_3 = -313.6 \times 3$ kcal mol^{-1}

Answer. (*c*)

23. Lyman series is obtained when the electrons from higher energy levels return to

(*a*) 1st orbit (*b*) 2nd orbit

(*c*) 3rd orbit (*d*) 4th orbit

Answer. (*a*)

24. A line in Pfund series is obtained when an electron from higher energy levels returns to

(*a*) 1st orbit (*b*) 3rd orbit

(*c*) 5th orbit (*d*) 6th orbit

Answer. (*c*)

25. The energy of an electron in Bohr's atom ________ as we move away from the nucleus

(*a*) remains the same (*b*) decreases

(*c*) increases (*d*) sometimes increases, sometimes decreases

Answer. (*c*)

26. When an electron drops from a higher energy level to a lower energy level, then

(*a*) the energy is absorbed (*b*) the energy is released

(*c*) the nuclear charge increases (*d*) the nuclear charge decreases

Answer. (*b*)